Stanford Research Institute

NASr-49(06)

554579

P14

14p

N63 17139

UNPUBLISHED PRELIMINARY DATA

code-1

FREQUENCY DISTRIBUTIONS OF SHOWER SIZES

by

A. S. Dennis and F. G. Fernald

Stanford Research Institute, Menlo Park, California

Manuscript received , 1963

OTS PRICE

XEROX $ [redacted]

MICROFILM $

ABSTRACT

17139

Classification of radar echoes from isolated showers in terms of radius, r_o, has shown that the number per unit radius interval is proportional to exp $(-\beta r_o)$, where β is a constant for a given sample. Calculated values of β range from 0.8 to 1.7 (n. mi.)$^{-1}$. Intense convective activity is characterized by small values of β. Weak or shallow showers, such as those forming in trade-wind cumuli, are associated with large values of β.

1. Introduction

Newell (1960) has presented histograms of the diameters, heights and spacings of convective cells based on radar observations. His results suggest that the frequency distribution of convective cells decreases exponentially as a function of cell width and also as a function of height. The fact that the same type of distribution appears in the two cases is in line with the earlier finding of a roughly linear relationship between cell diameter and height, e.g., Byers and Braham (1949), Mather (1949), Donaldson (1958).

Blackmer (1962) has obtained frequency distributions of the length, width and height of cumuliform clouds from aerial photographs.[1] These also approximate an exponential distribution. Cumulonimbus clouds, if present, are invariably outnumbered by towering cumulus, which in turn are outnumbered by small cumulus clouds.

[1] Blackmer, R. H., Jr., 1962: "Statistical Distribution of Cumulus Clouds from U-2 Photographs," Tech. Report 1, Contract A3(653)-3892, Stanford Research Institute, Menlo Park, California (80 pp).

2

Turning to large convective storms, the data on frequency of occurrence of thunderstorms entered in Fig. 83 of Byers and Braham (1949) yield an exponential distribution when plotted against height. This sample includes storms with tops to 50,000 ft.

The above results suggest that convective clouds and the showers within them are distributed systematically with respect to their linear extent over a range exceeding an order of magnitude.

2. Results of Case Studies

The work reported herein forms part of a study of the feasibility of detecting showers and other precipitation forms by a satellite-borne weather radar.[2] Frequency distributions of radar shower echoes have been obtained using PPI photographs from a number of widely separated points.

The first sample studied consisted of 2,429 showers observed on a CPS-9 (3-cm) radar at Eniwetok Atoll between April 5 and April 12, 1960. The sample was obtained by counting and measuring at hourly intervals all the isolated showers present between 25 and 75 n mi. Most of the showers were nearly circular and appeared to consist of single cells. Some of the larger ones tended toward an elliptical shape and gave evidence of multicellular structure. They were assigned a radius found by averaging their major and minor axes. Samples obtained in this way include many showers in their growing and dissipating stages. Thus they are not directly comparable to those obtained by following the history of shower echoes and noting the maximum height or diameter attained.

---

[2] Dennis, A. S., 1963: "Rainfall Determinations by Meteorological Satellite Radar," Final Report, Contract NASr-49(06), Stanford Research Institute, Menlo Park, California (105 pp).

A first inspection of the data indicated that the number of showers in a given radius interval does decrease exponentially with increasing radius. Accordingly, the data were plotted on semi-logarithmic paper (Figure 1) and fitted by a linear regression of the form

$$\log N = \log N_o - \beta_{10} r_o \qquad (1)$$

where N is the number of showers with radii between r_o and $r_o + dr_o$, expressed in $(n\ mi)^{-1}$, $\log N_o$ is the intercept of the regression line upon the log N axis, and $(-\beta_{10})$ is the slope of the regression line expressed in $(n\ mi)^{-1}$. The point corresponding to the smallest shower size was not used in fitting the regression line, as it corresponds to a different radius interval than the other points, while uncertainties are introduced by the beamwidth and, possibly, failure to detect the very smallest echoes.

Equation (1) can be converted readily to

$$N = N_o \exp(-\beta r_o) \qquad (2)$$

where β is equal to 2.30 β_{10}. For the Eniwetok sample,

$$N = 5900 \exp(-1.4 r_o) \qquad (3)$$

Upon integration over all values of r_o, this yields for the total number of showers 4,100 or about 70% more than the sample contained. It is possible that the exponential distribution breaks down for very small showers, but this is considered unlikely. Figure 2, based upon Blackmer's (1962) results, shows that the exponential distribution holds for cumulus clouds with lengths down to 0.5 n. mi. As the radar echoes within cumulus are somewhat smaller than the clouds themselves, Blackmer's results can be considered applicable to all precipitating cumulus, and to many non-precipitating ones as well.

There are two alternative explanations for the discrepancy between the shower count and the area under the fitted line, namely, failure to detect very small showers, and the apparent stretching of those detected because of the finite resolution of the radar system and of the photographic process. As CPS-9 radar sets are very sensitive, frequently detecting virga as well as precipitation reaching the ground, the second explanation appears more reasonable in this case. Agreement between Equation (3) and the total shower count can be reached by assuming that the apparent radius of each shower was increased approximately 0.4 n mi due to limited resolution.

Similar analyses of isolated showers have been performed using data from radars at Champaign, Illinois and Brize-Norton, England, and on picket ships off the west coast of the United States. The available Illinois and English data were limited to the spring months. The picket ship records extended over a year, though with some gaps. One date to be examined in each month was chosen at random for each synoptic map time for each picket ship station. The computed value of β and the correlation coefficient (r) for each sample are given in Table 1. (The correlation coefficients have not been corrected for small sample size.) The closeness of the fit to the exponential distribution is indicated by the high values of r. Plots on semi-logarithmic paper, not reproduced here, yielded results comparable to Fig. 1.

5

TABLE 1

Fitted Values of β, the Size-Distribution Parameter
For Isolated Showers, and Correlation Coefficient, r

Location		Season or Date	β $(n\ mi)^{-1}$	r
Brize Norton, England		Spring	0.8	0.98
Champaign, Illinois		Spring	1.1	0.98
	49N, 131W	Entire Year	1.0	0.99
Picket	45N, 130W	Entire Year	0.9 & 1.2*	0.99
Ship	40N, 130W	Entire Year	1.3	1.00
Stations	36N, 128W	Entire Year	1.4	0.92
	32N, 124W	Entire Year	1.4	1.00
Eniwetok		April 5-12, 1960	1.4	0.99

*The first random sample chosen yielded 0.9, largely because of some very big showers which occurred during March in association with a cold low. A second sample yielded 1.2. The low result for the first sample can be attributed to sampling error, rather than any peculiarity of the location.

An obvious question at this point is whether the exponential rule holds for instantaneous distributions, or whether it arises from the manner in which some function of the instantaneous distributions, such as the mean shower radius, is distributed in time. Examination of the original data indicates that instantaneous distributions follow the exponential relationship, but that the function β varies from day to day as well as with location. The values of β reported in Table 1 are thus to be considered as averages over time.

Obviously, the function β can be determined only for regions large enough to contain statistically significant samples of cumuliform clouds. Cloud and shower patterns within such areas must be regarded, from the synoptic-scale viewpoint, as random phenomena. Further study of the variability of β with space and time would help determine the degree of resolution required in descriptions of cloud and shower patterns to preserve all information relatable to synoptic-scale events, while excluding local variations.

The combination of a number of samples which follow the exponential law, but with differing values of β, cannot conform to it <u>exactly</u>. The discrepancies involved in practice are not critical, as shown by the correlation coefficients in Table 1.

The possibility of obtaining higher correlations by plotting log N against $(r_o)^\gamma$, where γ is an arbitrary constant, has been explored for the Eniwetok and the picket ship data. In some cases, a slight improvement was obtained by setting γ around 1.1, but, in general, no significant improvement was possible through choosing values of γ other than 1.

7

3. Meteorological Significance of Parameter β.

The results of Section 2 indicate that the distribution of the radii of isolated showers can be described by a single function β, which varies with geographic location and with time. Shower distributions containing a relatively high proportion of large showers are described by low values of β; those containing few large showers by high values of β.

The close correlation between the radius and height of showers noted above indicates that weather situations with strong convection in deep layers would be characterized by small values of β, and that convection in shallow layers would be characterized by large values of β. This is borne out in Table 1, which shows β to be small over land in spring and off the northwestern United States, and large off the California coast and at Eniwetok.

A number of Blackmer's (1962) samples of cloud sizes (in addition to that shown in Fig. 2) have been replotted on semi-logarithmic paper, and the points fitted visually by straight lines. The resulting values of β are in the range 1.5 to 1.9. Thus they overlap the range of values found for the radar data, but extend somewhat higher. This is reasonable, as the radar data, being limited to samples including precipitating clouds, would not include these cases with very large values of β.

As a check on the possibility of a systematic relationship between β and the daily shower counts, β has been computed for each of the daily shower samples observed at Eniwetok. Figure 3 is a scatter diagram showing the value found versus the number of showers observed for each day. Inspection of this figure indicates that the two variables are independent. This shows

8

that at least one more parameter, related to shower spacing, is needed to describe shower arrays adequately. It also indicates that some factor, or factors, other than the depth of the unstable layer influence(s) shower frequency, at least in the tropics. These could include the relative humidity near the surface, wind shear, the degree of instability (as opposed to the depth of the unstable layer), and low-level convergence or divergence. Studies of tropical showers in the Caribbean area, e.g., Malkus (1952), indicate that the convergence-divergence factor is of major importance.

ACKNOWLEDGMENTS

The research reported herein was sponsored by the National Aeronautics and Space Administration under Contract NASr-49(06) with Stanford Research Institute.

9

REFERENCES

Byers, H. R., and R. R. Braham, Jr., 1949: The Thunderstorm, U.S. Weather Bureau, Washington, D.C., 287 pp.

Donaldson, R. J., Jr., 1958: Analysis of severe convective storms observed by radar, J. Meteor., 15, No. 1, pp. 44-50.

Malkus, J. S., 1952: Recent advances in the study of convective clouds and their interaction with the environment, Tellus, 4, pp. 71-87.

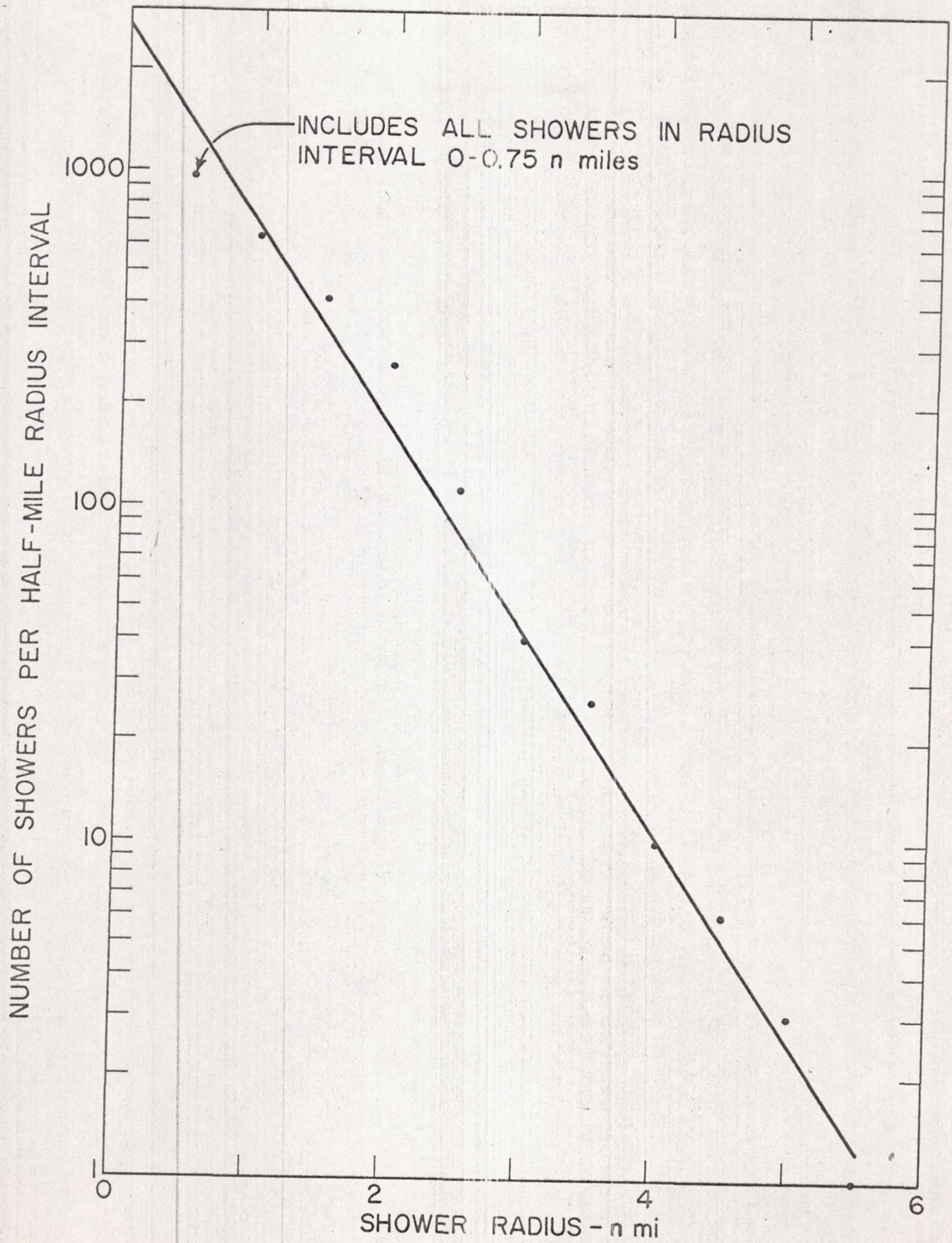
Mather, J. R., 1949: An investigation of the dimensions of precipitation echoes by radar, Bull. Amer. Meteor. Soc., 30, No. 8, pp. 271-277.

Newell, R. E., 1960: Some radar observations of tropospheric cellular convection, Proc. 8th Weather Radar Conf., pp. 315-322.

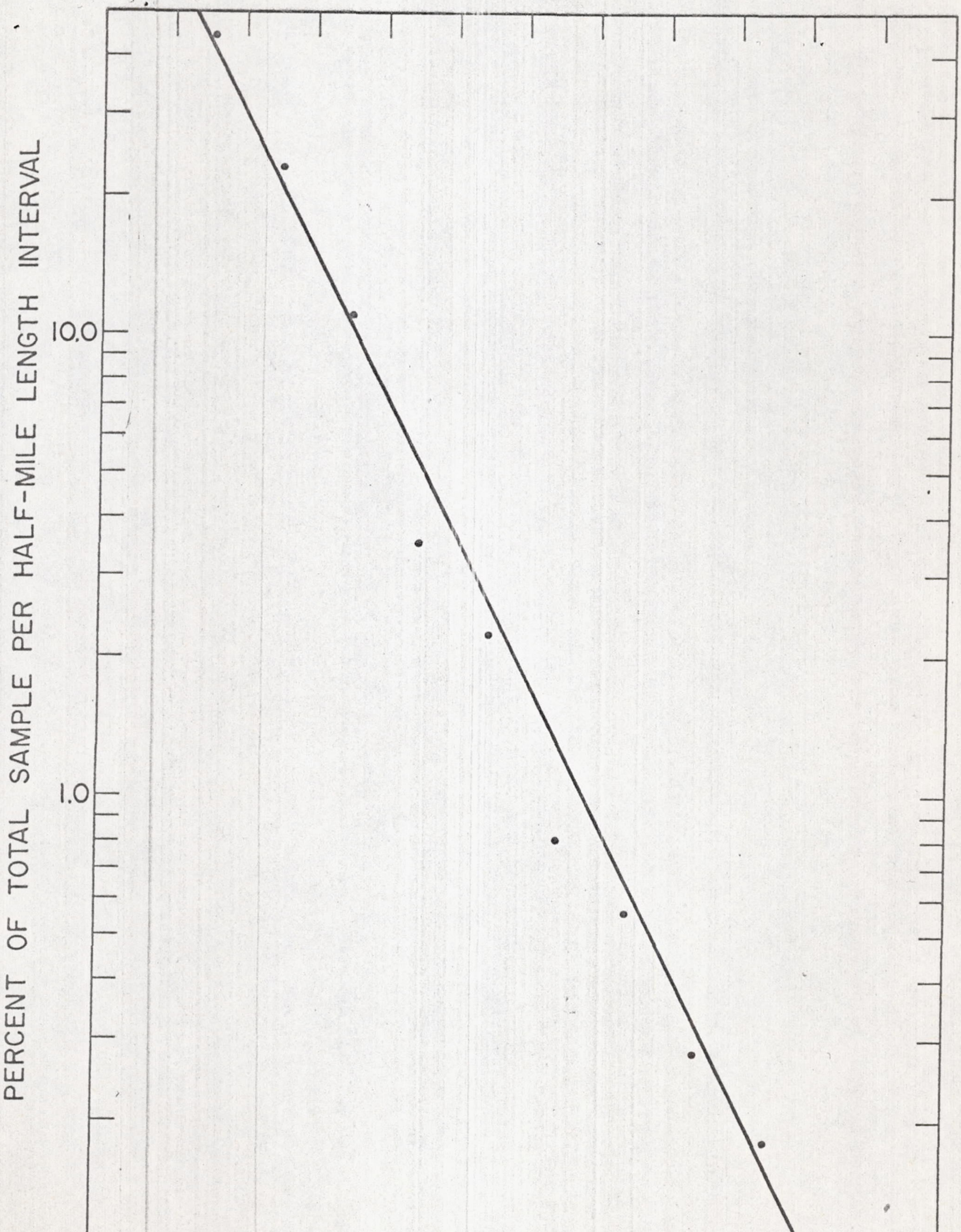
10

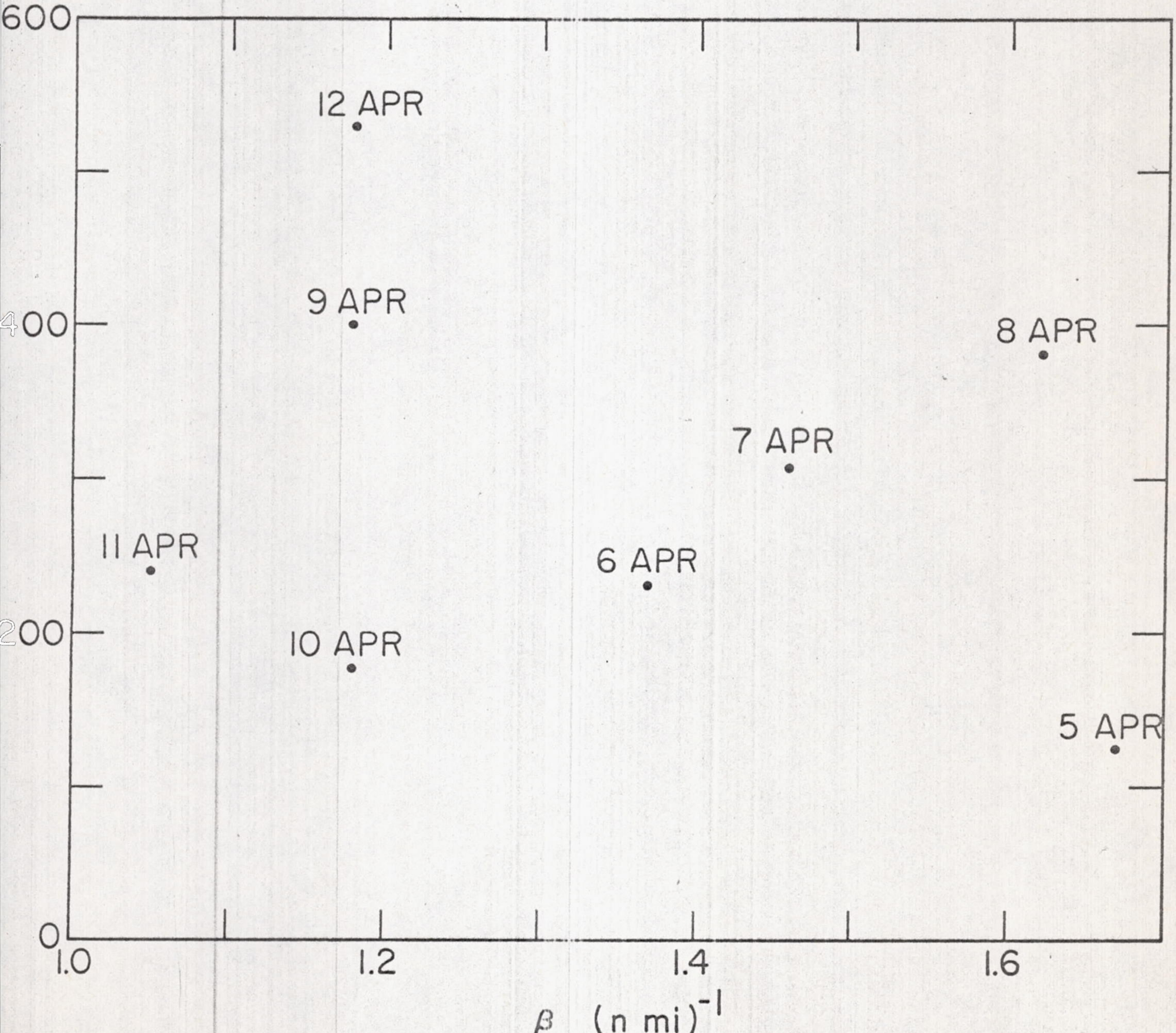
LIST OF FIGURES

11



INCLUDES ALL SHOWERS IN RADIUS INTERVAL 0-0.75 n miles
1000
100
10
1
0
2
4
6
NUMBER OF SHOWERS PER HALF-MILE RADIUS INTERVAL
SHOWER RADIUS - n mi


PERCENT OF TOTAL SAMPLE PER HALF-MILE LENGTH INTERVAL
10.0
1.0
0.1
0
2
4
6
LENGTH—n mi


600
400
200
0
1.0
1.2
1.4
1.6
12 APR
9 APR
8 APR
7 APR
11 APR
6 APR
10 APR
5 APR
β (n mi)⁻¹