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FINAL REPORT
ON THE
EVALUATION OF THE CLOUDCROFT, NEW MEXICO SITE
FOR A UNITED STATES AIR FORCE PLANETARY OBSERVATORY

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ABSTRACT

An evaluation of a potential Air Force planetary observatory site near Cloudcroft, New Mexico is presented as the combined efforts of the Research Center of the New Mexico State University and the Lunar and Planetary-Exploration Branch, Research Instrumentation Laboratory of the Geophysics Research Directorate. Included are the results of a preliminary study of existing data and the results of a seeing-weather survey, carried out at the site between December 1960 and September 1961. The data are presented for comparison with those of the Association of Universities for Research in Astronomy, Inc. (AURA) survey of Arizona and surrounding areas. The Cloudcroft site is evaluated from the points of view of rainfall, dendroclimatology, cloud cover, contrails, wind velocity, temperature, microthermal data, visual seeing records, and site practicality. The conclusion drawn from these data indicate that, although the Cloudcroft site has many factors in its favor, the modal seeing was found to be somewhat inferior to that at AURA's Kitt Peak.

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1.0 INTRODUCTION

A site near Cloudcroft, New Mexico (Figures 1, 2, 3, and 4), which is available to the Air Force, is being considered as a possible location for an Air Force Planetary Observatory for studies of the solar system and inter-planetary space. The appropriateness of this site for such a facility is dependent principally upon the quality of the astronomical "seeing" and the number of cloudfree nights available. (The term "seeing" as used by most astronomers is a quantitative description of the degree of telescopic image aberrations, which are produced by the diffraction and interference effects of atmospheric inhomogeneities. Although many individual scales are used, the scale value customarily increases with image quality.)

In order to determine the required parameters of astronomical seeing and cloud cover, the Under Secretary of the Air Force directed that ARDC (now OAR), through AFCRC (now AFCRL), undertake the necessary studies. The Lunar-Planetary Exploration Branch of the Research Instrumentation Laboratory, Geophysics Research Directorate, has been assigned this responsibility. A preliminary study of existing data was forwarded to Headquarters, USAF, on 1 October 1960, and an interim report based on the first five months of observations was submitted on 1 August 1961.

This final report presents the results of a ten-month (December 1960-September 1961) seeing and weather study at the site, together with a review of data presented in the preliminary report. Contained herein then, are the combined efforts of the Lunar-Planetary Exploration Branch of the Research Instrumentation Laboratory, Geophysics Research Directorate, which conducted the preliminary study; and the Research Center of the New Mexico State University, which conducted the Cloudcroft seeing-weather study under the supervision of Dr. Clyde W. Tombaugh.

In this final report, data concerning several other astronomical observatory sites in the Southwest are included for comparison with those concerning Cloudcroft. To facilitate comparisons, this study has been generally patterned after the seeing study performed under the supervision of Dr. A. B. Meinel of the Association of Universities for Research in Astronomy (AURA) for the selection of the National Astronomical Observatory site, subsequently located at Kitt Peak in southern Arizona. The format of this report is approximately the same as that used by Meinel (1958) in the AURA final report.

In all references to data obtained at the Cloudcroft site, the date of a given night is the local calendar date at the beginning of the night. A night is defined as the interval between the end of local evening twilight and the beginning of local morning twilight. All times are Mountain Standard Time.

The Cloudcroft survey was conducted at point "D" in Figure 3.

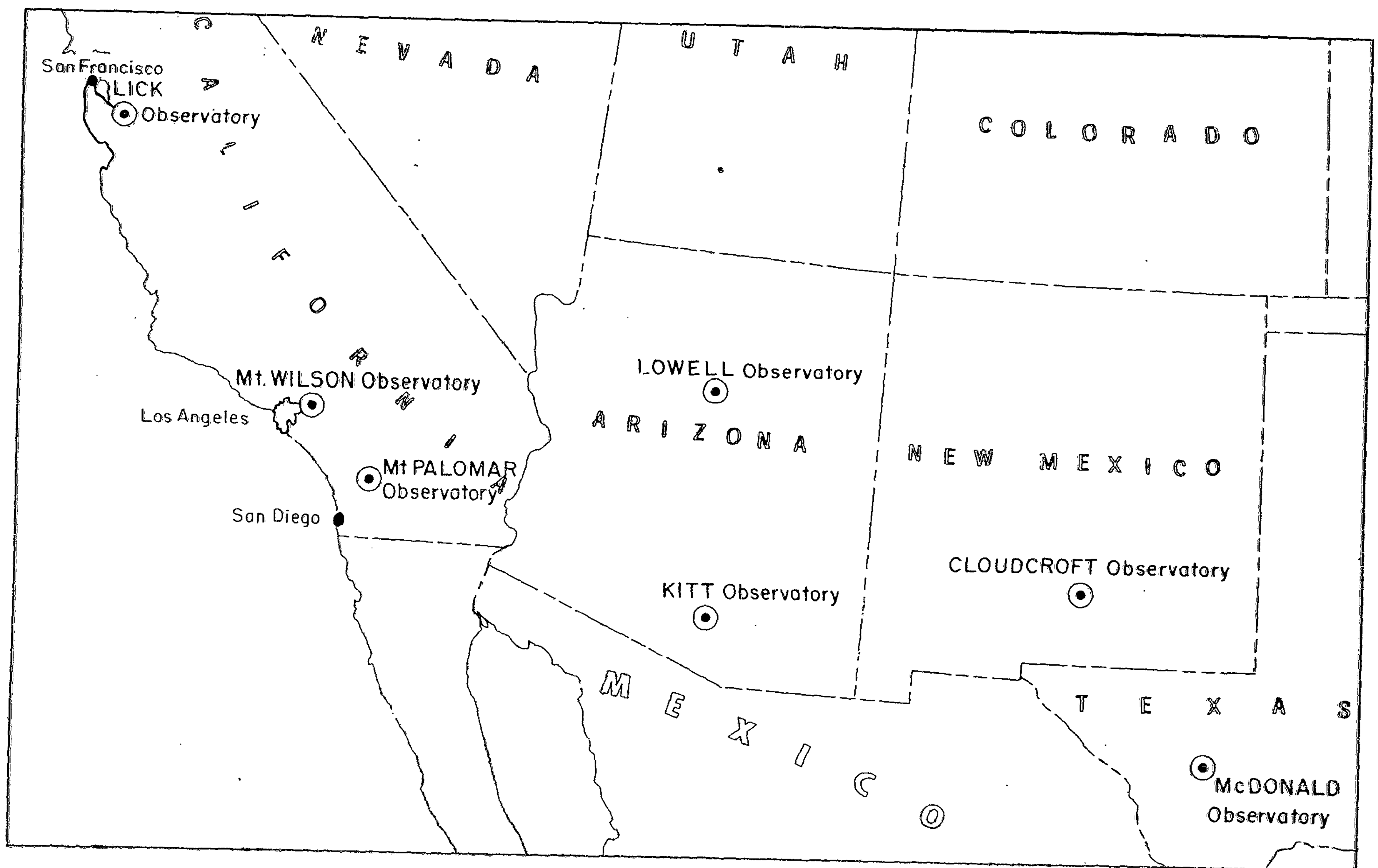

NEVADA
UTAH
COLORADO
CALIFORNIA
San Francisco
LICK Observatory
Mt. WILSON Observatory
Los Angeles
Mt PALOMAR Observatory
San Diego
LOWELL Observatory
ARIZONA
KITT Observatory
NEW MEXICO
CLOUDCROFT Observatory
TEXAS
McDONALD Observatory
MEXICO

FIGURE 1

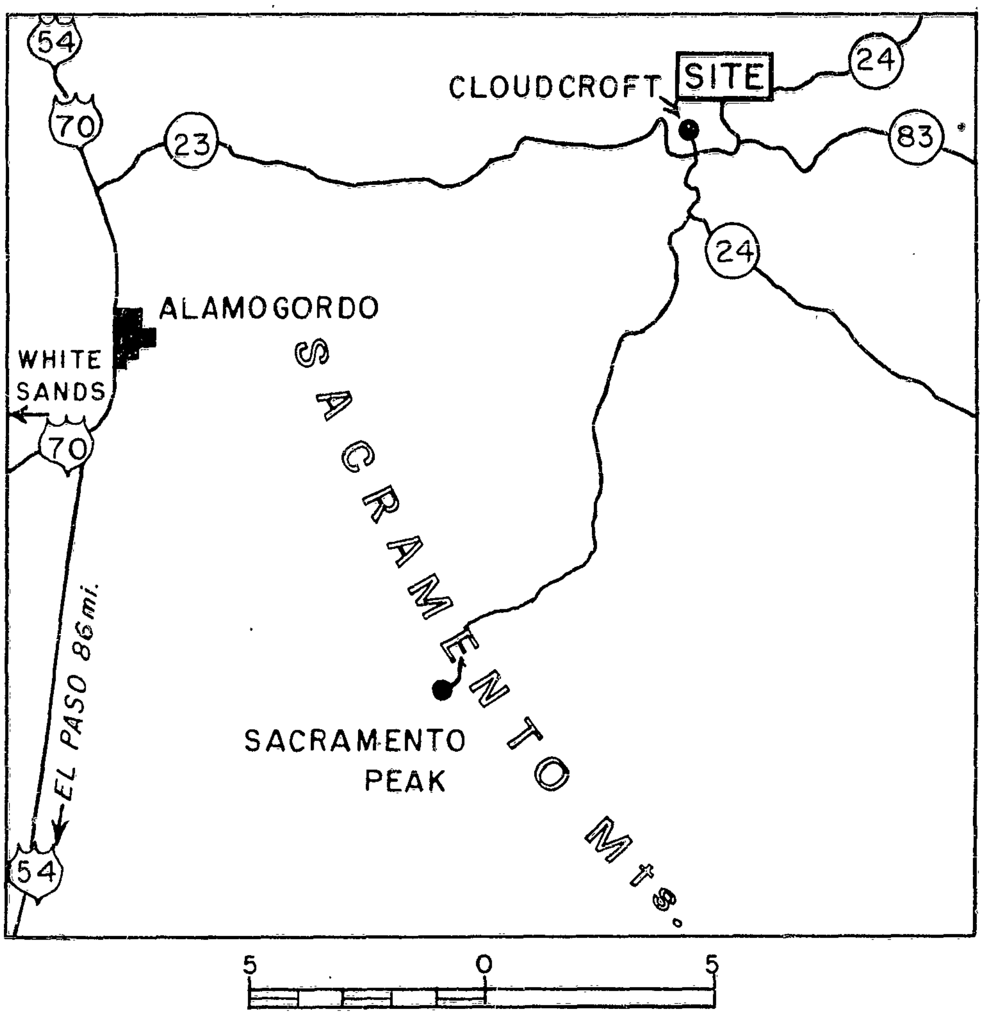

54
70
23
CLOUDCROFT
SITE
24
83
24
ALAMOGORDO
WHITE SANDS
70
SACRAMENTO Mts.
EL PASO 86 mi.
SACRAMENTO PEAK
54
5
0
5
STATUTE MILES

FIGURE 2

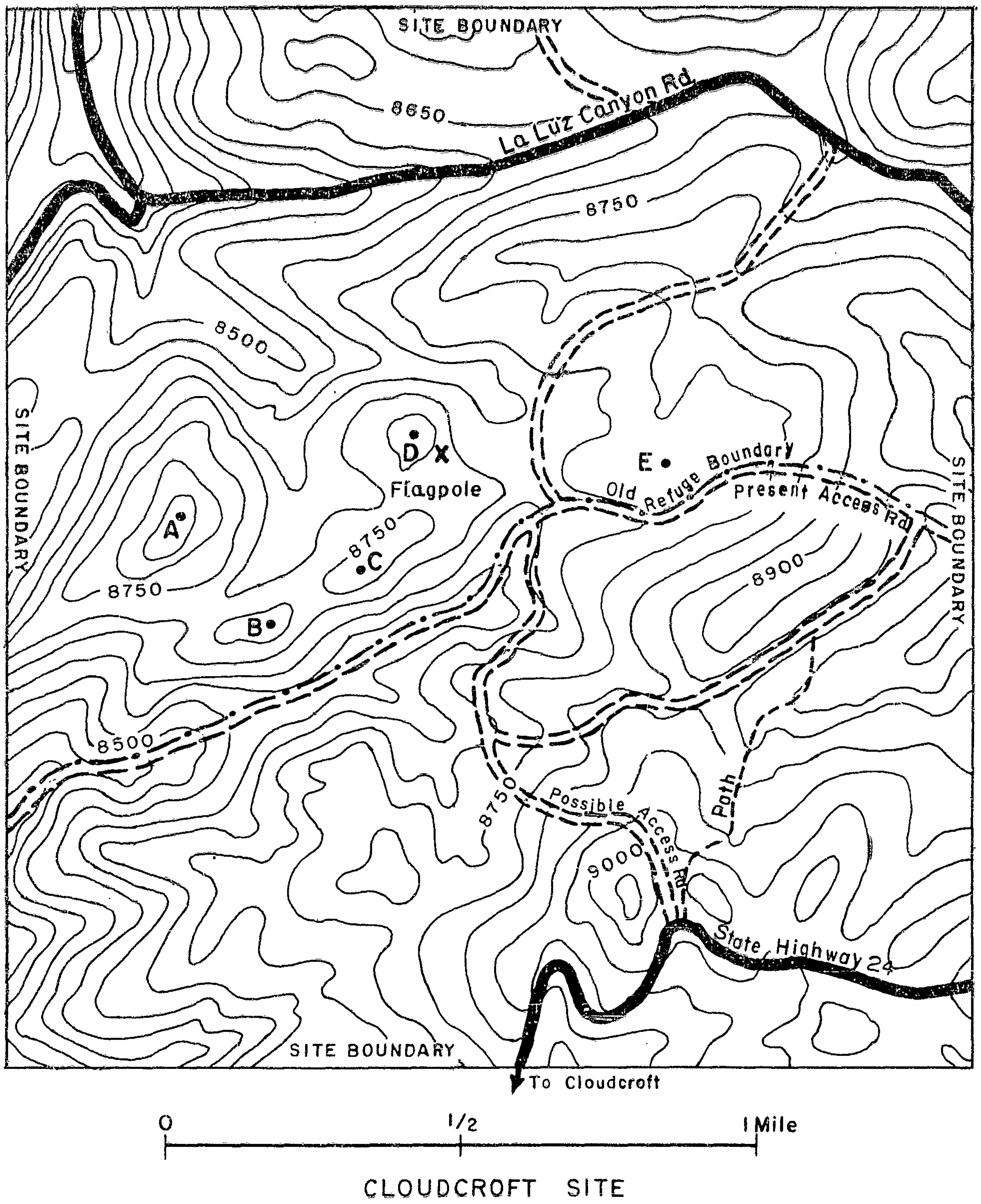
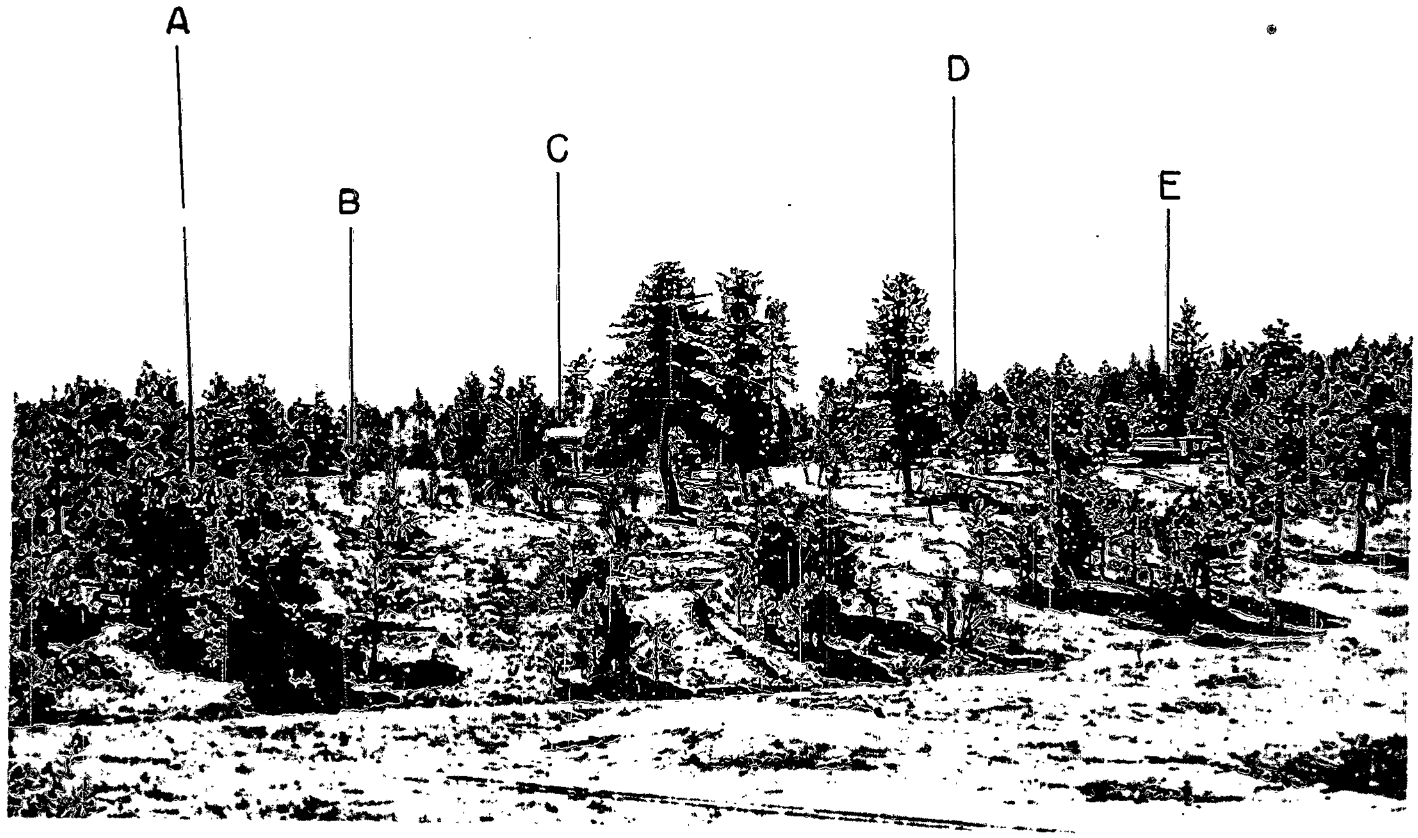


FIGURE 3. Contour map of the Cloudcroft Site, showing interior roads and trails. Letters indicate proposed instrument and laboratory locations.



A. Flagpole B. Polaris Telescope C. 16-inch telescope
D. 12-inch telescope E. Personnel Trailer

FIGURE 4. Overall View of Area "D" of the Cloudcroft Site.
(New Mexico State University Photograph)

2.0 RAINFALL

2.1 General Study

Rainfall (including all precipitation) data are an important part of any seeing study because of the hampering effect of rain on planetary observation, and because of the importance of rainfall for the observatory water supply. It is necessary to know, however, more than simply the total rainfall at each site. Seasonal distribution, and especially nighttime frequency of rainfall, are also of importance.

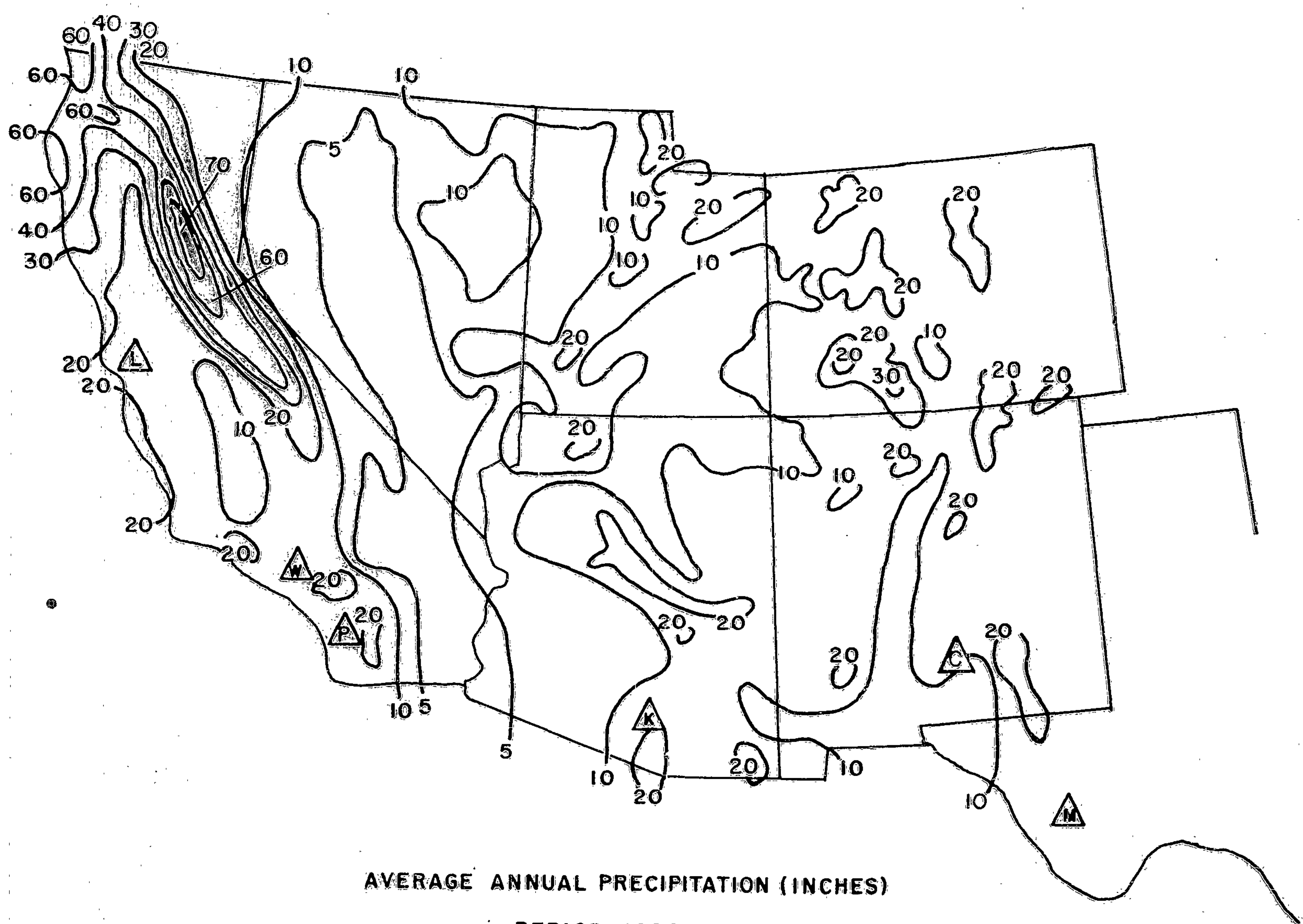
Figure 5, which is a generalized map of precipitation over the whole region, presents the pattern of rainfall distribution. It is important to note that this map does not take into account high local rainfall caused by orographic effects and should not be used to determine rainfall at specific sites. ("Orographic effects" are those effects on an air mass which occur when this air mass is forced to rise by mountain-ranges lying athwart the path of the wind.) Table I gives a more detailed breakdown of the rainfall at each observatory site, or at stations close to each site(see Table II). It can be seen that Cloudcroft ranks third in total rainfall.

Another, and more meaningful aspect of the rainfall pattern in the Southwest, illustrated by Figure 6, is the average number of days per year on which it rains. Cloudcroft clearly has the greatest number (70) of days of rain per year.

Figure 7 shows the variation in time of maximum rainfall for different areas within the Southwest region. Note here that the California observatory (Mt. Wilson) receives the major portion of its total rainfall during the winter months, while Cloudcroft and McDonald in New Mexico and West Texas receive the major portion of their rain during the summer.

The relative percentage of rain falling at night has not been determined in detail, but figures in the Visher Climatic Atlas of the United States do show, for example, that 70 per cent of all thunderstorms occur during the evening and early morning in the Kitt Peak area, while only 50 per cent of all thunderstorms occur during this same period in the Cloudcroft area.

The information presented above is sufficient to show that Cloudcroft is in a fairly advantageous position with respect to total rainfall, but has the greatest number of days on which some rain falls. Seventy days of rain per year are not, however, an unacceptable limitation on the operation of an observatory; especially in view of the fact that a large proportion of the rain falls during the day. Actually, in one important respect, the rainfall is a distinct advantage in that Cloudcroft has no water supply problem as has been experienced at Kitt Peak.



AVERAGE ANNUAL PRECIPITATION (INCHES)

PERIOD 1899—1938

FIGURE 5

TABLE I

CLIMATIC SUMMARY
PRECIPITATION

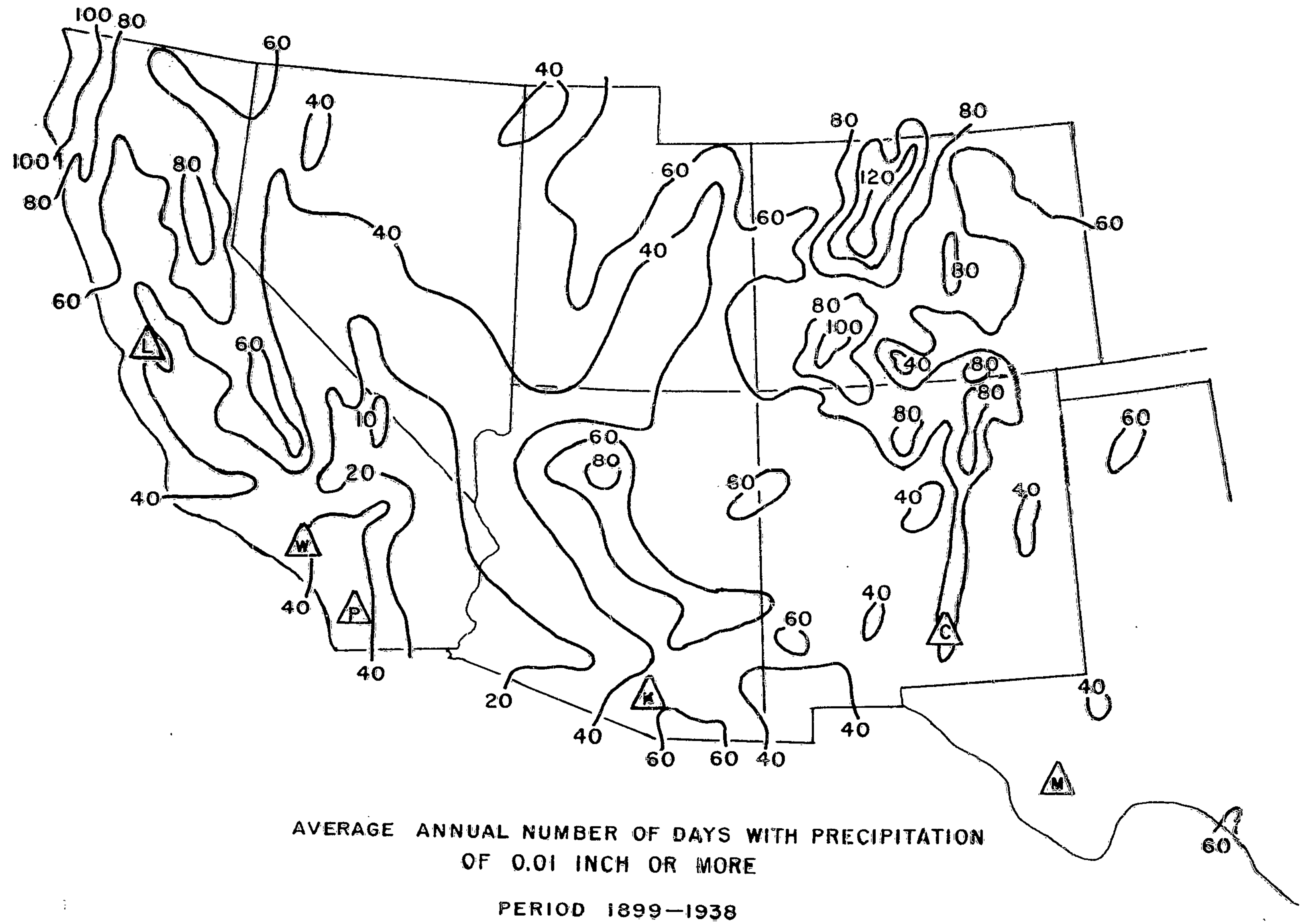
STATION	DATA	YEARS	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
Baboquivari Canyon (Kitt Peak)	Ppt (in.)	10	-	-	-	-	-	-	-	-	-	-	-	-	18.00
Mt. Locke (McDonald)	Ppt (in.)	18	1.00	.33	.35	.49	1.97	2.79	3.79	2.88	2.93	1.72	.60	.69	10.54
Cloudcroft	Ppt (in.)	50	1.66	1.57	1.40	.86	1.09	1.72	5.05	4.67	2.82	1.54	1.16	1.53	25.07
	No. of days ≧ 0.01"	28	5	5	4	3	3	5	12	13	7	4	4	5	70
Mt. Palomar	Ppt (in.)	11	4.65	4.24	5.00	1.46	.27	.04	.33	.43	.35	.88	2.78	5.04	25.47
Mt. Hamilton (Lick)	Ppt (in.)	21	5.74	5.38	4.09	2.35	.92	.21	.02	.01	.09	1.43	2.85	5.52	28.61
Mt. Wilson	Ppt (in.)	51	6.09	7.79	6.17	2.76	.79	.15	.02	.11	.57	1.45	2.35	5.95	34.20
	No. of days ≧ 0.01"	14	6	7	7	5	4	1	0	0	1	3	4	6	44

TABLE II

STATION INDEX

STATION	LAT. N.	LONG W.	ELEVATION, FT.
Cloudcroft	32°57′	105°44′	8575
Mt. Hamilton (Lick Observatory)	37°20′	121°39′	4209
Mt. Wilson	34°14′	118°03′	5850
Mt. Palomar	33°21′	116°51′	5560
Sells	31°55′	111°53′	2369
Kitt Peak	31°57′	111°42′	6875
McDonald Observatory	30°40′	104°01′	6805
Mt. Locke	30°40′	104°00′	6790

Baboquivari Canyon, exact location not known. According to W. W. Baustian, who studied the water supply problem at Kitt Peak, the station is a short distance southwest of Kitt Peak and at a slightly lower elevation.



AVERAGE ANNUAL NUMBER OF DAYS WITH PRECIPITATION OF 0.01 INCH OR MORE

PERIOD 1899—1938

FIGURE 6

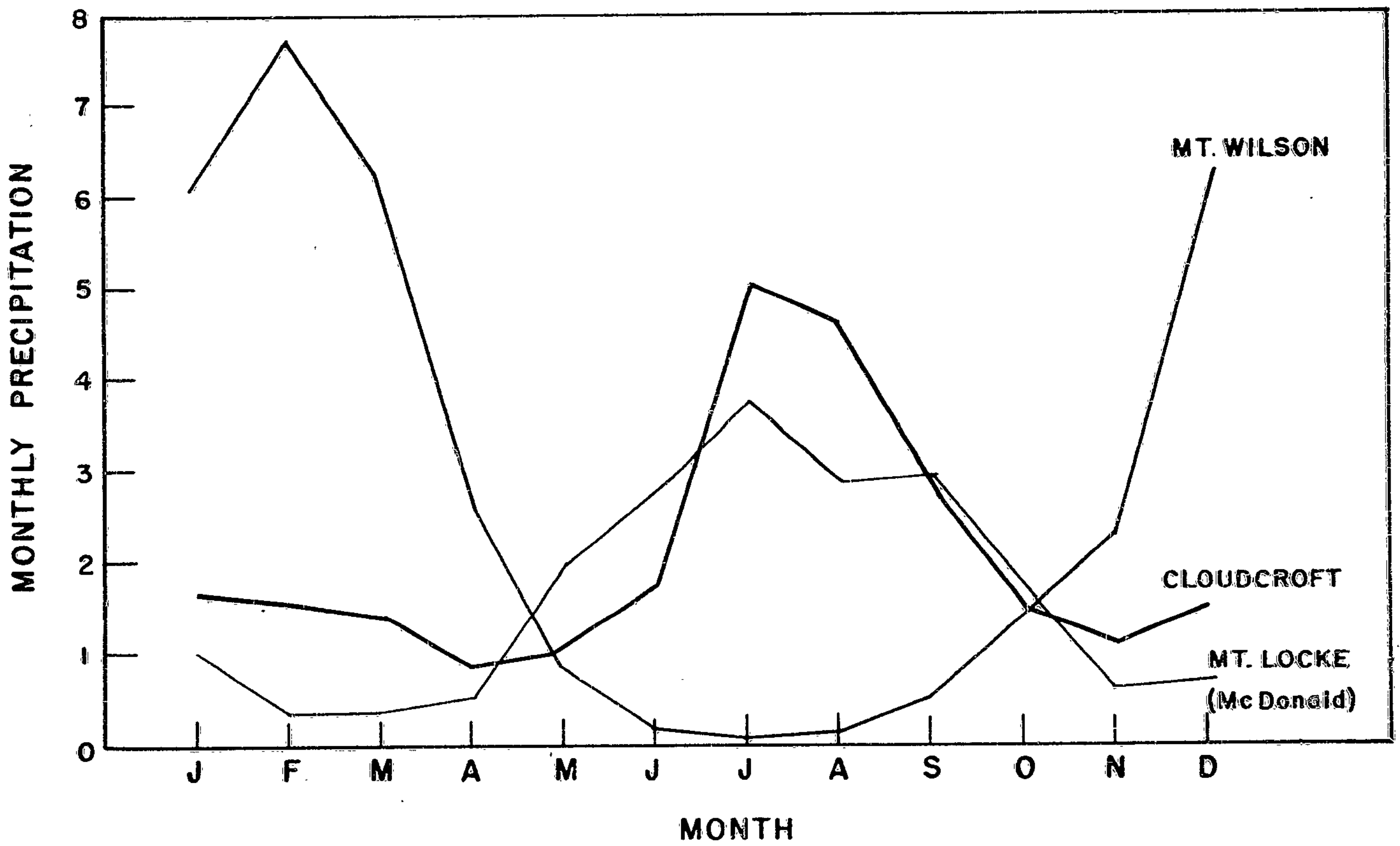


FIGURE 7. Monthly Precipitation

2.2 Cloudcroft Survey

2.2.1 Description

Precipitation totals were recorded daily without regard to the form of the precipitation. Daily totals were added to give monthly totals. Precipitation data were gathered between December 1960 and September 1961.

2.2.2 Results

Table III presents the monthly precipitation along with the total number of days per month on which fell at least 0.01 inches of rain. Included for comparison are long-term monthly means from Table I.

2.2.3 Conclusions

From Table III it appears that the precipitation throughout the period of the Cloudcroft survey was very close to the 50-year average. It will be noted, however, that the number of days on which rainfall occurred was somewhat above the 28-year average. The Cloudcroft survey period might then be described as one of slightly less-than-average rainfall on a greater-than-average number of days.

TABLE III

PRECIPITATION

MONTH	INCHES	MONTHLY MEAN (50 YR.)	NO. OF DAYS ≥ 0.01"	NO. OF DAYS ≥ 0.01" (28 YR.)
DECEMBER 1960	1.49	1.53	6	5
JANUARY 1961	1.20	1.66	6	5
FEBRUARY 1961	0.56	1.57	2	5
MARCH 1961	1.41	1.40	9	4
APRIL 1961	0.02	0.86	2	3
MAY 1961	0.42	1.09	2	3
JUNE 1961	2.37	1.72	13	5
JULY 1961	6.49	5.05	11	12
AUGUST 1961	5.29	4.67	14	13
SEPTEMBER 1961	3.40	2.82	9	7
OCTOBER 1961	----	1.54	--	4
NOVEMBER 1961	----	1.16	--	4
TOTAL	22.65	25.07	74	70
LESS OCTOBER AND NOVEMBER	22.65	22.37	74	62

3.0 CLOUD COVER

3.1 General Study

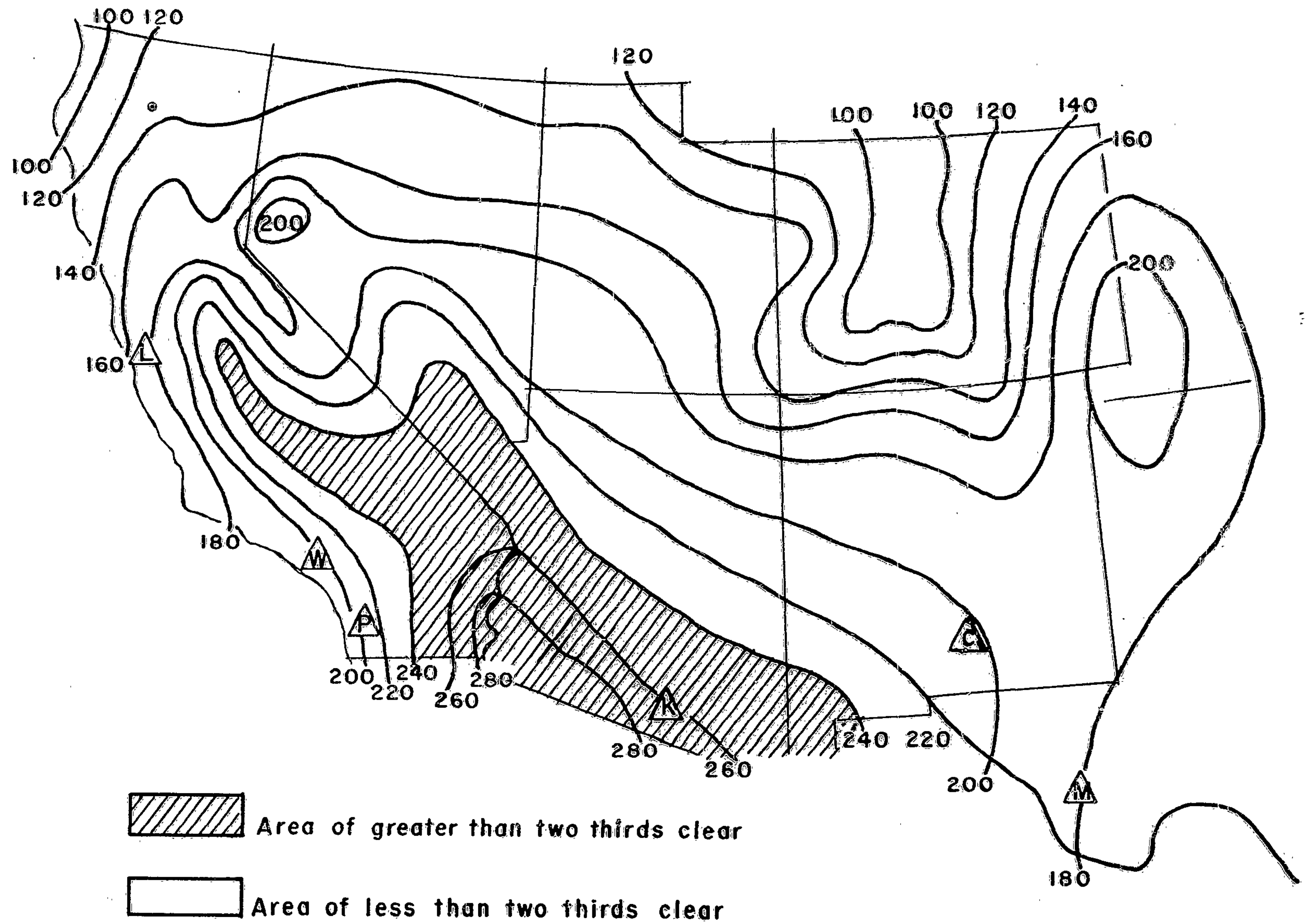
Cloud cover is an extremely important parameter in the choice of an observatory site, but one which is difficult to obtain in the desired form from existing data. Generalized maps of cloud cover are readily available, and one is reproduced as Figure 8. Unfortunately, such maps describe only daytime conditions, and Hess (1952) has suggested good physical reasons for believing that the spatial distribution of daytime cloudiness may be quite different from that of nocturnal cloudiness. In this he was supported by the British Astronomer-Royal, H. S. Jones (1952), who showed that the new Royal Observatory has 40 per cent more sunshine but only 6 per cent more clear skies at night than the old Greenwich Observatory.

To overcome this difficulty, Smith and McCrosky (1954) tabulated cloudiness as reported during the nighttime synoptic observations at twenty weather stations in the southwestern United States. A map based on their data is presented in Figure 9. From a comparison with Figure 8, it is apparent that the pattern of nighttime cloud cover is quite differnt from the pattern of daytime cloud cover. All of the observatories, except Lick, average between five and six hours of clear skies per night, with Kitt Peak, McDonald, and Palomar averaging 5.6 - 6.2 hours, and Cloudcroft and Mt. Wilson averaging 5.0 - 5.6 hours per night. Lick Observatory where the new 120-inch telescope has recently been completed, averages less than five hours of clear skies per night. It is of interest to note for comparison that Boston, Massachusetts averages 2.9 hours of clear skies per night.

Nighttime cloud cover has also been studied by Arnold Court, Murray Gutnich, and Henry Salmela of the Applied Climatology Branch of the Air Force Cambridge Research Laboratories. An estimate was made of the number of clear or cloudless nighttime hours at Cloudcroft by considering the number of hours that three surrounding stations were simultaneously clear or cloudless. This was done over the five-year period from 1950 through 1954.

This method was validated by similar tabulations for two other three-station networks in the Southwest for which the central cloud cover was known. A study of the data indicated that the percentage (Y) of clear or cloudless hours at the interior station is approximated by the relationship: $Y=30+0.8X$, where X is the percentage of simultaneous cloud-free hours of the surrounding network.

This novel method of predicting cloud cover over an unknown station has given results that agree with cloud-cover data gathered from other sources, indicating that clear nights at Cloudcroft are about as frequent as at other mountain areas in the southwestern United States where astronomical observatories operate successfully. Specifically, about 66 per cent of the nighttime hours at Cloudcroft are predicted to be clear (less than 4/10 clouds), and about 50 per cent to be cloudless (less than 1/10 clouds).



PERIOD 1899–1938.

FIGURE 8. Annual Number of Clear Days

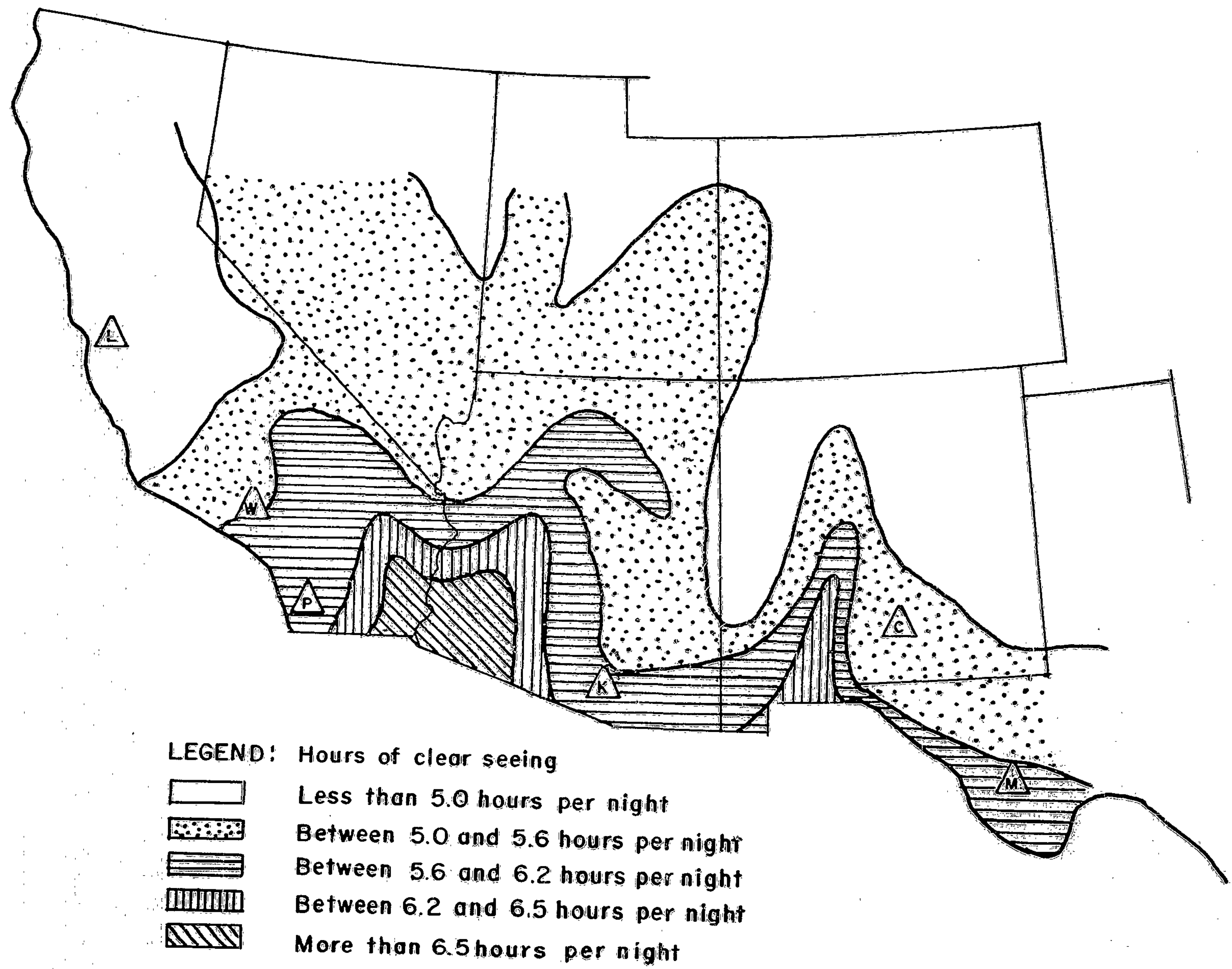


FIGURE 9. Nighttime Cloud Cover In the Southwest
(After Smith and McCrosky)

3.2 Cloudcroft Survey

3.2.1 Nighttime Cloud Cover

(a) Description

Cloud-cover estimates were made hourly throughout the nighttime only. The fraction of sky covered, in tenths, was recorded without regard to the type of cloud or its transparency. On nights when the site had gone unmanned for weather reasons, cloud-cover observations were made from the town of Cloudcroft, three miles to the south. Cloud-cover data were taken between 28 November 1960 and 15 September 1961.

(b) Results

Figure 10 shows the nightly arithmetic mean of cloud cover along a continuous time axis.

Figures 11 through 16 give the monthly arithmetic means of cloud cover as a function of the hour of the night. The purpose of such a presentation is to reveal the existence of a diurnal effect upon cloud cover, if such exists at all.

A nominal ten-month arithmetic average of cloud cover versus hour of the night is shown in Figure 16.

Table IV lists, by the month, the occurrence of clear ($\leq$4/10 cloud cover) and cloudless ($\leq$1/10 cloud cover) hours as a percentage of occurrence and as the average number of hours per night.

(c) Conclusions

The results of the Cloudcroft nighttime cloud cover study indicates that this site compares very favorably with the Western and Southwestern observatories. The average number of clear hours per night (6.8) observed at Cloudcroft indicates clearer nighttime skies than any of the observatories listed under Section 3.1. It might be noted that the Cloudcroft averages do not include the months of October and November, normally clear months in southern New Mexico. It would be expected, therefore, that the percentage of clear and cloudless skies as well as the number of clear and cloudless hours per night (the nights in October and November being longer than average) would be somewhat greater when averaged over an entire year.

The diurnal effect upon cloud cover appears to vary with the season. For example, the heavy cloudiness in the early evening in July, the rainiest month, is a carry-over from the late afternoon thunder-showers. The ten-month average shows a slight tendency for cloudiness to increase in the early morning hours. However, the effects are slight and over an interval of a year there appear to be no unfavored hours of the night.

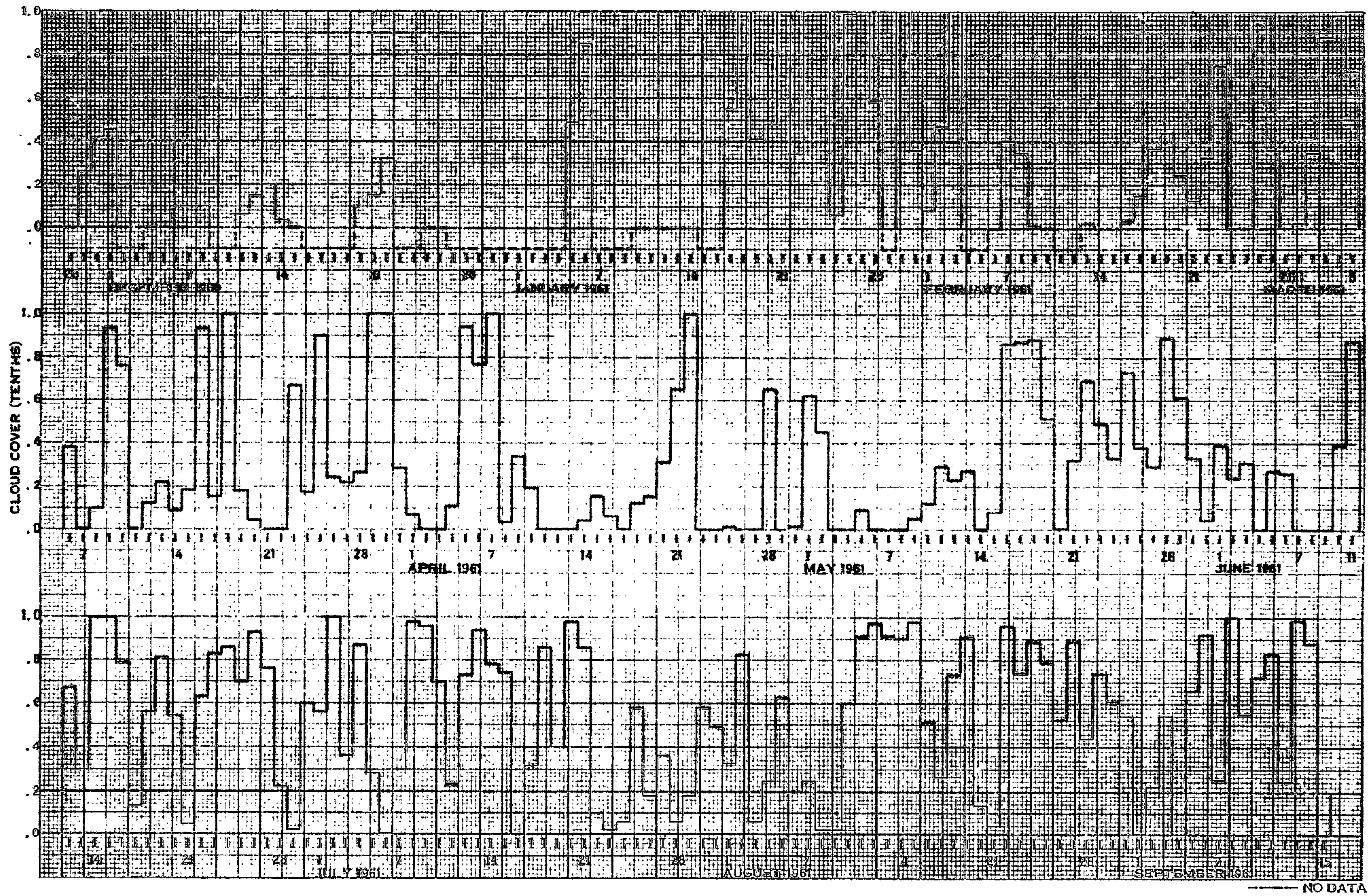


FIGURE 10. Nightly Continuous Time Average Cloud Cover

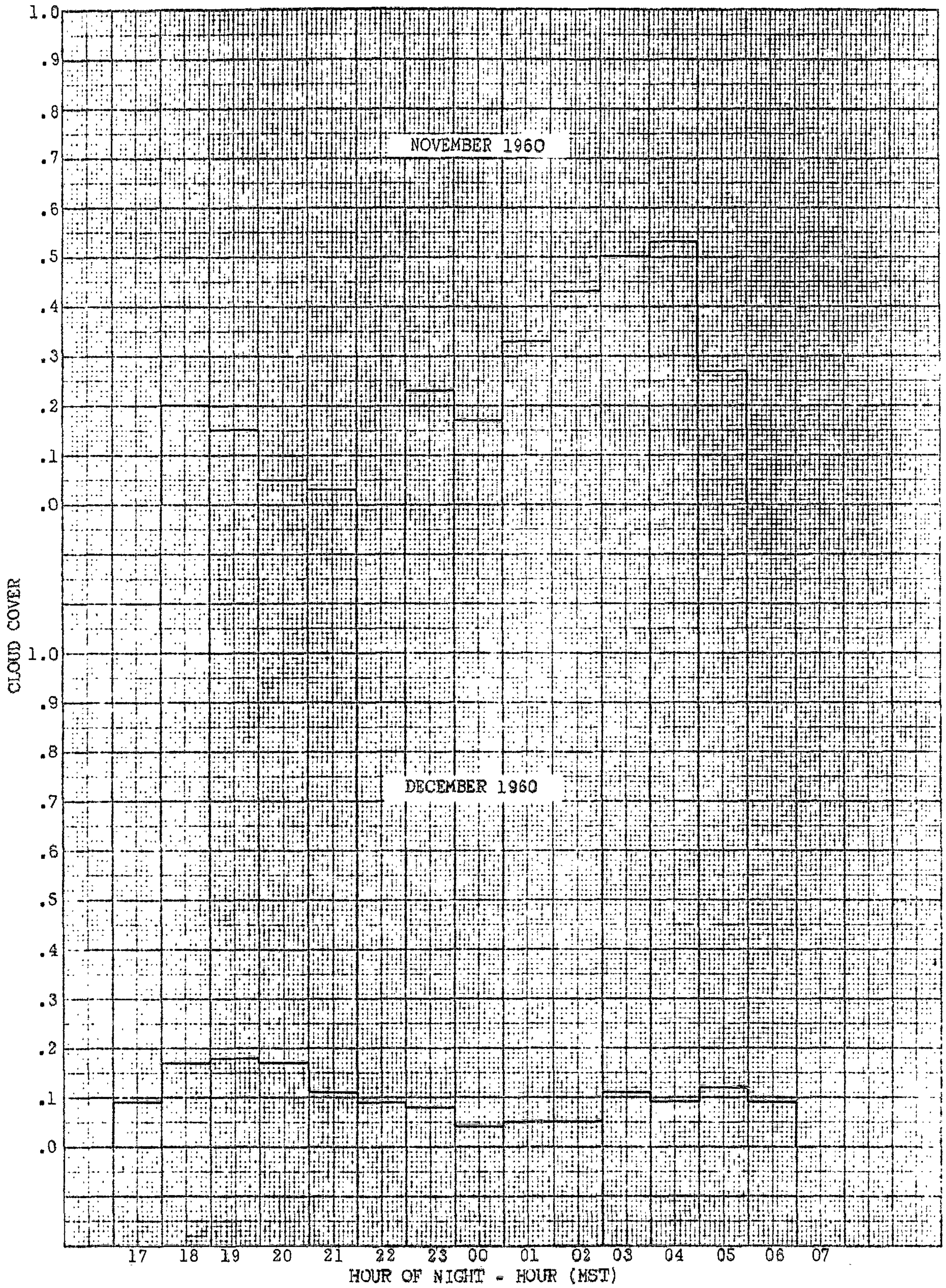


FIGURE 11. Monthly Arithmetic Mean of Cloud Cover vs. Time of Night

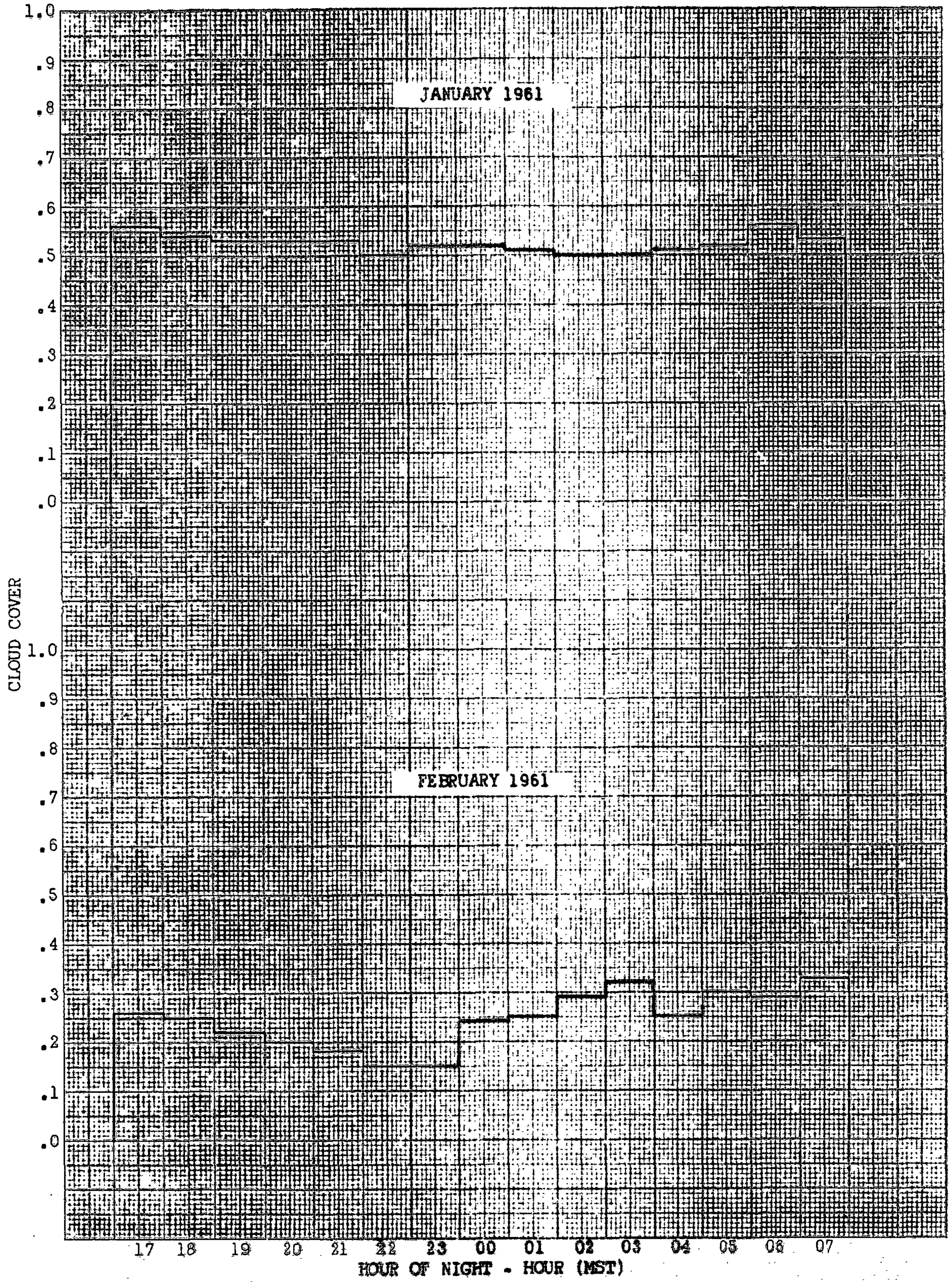


FIGURE 12. Monthly Arithmetic Mean of Cloud Cover vs. Hour of Night

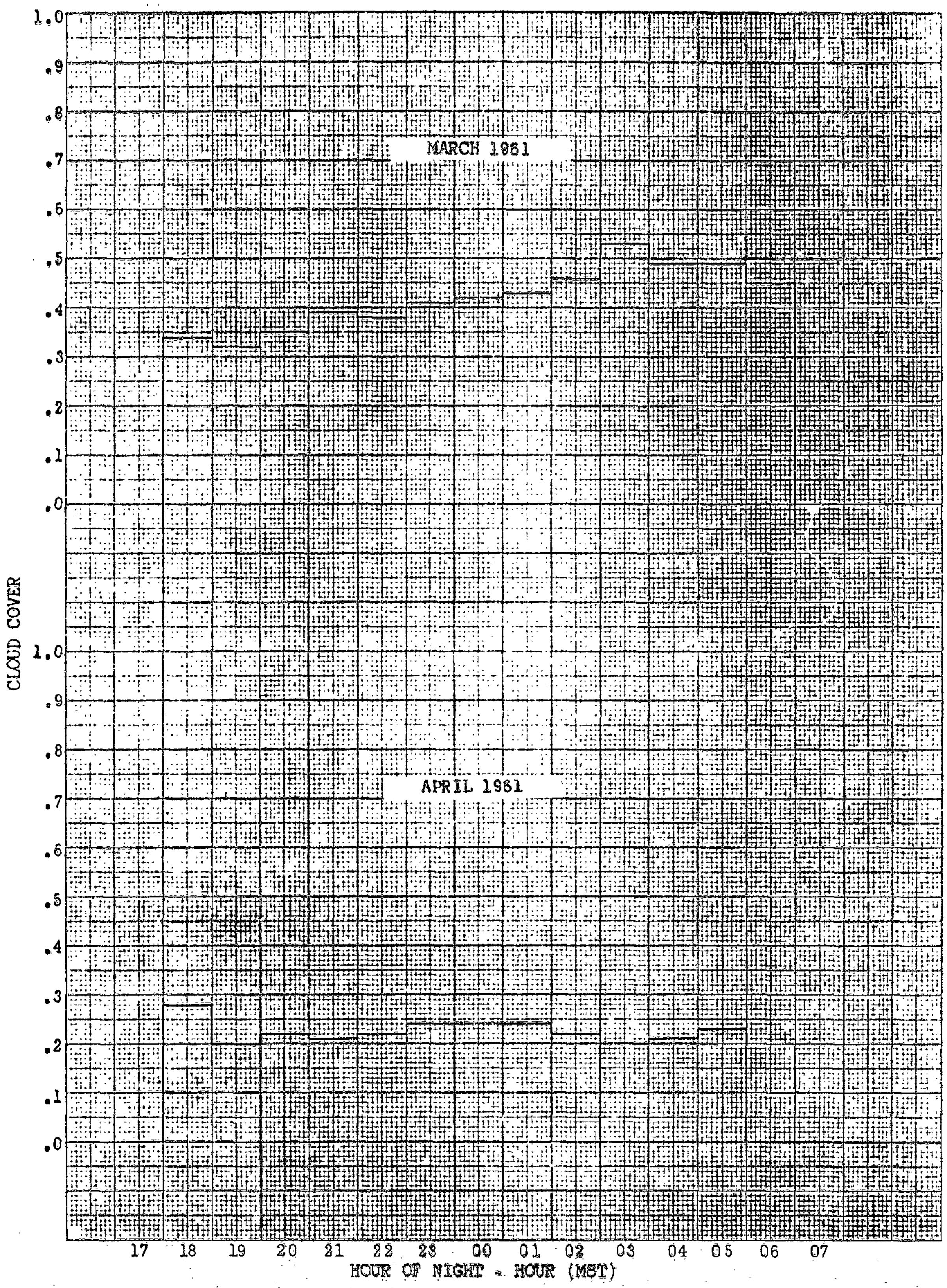


FIGURE 13. Monthly Arithmetic Mean of Cloud Cover vs. Hour of Night

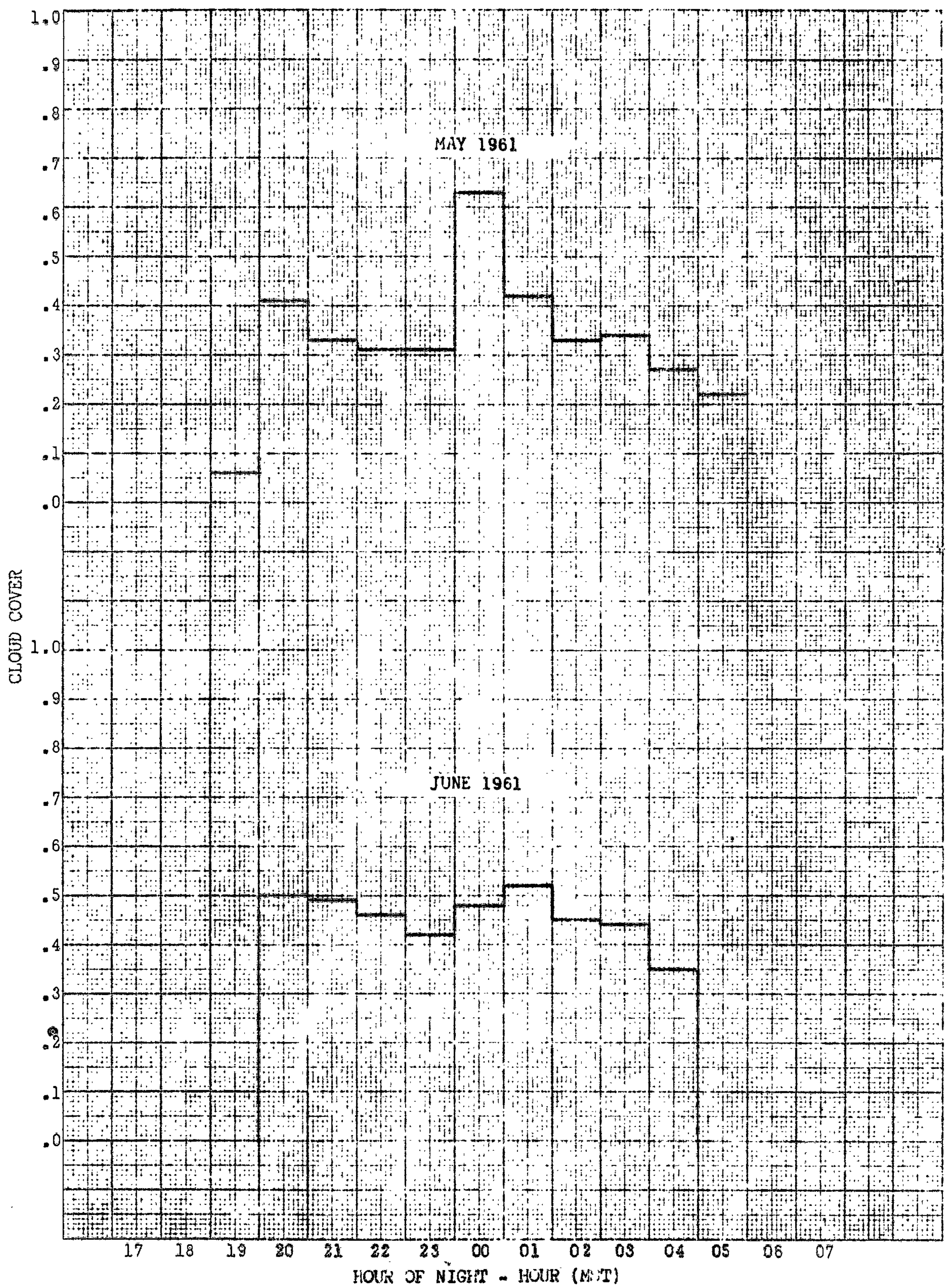


FIGURE 14. Monthly Arithmetic Mean of Cloud Cover vs. Hour of Night

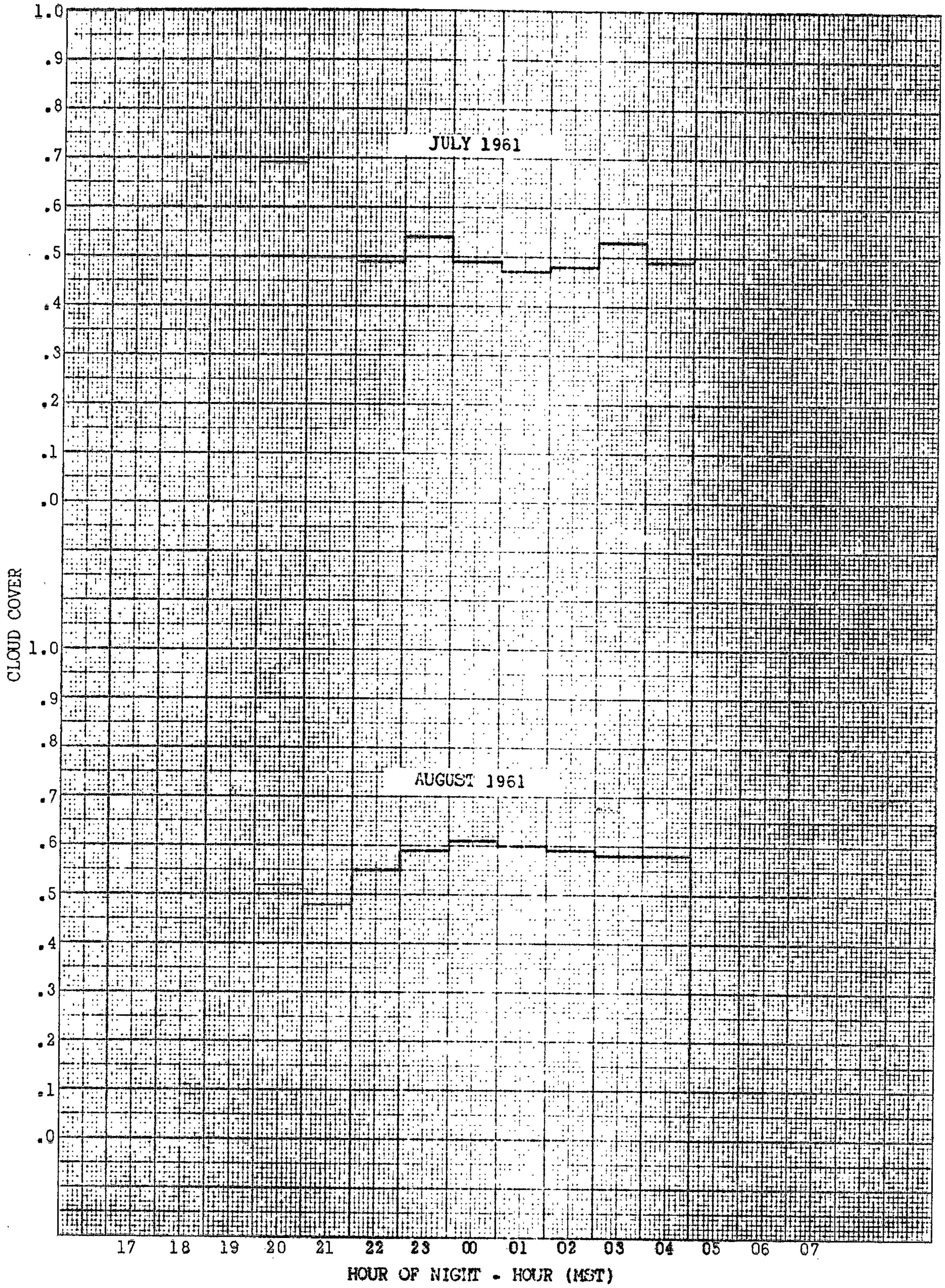


FIGURE 15. Monthly Arithmetic Mean of Cloud Cover vs. Hour of Night

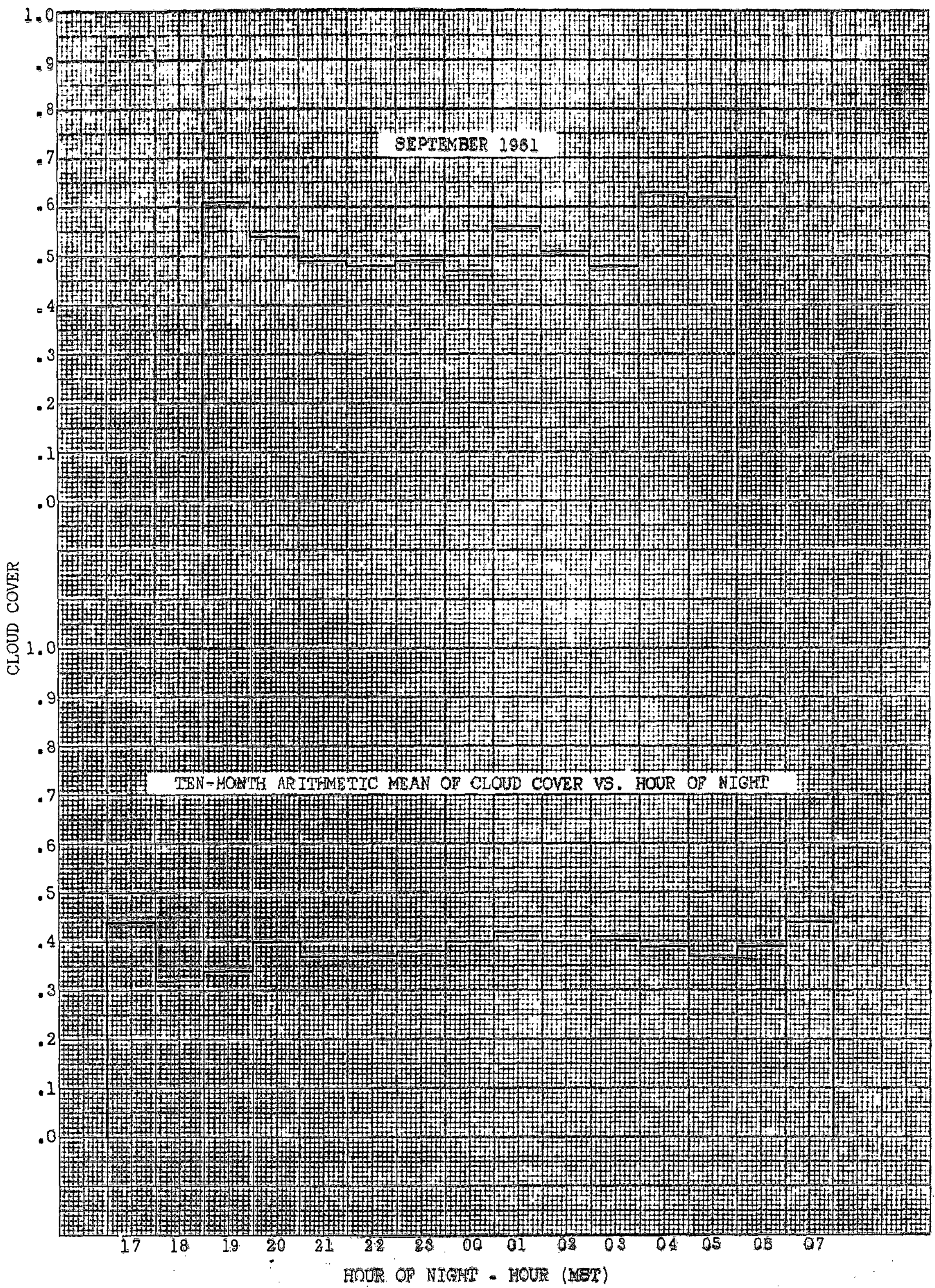


FIGURE 16. Monthly Arithmetic Mean of Cloud Cover vs. Hour of Night and Ten-Month Period

TABLE IV

MEASURED NIGHTTIME CLOUD COVER

MONTH	CLEAR (≤4/10)	DAYS OF OBSER-VATION	AVERAGE HOURS/NIGHT ≤4/10 COVER	CLOUD-LESS (≤1/10)	DAYS OF OBSER-VATION	AVERAGE HOURS/NIGHT ≤1/10 COVER
NOVEMBER 1960	67%	3.0	7.3	61%	3.0	6.7
DECEMBER 1960	93%	16.0	11.2	83%	16.0	10.1
JANUARY 1961	47%	20.5	7.1	35%	20.5	5.3
FEBRUARY 1961	73%	24.0	10.5	62%	24.0	8.9
MARCH 1961	58%	31.0	7.4	44%	31.0	5.6
APRIL 1961	84%	30.0	9.6	65%	30.0	7.5
MAY 1961	64%	31.0	6.1	50%	31.0	4.7
JUNE 1961	54%	30.0	4.7	35%	30.0	3.1
JULY 1961	49%	31.0	4.4	30%	31.0	2.6
AUGUST 1961	42%	31.0	4.1	20%	31.0	1.9
SEPTEMBER 1961	43%	16.0	4.8	25%	16.0	2.8
TOTAL	61%	263.5	6.8	45%	263.5	5.0

3.2.2 Observability

(a) Description

Observability differs from cloud cover in that it depends upon the distribution of the cover and the type of clouds involved. For example, the entire half of the sky below 60 degrees zenith angle might be covered by clouds, but since planetary observations are seldom made at zenith angles of greater than 60 degrees, the sky would be considered "observable". Another example would be a sky completely covered by a barely perceptible cirrus overcast. This would also be considered "observable" for almost all types of planetary photography.

These observations which are necessarily subjective in nature were made hourly throughout the night only, and were classified into three categories: "observable", "partly observable", and "not observable". Obviously a considerable amount of individual personal judgment was necessary in placing the important parts of the sky within a given category.

The total observability of a given night, based on the individual hourly observations, is arbitrarily defined as follows:

(i) Observable: If $\sum$(partly observable) + $2\sum$(not observable)* ≤ 2.

(ii) Partly Observable: If the conditions for (i) are not fulfilled but $\sum$(observable) + $\sum$(partly observable) ≥ 2.

(iii) Not Observable: If neither (i) nor (ii) are fulfilled.

---

* Provided that, if a "not observable" is involved, it occurs at either end of the night; i.e., it is either the first or last observation of a given night. Otherwise, no "not observable" will satisfy condition (i).

(b) Results

The normalized distribution of the observability of nights and the actual numbers of nights is given along with a normalized ten-month total in Table V.

(c) Conclusions

The observability of the site for this period appears to be rather good. Half of the nights would permit long uninterrupted periods for continuous or intermittant photography. Nearly nine-tenths of the nights

TABLE V

NORMALIZED OBSERVABILITY DISTRIBUTION
ACTUAL NUMBER OF DAYS AND PER CENT OF OCCURRENCE

MONTH	FULLY OBSERVABLE	PARTLY OBSERVABLE	NOT OBSERVABLE	NO. OF DAYS DATA TAKEN
NOVEMBER 1960	2 67%	1 33%	0 0%	3
DECEMBER 1960	9 56%	4 25%	3 19%	16
JANUARY 1961	8 38%	6 29%	7 33%	21
FEBRUARY 1961	11 46%	12 50%	1 4%	24
MARCH 1961	16 52%	10 32%	5 16%	31
APRIL 1961	23 77%	5 16%	2 7%	30
MAY 1961	16 52%	14 45%	1 3%	31
JUNE 1961	14 47%	14 47%	2 6%	30
JULY 1961	12 39%	14 45%	5 16%	31
AUGUST 1961	10 32%	15 49%	6 19%	31
SEPTEMBER 1961	6 40%	7 47%	2 13%	15
TOTAL	127 48%	102 39%	34 13%	263

would permit at the very least some photographic coverage. As with cloud cover, this period does not include part of the Autumn which is a relatively clear time of year in southern New Mexico.

3.2.3 Transparency

(a) Description

As was stated in Section 3.2.2(a), a sky having some transparency losses could still be considered perfectly usable for most types of planetary studies. Meinel (1958) has stated that optically thin layers of clouds will give better than average seeing. This effect has also been noted by one of the writers (B. A. S.) in connection with the Research Center's planetary and lunar photographic programs.

Transparency becomes an important factor, however, when photometric work is being considered. It was originally intended to make use of the photoelectrically operated Polaris telescope (see Section 10.1) as a means for determining sky transparency. The lack of gain stability and operational difficulties, however, precluded the use of the Polaris telescope.

It has been the practice of the observer to estimate, simultaneously with each double star observation (see Section 9.1.1), the sky transparency (in the region of the sky where the telescope is pointed) on a rather coarse and subjective scale by means of noting the limiting visual stellar magnitude. Because of the subjectiveness of this technique and because the attempted corrections for the effects of scattered moonlight (the moon is above the horizon 50 per cent of the time) are even more uncertain, considerable discretion should be used in interpreting these results. Because no other transparency measurements were available, it was decided to publish the visual estimates, which may at least serve as a rough guide.

(b) Results

Estimates of transparency, taken each half-hour and recorded on a numerical scale, have been interpreted as falling into one of the following categories, for "observable" conditions: excellent, good, fair, and poor. The normalized distribution for each month and for the total observing period (January - September 1961) appears in Table VI.

(c) Conclusions

Table VI shows that most of the skies described as "observable" (this would also include the clear areas of a "partly observable" sky) have good transparency. The high percentage of excellent transparency in September may be due to the cleaning of the lower atmosphere by late summer rains.

TABLE VI

NORMALIZED TRANSPARENCY

MONTH	EXCELLENT	GOOD	FAIR	POOR
JANUARY 1961	.00	.74	.10	.16
FEBRUARY 1961	.00	.87	.02	.11
MARCH 1961	.09	.55	.07	.29
APRIL 1961	.00	.83	.02	.15
MAY 1961	.00	.83	.05	.12
JUNE 1961	.10	.58	.05	.27
JULY 1961	.06	.67	.05	.22
AUGUST 1961	.00	.65	.15	.20
SEPTEMBER 1961	.42	.35	.07	.16
TOTAL	.05	.71	.06	.18

4.0 DENDROCLIMATOLOGY

The rainfall and cloud-cover summaries presented in this report are of a relatively short-term nature, and twenty to thirty-year climatic cycles may seriously bias such data. In an effort to overcome this difficulty, a dendroclimatological study of the Cloudcroft area has been made for the Air Force by the Laboratory of Tree-Ring Research of the University of Arizona. Dendroclimatology involves a study of tree rings in order to obtain a qualitative measure of the relative amounts of rainfall and cloud cover during the past. Trees up to 300 years old are growing in the Cloudcroft area, and have provided a general climatological record long enough to reveal the effect of short-term climatic cycles.

Rainfall has the greatest effect on the width of tree rings in the Southwest. Correlation coefficients for the relationship of tree rings to rainfall show the method to be very accurate. The correlation of tree rings with cloud cover, on the other hand, is much more approximate.

Fifty-four trees were sampled in the Cloudcroft area. Of these, seven cores were selected as suitable for measurement. The tree-ring evidence indicates that, as is generally the case in the southwestern United States, the last 120 years have been drier than the 300-year mean, except for the interval 1925-1945. Previous to 1840, the tree rings indicate alternating periods of wet and dry conditions of about thirty years duration.

All rainfall data presented in Section 2.1 are derived from measurements made during both wet and dry intervals, and are probably as representative of mean conditions as it is possible to obtain.

The low correlation of cloud cover with rainfall and with tree rings makes the following cloud-cover data extremely difficult to evaluate in terms of the long-term mean cloud cover. Fortunately, although mean precipitation at Cloudcroft is important for site water supply predictions, mean cloud cover is not. It is only the relative amount of cloud cover over observatories throughout the Southwest that is important, and comparisons of relative cloud cover are probably valid even when the absolute cloud cover changes slightly from year to year.

5.0 CONTRAILS

Climatological summaries contain no data on one uniquely modern aspect of cloud cover, that is, aircraft condensation trails.

Accordingly, one of the writers of this report (J. W. S.) has prepared the following analysis of contrail producing flights and the effects of these flights relative to a number of Western and Southwestern observatories and Cloudcroft.

In order to evaluate the seriousness of this contrail problem, it is necessary to know how many contrails are formed, how long they persist, and the expected future increase in contrails.

The number of contrails formed over a site depends mainly upon the number of aircraft, their flight altitudes, and atmospheric humidity.

Information concerning the number of aircraft and their general flight altitudes has been obtained from the Federal Aviation Agency (see Figures 17-21). According to FAA charts of peak day air traffic during the first half of 1960, only the California observatories have an appreciable number of high altitude (contrail producing) flights in their immediate vicinity. Kitt Peak (Figure 17) appears to be in the best position with respect to high altitude air traffic, followed by McDonald (Figure 18), Cloudcroft (Figure 19), Lick (Figure 20), Mt. Palomar (Figure 21), and Mt. Wilson (Figure 21).

Charts of air traffic do not, however, present a complete picture, since not all flights produce contrails. As indicated above, the probability of contrail production varies with altitude, but high altitude flights as defined by FAA include all flights above 24,000 feet. Taking the worst possible case, with atmospheric humidity at 100 per cent, the probability of contrail formation by a jet engine using JP-4 fuel at 30,000 feet is 16 per cent. At 40,000 feet it is 98 per cent, and at 40,000 feet to 60,000 feet it is 100 per cent (Handbook of Geophysics, Table 19-1A, 1960). Considering the probable number of flights between 24,000 and 30,000 feet, where contrail formation probability approaches zero, it is estimated that a maximum of 50 per cent of high altitude flights will produce contrails.

The question now arises concerning downwind drift of contrails formed near, but not over a site. It is estimated that an average contrail persists for one-half hour, although the range in persistence is from a few seconds to more than four hours. A contrail may even, under adverse weather conditions, catalyse the formation of enough high cirrus to cover the whole sky.

Assuming, however, an average contrail persistence of one-half hour, a study of the upper air trajectories has permitted the delineation of lines of 50 and 10 per cent probability of a contrail drifting near the site before it dissipates. These lines are shown as ovals around the observatory sites, inside of which any contrail formed has a greater than 50 per cent (or 10 per cent) chance of drifting to within a 15-mile radius of the site.

Because of their small number, contrails are at present of minor importance over the Cloudcroft site. They are of even less importance over Kitt Peak and McDonald. The increasing seriousness of the contrail problem in California is, however, a forecast of the future for even the most favorably located United States observatories. The Curtis report (1957), for example, predicts that the number of large civilian jets alone will increase by 300 per cent by 1975. It is not anticipated that contrail suppression devices will be used within Continental United States. Considering the presence of the Air Force solar observatory at nearby Sacramento Peak, the need for prompt action to preserve the relatively clear sky over the Cloudcroft area is indicated, regardless of whether or not a planetary observatory is constructed at the Cloudcroft site. All territory within the 10 per cent probability line on Figure 19 should be made a proscribed area for high altitude flights, and, as the only flights which will have to be re-routed are military, such action would appear not to be difficult at this time. Such action would also reduce the number of contrails over the Cloudcroft site to an acceptable number, even if the volume of traffic outside the proscribed area increased many times.

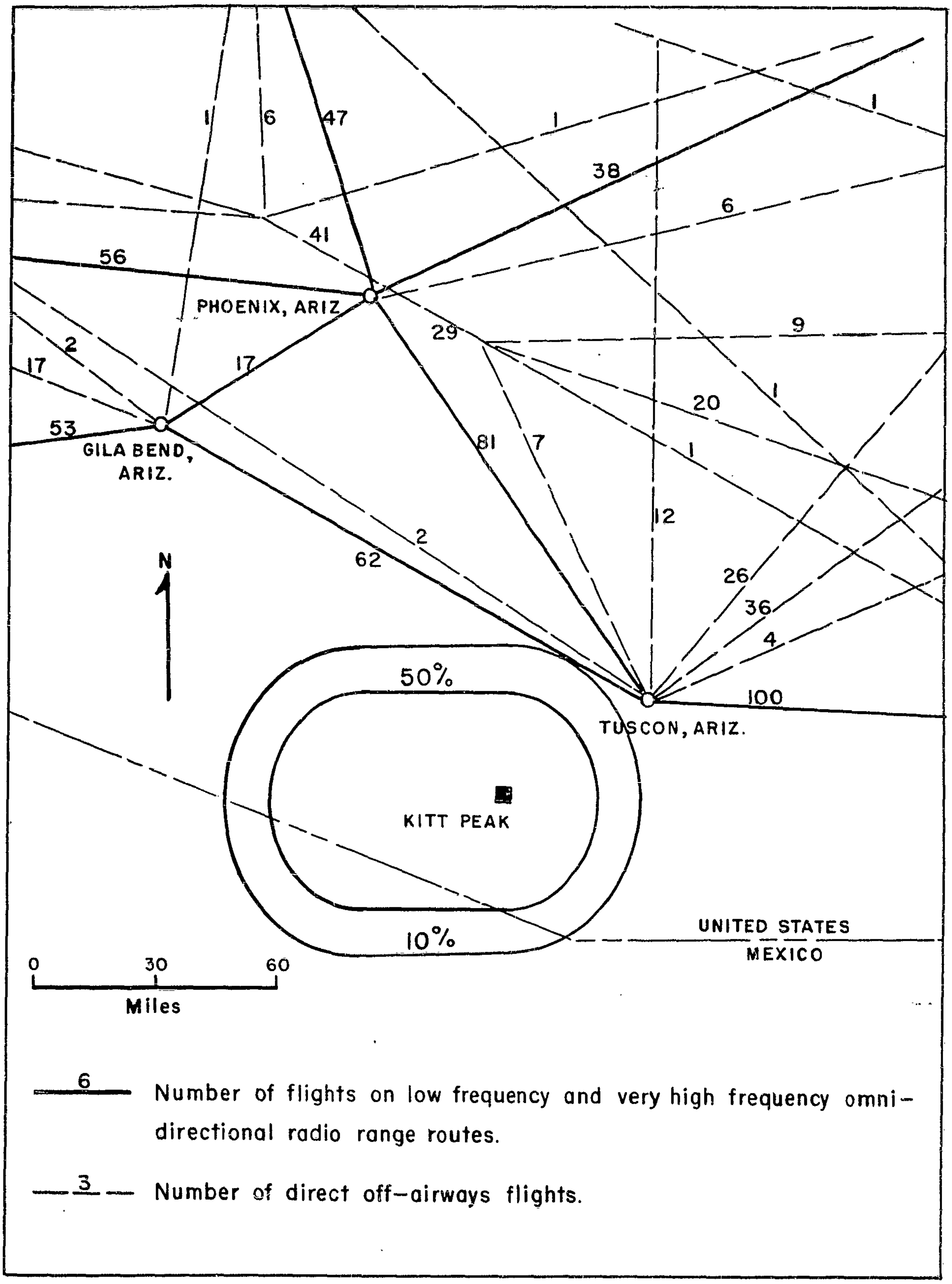


FIGURE 17. Kitt Peak Observatory Air Traffic Chart

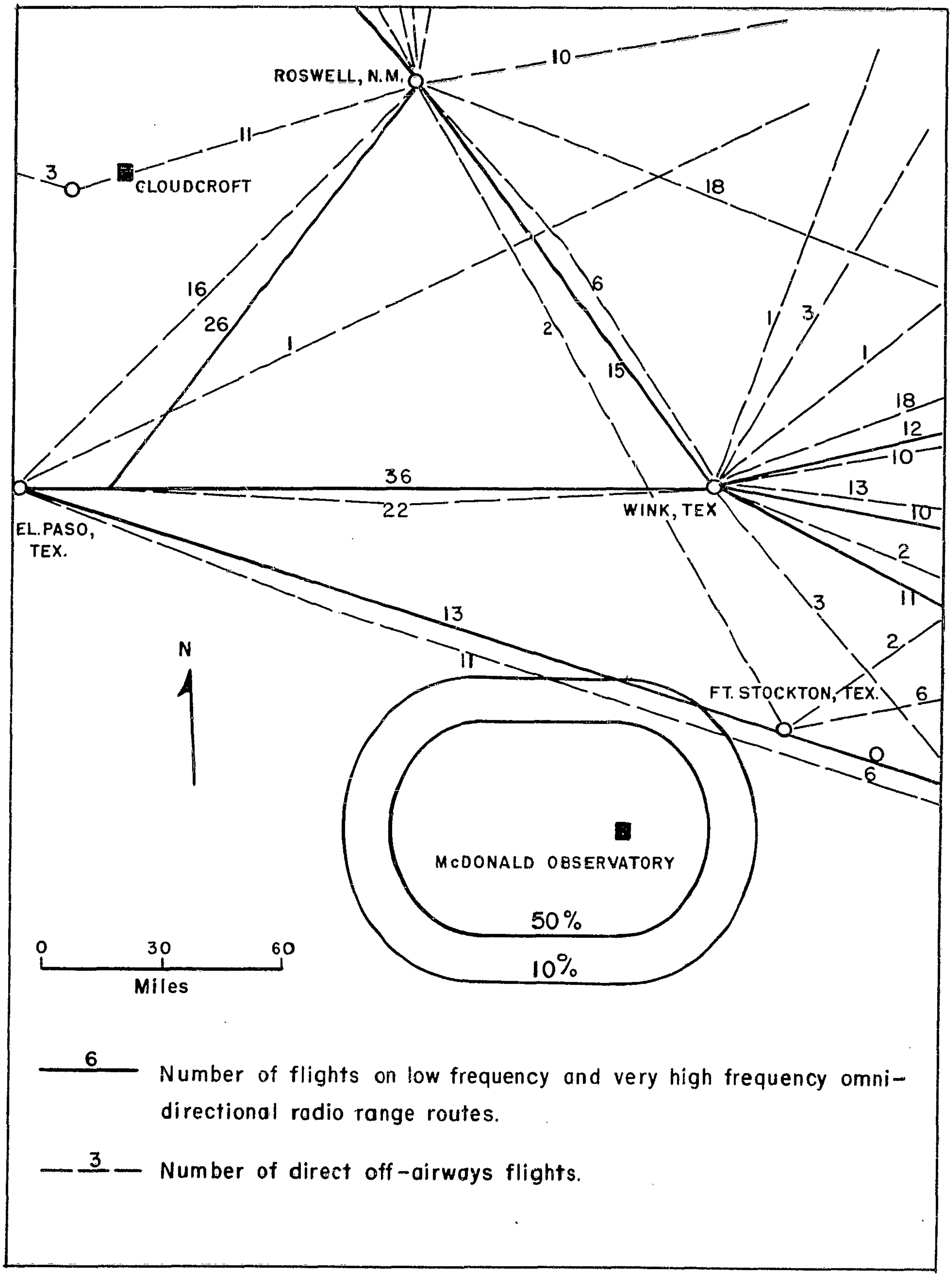


FIGURE 18. McDonald Observatory Air Traffic Chart

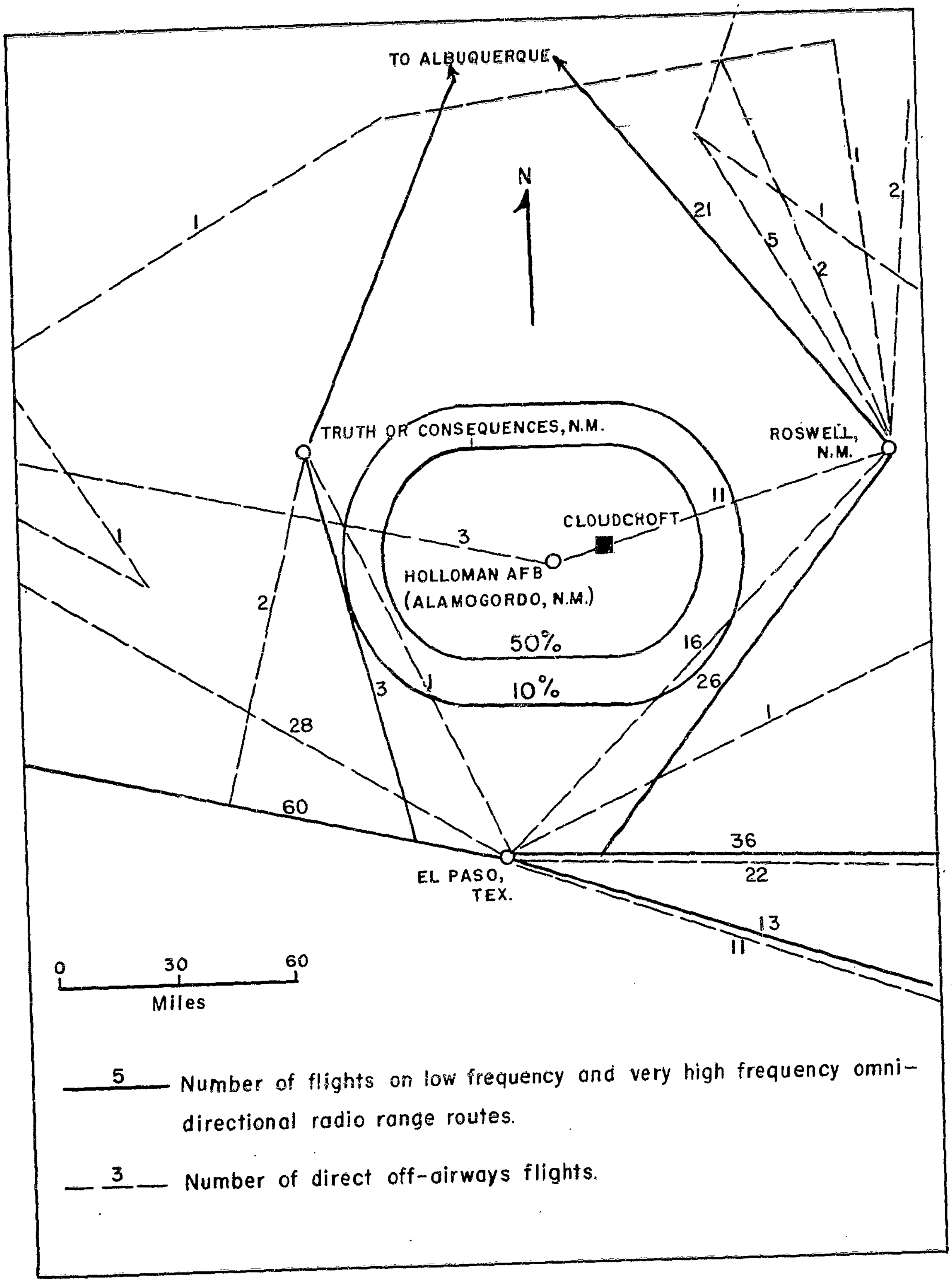
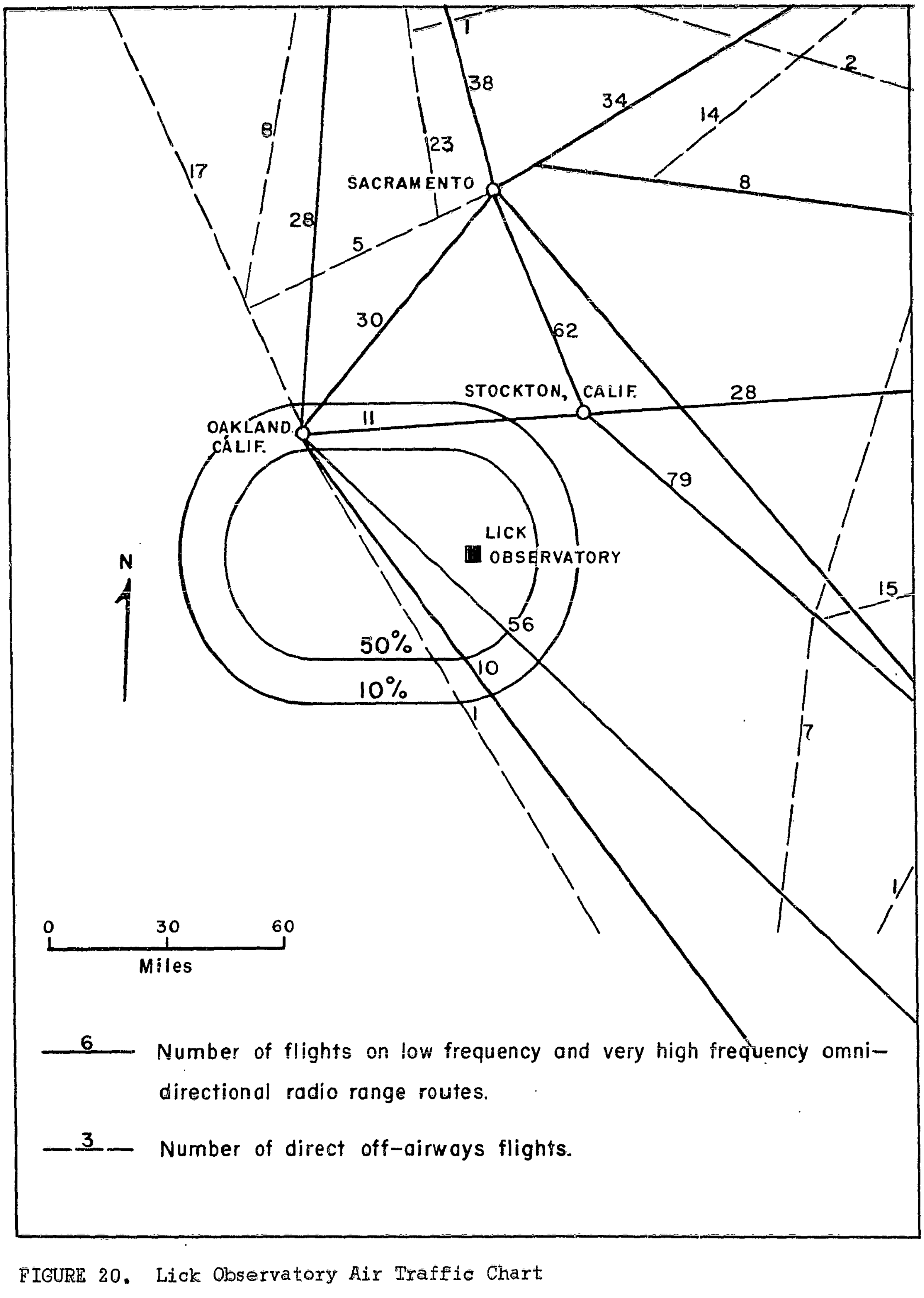


FIGURE 19. Cloudcroft Site Air Traffic Chart



Number of flights on low frequency and very high frequency omni-directional radio range routes.

Number of direct off-airways flights.

FIGURE 20. Lick Observatory Air Traffic Chart

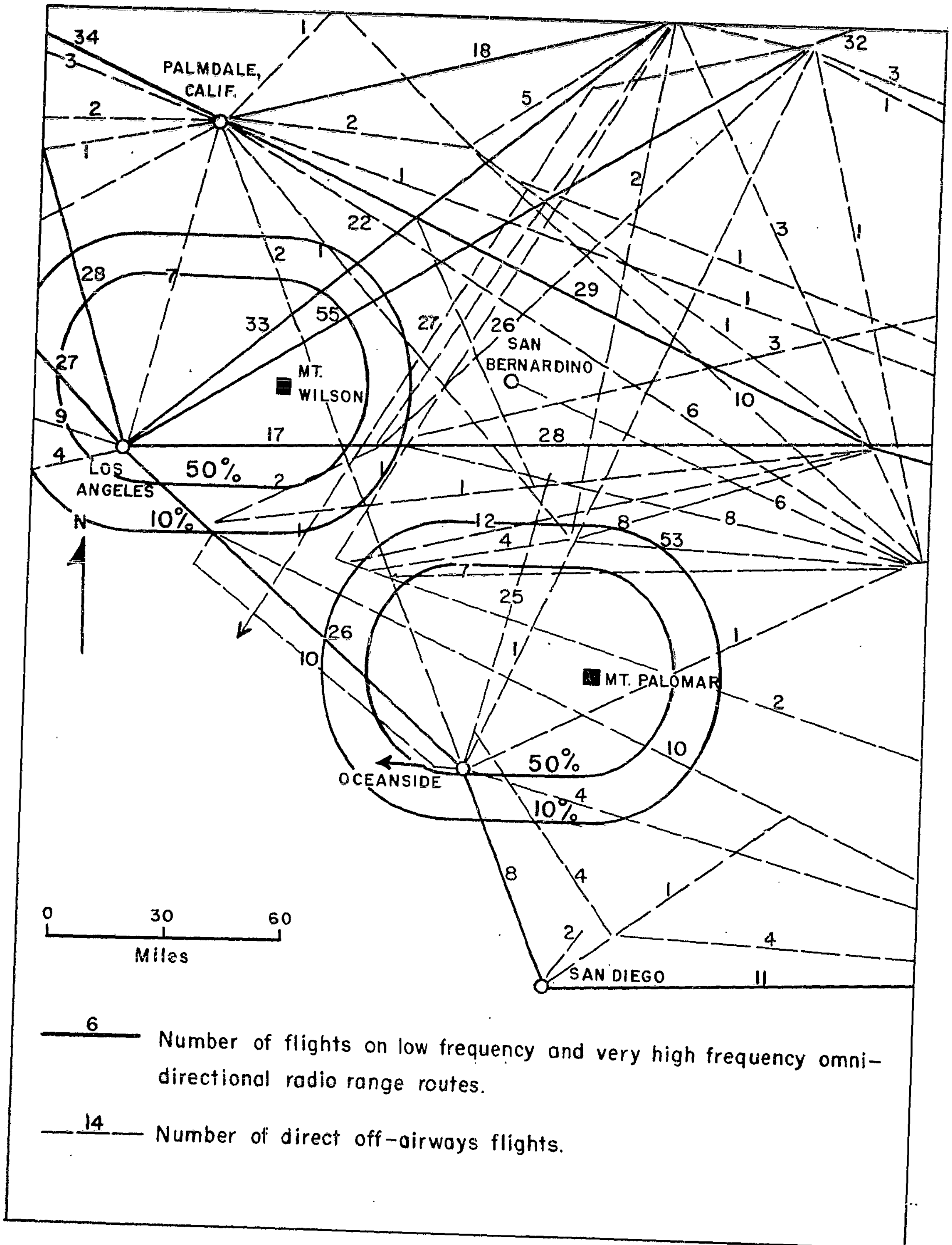


FIGURE 21. Mt. Wilson and Mt. Palomar Observatories Air Traffic Chart

6.0 WIND VELOCITIES

6.1 Cloudcroft Survey

6.1.1 Wind Speed

(a) Description

Near-surface wind speeds at an observatory site may be an important factor, as strong winds tend to produce telescope vibration, observer discomfort, and sometimes (but not always) image-disturbing low-level turbulence. Wind speed was recorded twice per hour throughout the night during the Cloudcroft seeing study, usually with an anemometer located approximately ten feet above the ground (see Figure 50). During the months of August and September, wind speed profiles were obtained by running the anemometer up and down the 75-foot "flagpole" shown in Figure 4. Runs were made at 2100, 0000, and 0300 hours on each night that the site was manned, with readings being taken at the 2, 10, 20, 30, 40, 50, and 68-foot levels.

(b) Results

The weekly arithmetic means of nighttime ranges (minimum to maximum) along with total weekly averages for the fixed ten-foot level are represented in Figure 22 along a continuous time axis. Insufficient data were taken during November and December to warrant inclusion in this figure.

Normalized distributions for each month and the total study period are given in Table VII.

Figure 23 shows the profiles of the average wind speeds for the total of the flagpole readings at 2100, 0000, and 0300 hours.

(c) Conclusions

The normalized distributions of wind speeds indicate that winds are rather mild at the Cloudcroft site. In a general sense this is true. However, it must be noted that two systematic errors are included in the distributions: (1) the site was not usually operated when strong winds were blowing, hence no wind data were taken; (2) the anemometer was located only ten feet above the ground, whereas the instruments proposed for the site would be situated some 25 to 75 feet above the ground. (A tall pine forest and a ring of low hills surrounding the site are certain to provide some shelter near the ground.) The magnitude of the first systematic error is probably not large, as there were only 15 nights on which strong winds prevented the operation of the site. The short-term profiles (Figure 23) would indicate that the second error is a factor with a magnitude of about 2.

However, it is not suggested that this factor be simply applied, indiscriminately, to Table VII. There is always the possiblity that the profiles vary with the season and/or with specific location within the site area.

Note that while Figure 22 shows little in the way of a seasonal effect on average wind speed, it does indicate that winds have a gusty characteristic during late winter and spring.

It is not felt that wind will pose a significant problem at Cloudcroft.

6.1.2 Wind Direction

(a) Description

Wind direction, defined as the direction from which the wind is blowing, was recorded simultaneously with the wind speed. Direction is subdivided to the eight standard points of the compass only.

(b) Results

Weekly modal values of wind direction are shown in Figure 22.

(c) Conclusions

An apparent seasonal effect is noted in Figure 22. The same precautions stated in Section 6.1.1(c) apply to wind direction. No readings of wind direction were taken on the flagpole run.

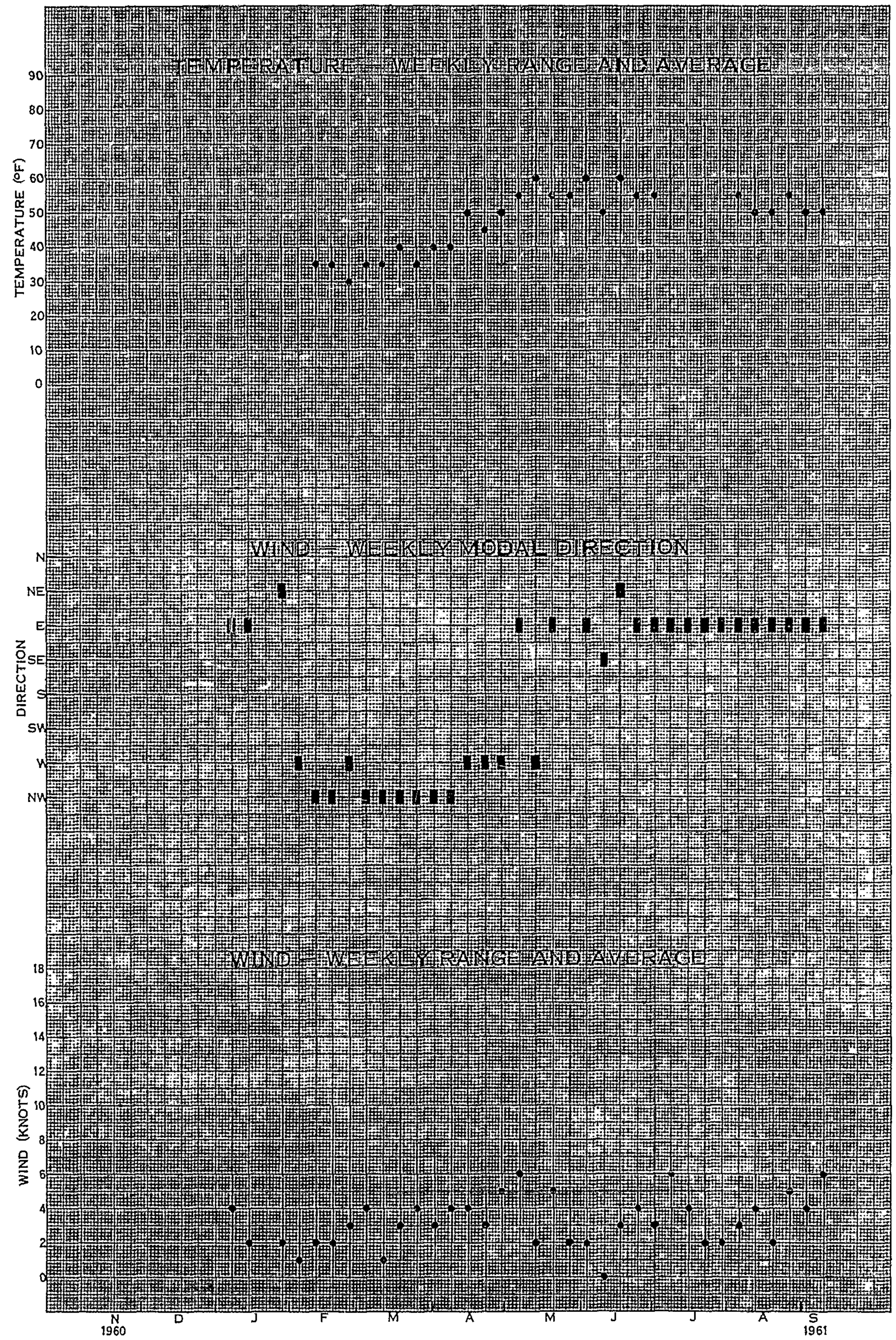

TEMPERATURE — WEEKLY RANGE AND AVERAGE
TEMPERATURE (°F)
90
80
70
60
50
40
30
20
10
0
WIND — WEEKLY MODAL DIRECTION
DIRECTION
N
NE
E
SE
S
SW
W
NW
WIND — WEEKLY RANGE AND AVERAGE
WIND (KNOTS)
18
16
14
12
10
8
6
4
2
0
N
1960
D
J
F
M
A
M
J
J
A
S
1961

FIGURE 22

TABLE VII

NORMALIZED WIND DISTRIBUTION
ACTUAL NUMBER OF READINGS AND PER CENT OF OCCURRENCE

MONTH	KNOTS 0-10	11-20	21-30	31-40	≧41	TOTAL READINGS
NOVEMBER 1960	44 100%	0 0%	0 0%	0 0%	0 0%	44
DECEMBER 1960	29 100%	0 0%	0 0%	0 0%	0 0%	29
JANUARY 1961	201 96%	9 4%	0 0%	0 0%	0 0%	210
FEBRUARY 1961	417 99%	4 1%	2 0%	0 0%	0 0%	423
MARCH 1961	367 94%	25 6%	0 0%	0 0%	0 0%	392
APRIL 1961	479 94%	31 6%	2 0%	0 0%	0 0%	512
MAY 1961	390 85%	56 12%	6 1%	8 2%	0 0%	460
JUNE 1961	361 100%	0 0%	0 0%	0 0%	0 0%	361
JULY 1961	373 89%	47 11%	0 0%	0 0%	0 0%	420
AUGUST 1961	370 93%	26 7%	0 0%	0 0%	0 0%	396
SEPTEMBER 1961	188 88%	22 10%	5 2%	0 0%	0 0%	215
ELEVEN-MONTH TOTAL	3219 93%	220 6%	15 1%	8 0%	0 0%	3462

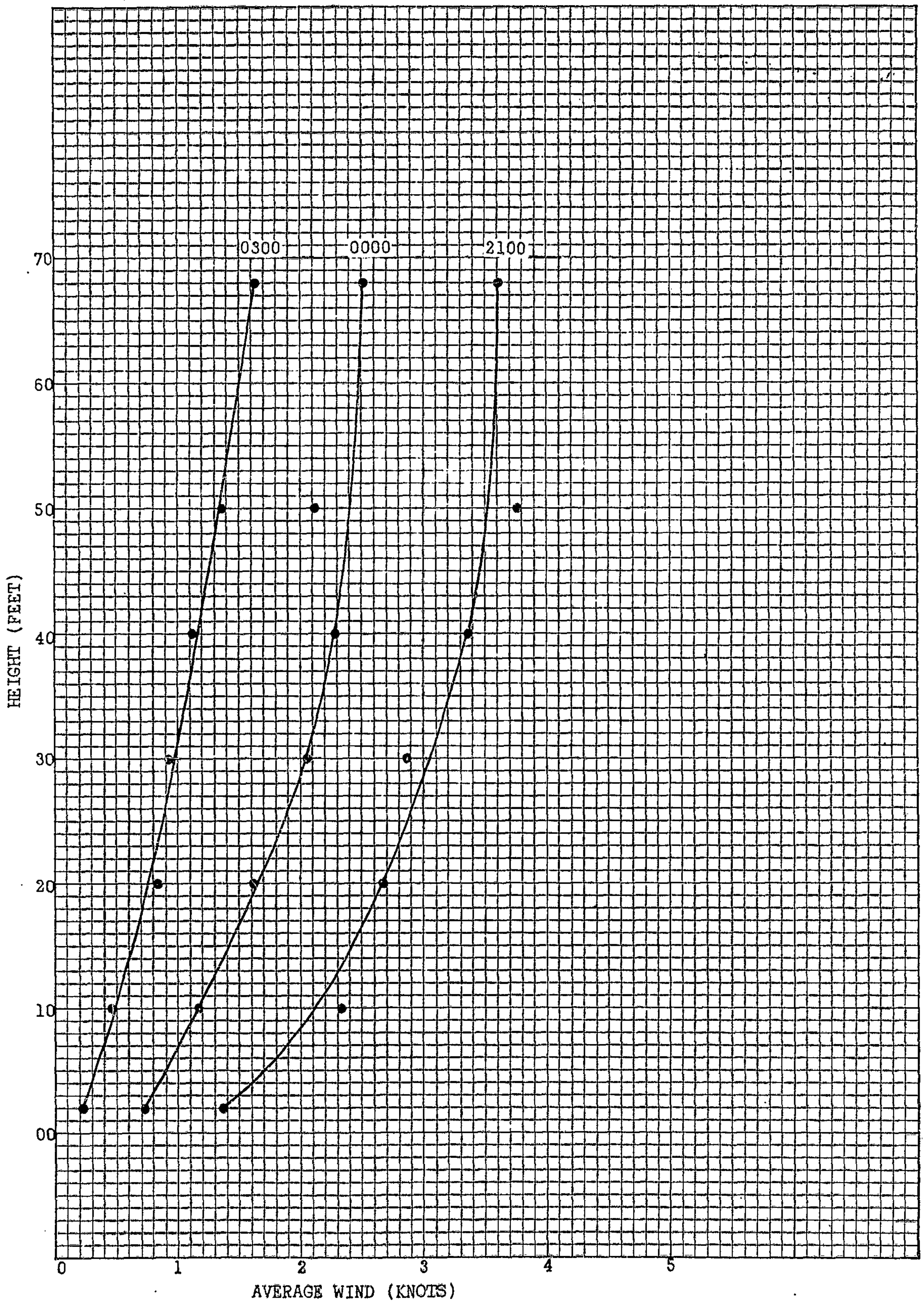


FIGURE 23. Height Above Ground vs. Average Wind Speed for Three Hours of Night

7.0 TEMPERATURE

7.1 Cloudcroft Survey

7.1.1 Description

Temperature ranges at observatory sites are an important factor in instrument stability and site habitability. The greatest effect of an excessive temperature range is that produced on the mirrors of reflecting telescopes. The differential expansion and contraction of the glass resulting from such temperature changes can warp a mirror sufficiently to change its optical figure and reduce the corresponding image quality.

Temperature was recorded automatically and continuously at the Cloudcroft site on a spring-wound thermograph throughout most of the study interval. An alcohol thermometer was used prior to the installation of the thermograph in February. During the time the thermometer was being used, continuous readings were impossible and only maxima and minima were recorded.

7.1.2 Results

The weekly arithmetic means of daily temperature range along a continuous time axis are given in Figure 22. Also shown are weekly average temperatures, estimated from the thermograph records. Weekly averages were not possible to obtain before the installation of the thermograph. The thermograph records for the month of July unfortunately were misplaced at some time after the maxima and minima had been tabulated. For this reason no weekly average temperatures are available for July.

7.1.3 Conclusions

The averages of the daily temperature ranges for the Cloudcroft site are somewhat higher than those averages for a number of Southwestern observatories shown in Table XIV. The mean temperatures are about the same or slightly lower than the Cloudcroft averages, which are, presumably, records made at the town itself.

There can be little question regarding personal physical discomfort in the early morning hours during the winter months. This, however, is typical of most high altitude observatories during their winter seasons, and does not seem to hinder astronomical research.

8.0 MICROTHERMAL MEASUREMENTS

8.1 General Study.

Small-amplitude, short-period fluctuations of temperature in the non-adiabatic layers of the atmosphere are indicative of the turbulent mixing of air masses of different temperatures. Such mixing produces cells of differential temperature, and, therefore, of differential index of refraction. These cells are the major cause of the optical disturbances observed at the telescope. Generally speaking, the greatest effects take place within the non-adiabatic planetary layer, i.e., relatively close to the ground; and at the tropopause and other inversion layers at heights many miles above the ground. Disturbances produced by the higher layers are generally unaffected by local topography and may be fairly uniform over large areas of the country, whereas the effects of surface-layer turbulence are certain to be strongly dependent upon local conditions. Numerous studies have been made attempting to relate local topography to seeing. The lack of agreement among individual observers would indicate that no simple relationships exist. It is not surprising, therefore, that astronomers tend to be somewhat biased toward rules which fit their individual experiences. Discussion in greater detail of the above generalizations may be found in "Optical Studies of Atmospheric Turbulence" and "Optical Astronomical Seeing: A Review".

Meinel (1958) has written that, in the case of three of the sites studied for the National Astronomical Observatory (Kitt, Chevalon, and Summit), the mean microthermal fluctuations were least at Kitt. He also noted that Chevalon and Summit are low sites with respect to their surroundings, being 800 and 400 feet higher respectively, while Kitt is 4,000 feet higher than its surroundings. He then stated (P. 41): "We now feel that relative elevation above surroundings may be one of the important factors bearing upon the excellence of a site." If this general statement is considered to hold rigorously for all sites, then it would imply poor observing conditions at the Cloudcroft site, because the Sacramento Mountains comprise an uplifted plateau. This plateau is covered with gently rolling hills rather than mountains, and the "peaks" at the Cloudcroft site are generally no more than 150 feet higher than their surroundings (see Figure 3).

In consideration of the seriousness of the implications of Meinel's generalizations concerning relative elevation of a site above its surroundings, the data presented in the AURA report were closely studied by micrometeorologists of the Geophysics Research Directorate, Air Force Cambridge Research Laboratories. They report that the mean of the average range in fluctuation for either Chevalon or Summit exceeded the mean of the average range for Kitt by no more than 0.08°F. These temperature differnces are so small that one cannot be sure that the Kitt fluctuations actually were weaker than the Chevalon and Summit fluctuations.

Even granting that the mean microthermal fluctuations were least at Kitt, the AURA report has failed to provide values of a statistical scatter about the means from which statistical significance could be computed. Also, the means referred to were not obtained from all the records collected, but from samples, the size and representation of which are not known. Nor is there any indication that the same nights were used in all three samples. It is not possible, therefore, to determine at this time whether the mean fluctuations were statistically significant in their difference.

Having questioned the reality and significance of the differences in temperature fluctuations between Kitt on the one hand and Chevalon and Summit on the other, it is also pertinent to question the reason offered for the temperature differences appearing in the AURA report. As indicated above, Meinel felt that relative elevation above surroundings was one of the more important factors bearing upon microthermal fluctuations. Some have taken this to indicate that, generally speaking, a peak site is to be preferred to a plateau or plain site.

Meterorological studies have shown, however, that the rougher the terrain, the more turbulent the air in the atmospheric boundary layer, all other things being equal. Thus, one would expect greater temperature or density fluctuations in the vicinity of a typical peak than on a typical plain or on a plateau about five miles to the leeward of an escarpment (Cloudcroft under a westerly wind) under the same general synoptic conditions, e.g., the same free-air wind speeds. It is clear, however, that there are no typical peaks or plateaus. Seeing characteristics change from peak to peak, and even from place to place on the same peak. The same thing is true for plateaus. It is evident, therefore, that seeing quality is the result of many variables, with the purely local surroundings of a site being of great importance.

8.2 Cloudcroft Survey

8.2.1 Description

Although it had been intended to conduct microthermal studies at Cloudcroft using the AURA equipment, it was found that the complete recording systems were unavailable. It was learned that some of the AURA microthermal equipment was being used on other projects and only the Esterline-Angus recorders were made available to the Research Center for use in the Cloudcroft survey.

The response of these recorders was examined by noting the recorded amplitude of constant-amplitude sine-wave inputs. At a frequency of 1 cycle per second, the recorder gave only 13 per cent of its d. c. calibration, with the recorded amplitude decreasing in the 0.5 to 5 cycle-per-second range by the relationship $\log A = -\log f$, where A and f are the recorded amplitude and the frequency of the constant-amplitude sine-wave input respectively. Because of the severe attenuation of these recorders, it was decided to assemble a completely new system employing a 10 cycle-per-second thermister, transistorized amplifier, and a Sanborn recorder which gave essentially linear response throughout the above frequency interval.

Microthermal measurements, made at various sites during the AURA survey, were taken at a single level of 60 feet. This sampling procedure, however, is considered to be inadequate for two principal reasons: (1) All density inhomogeneities within the optical cylinder from the telescope mirror to the edge of the atmosphere will affect the telescope image. (2) Air flow streams determined by local topography may set up stratified layers of microthermal activity, thus introducing the possibility that any given single level at a particular site might be highly nontypical of the average of the other layers.

Although the most logical approach would by synoptic recording of microthermal activity at many layers throughout the entire planetary boundary layer, this would obviously be impractical.

As a compromise, flights with a captive balloon were contemplated whereby microthermal activity could be measured at discrete levels up to 200 feet. This technique, however, proved to be impractical for routine operations and the final adopted procedure made use of the "flagpole" (see Figure 4) for profile data.

Throughout August and September 1961, microthermal measurements were taken at 2100, 0000, and 0300 hours on each night that the site was manned, with two-minute recordings being made at the 2, 10, 20, 30, 40, 50, and 68-foot levels.

8.2.2 Results

The results of the captive balloon run, made on the night of 22 June 1961 (with a single run on the night of 23 June) are shown in Figure 24. The ΔT for each height represents the arithmetic mean of 50 individual readings taken from each of the two-minute recordings. Each reading represents the total temperature range over a one-second interval. Every other one-second interval was read, starting with the first, until 50 readings were obtained.

These data were then interpreted in terms of the total effect at a given level. It is assumed that the time-averaged aberrations of the telescope image caused by the microthermal cells at a given level, produce a gaussian light distribution centered on the undisturbed position with a dispersion parameter proportional to the temperature fluctuation. The total effect of all layers above a given level "h" may then be described as $\tau_h = \left(\sum_{i=h}^{\infty} \overline{\Delta T_i}^{\,2} \right)^{\frac{1}{2}}$ where τ is an arbitrary microthermal dispersion parameter and $\overline{\Delta T_i}$ is the time-averaged temperature fluctuation of the "i"th layer. Since the maximum obtainable height with the captive balloon was 200 feet, the above relationship was rewritten as $\tau_h = \left(\sum_{200}^{\infty} \overline{\Delta T_i}^{\,2} + \sum_{i=h}^{200} \overline{\Delta T_i}^{\,2} \right)^{\frac{1}{2}}$ and the first term within the parenthesis was considered as a constant over the period of a single balloon flight. Although Figure 24 indicates that microthermal activity was becoming rather low at the higher levels, there is actually no way of knowing the magnitude of the first term compared to the second. Figure 25 presents normalized microthermal dispersion parameters versus height above the ground. The curved line represents a condition where $\sum_{200}^{\infty}$ is very small compared to $\sum_{h}^{200}$. A vertical line (no change with height) represents a condition where the second term is very small compared to the first. As stated above, Figure 24 suggests the reality of the first condition, but it is possible for any condition between the extremes to exist.*

The results of the August and September microthermal runs are given in Figures 26 and 27. The data reduction for the flagpole measurements is essentially the same as for the captive balloon runs, with the exceptions that 25 instead of 50 readings were taken from each two-minute run, and that the arithmetic means represent the averages of all runs for the one-month period. The magnitude of the standard deviation for each level is indicated as a barred dot in Figure 26. Since the maximum height possible on the flagpole was 68 feet, the microthermal dispersion parameter will be redefined as $\sigma_h = \left(\sum_{68}^{\infty} \overline{\Delta T_i}^2 + \sum_{i=h}^{68} \overline{\Delta T_i}^2\right)^{\frac{1}{2}}$, with the first term within the parenthesis again being considered a constant throughout a total run.

8.2.3 Conclusions

The results of the balloon runs clearly confirm the suspicion that the microthermal activity might be stratified. There also appears to be a tendency for these layers to exhibit vertical displacement throughout the night, although not much can be concluded from a single set of observations. Although Figure 26 represents the averages of only 30 days and the standard deviations are large, there appears to persist a more highly active layer at 40 feet during the early evening. This suggests a topographical effect and further indicates possible systematic errors in taking readings at a single level.

Figures 25 and 27 show the advantages of getting the telescope mirror well above the ground. If activity above the top of the flagpole is negligible, an improvement in image quality by a factor of 2 might be expected by having the telescope 50 feet above the ground. The same improvement at even lower levels might be obtained by locating the instruments on the small hills (A, B, C, or D) shown in Figure 3.

The microthermal data presented here certainly cannot be compared with the AURA data. Microthermal fluctuation frequencies as observed at Cloudcroft usually ranged between 0.5 and 5.0 cycles per second. In this range the Cloudcroft equipment gave nearly linear response while it would appear that the AURA equipment was strongly damped (variable with frequency) within the same range. Thus the AURA results may offer some comparative information within themselves (subject to objections previously discussed) but do not permit comparison with Cloudcroft data.

It should be noted that Meinel's microthermal "seeing" scale is completely arbitrary and should not be confused with the double star seeing scale (Table IX). Although the scale is defined in terms of ΔT in the text of the AURA report, it is unfortunate that ΔT was not given directly.

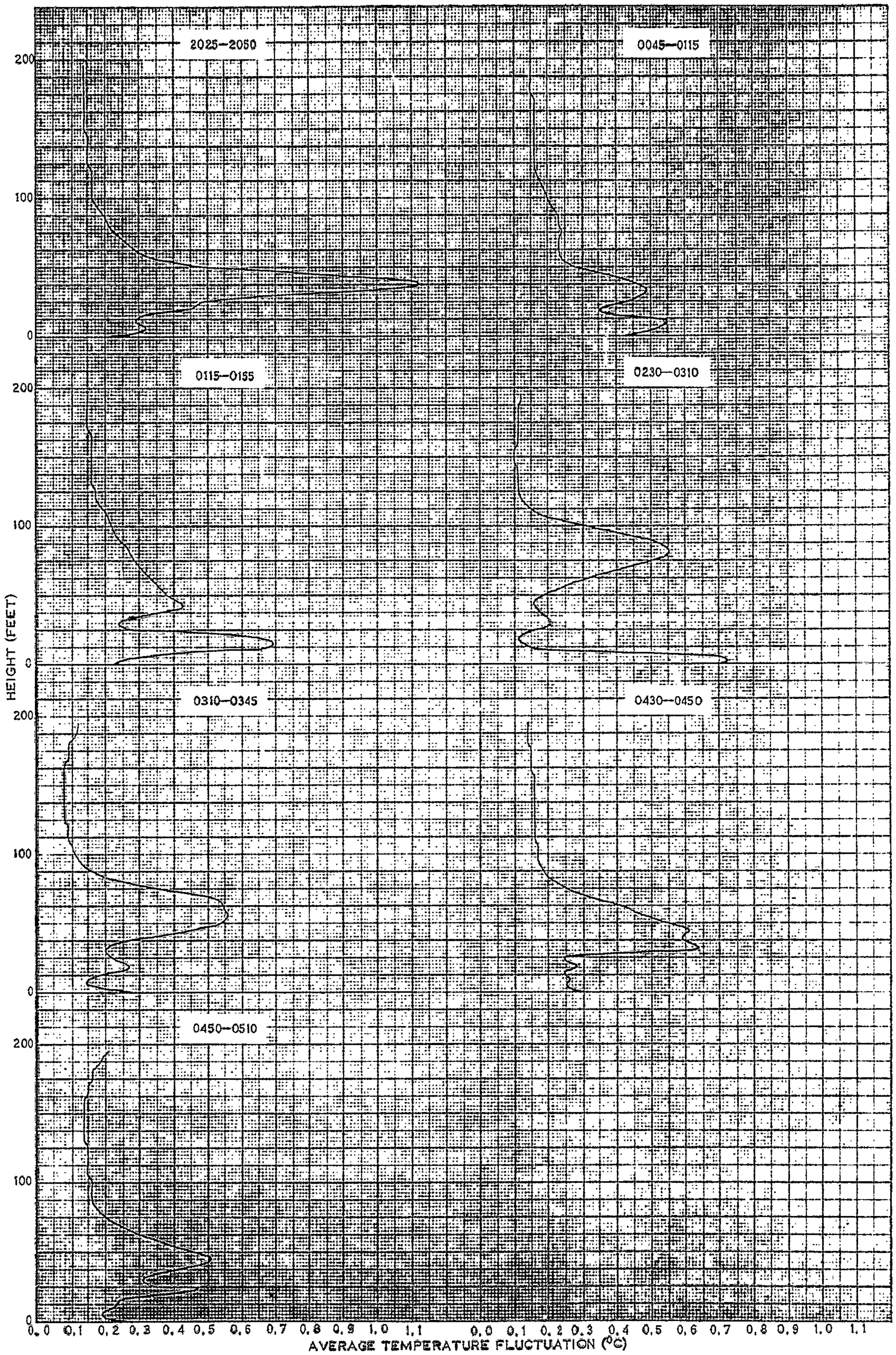


FIGURE 24. Height Above Ground vs. Average Microthermal Temperature Fluctuations for 23 June 1961

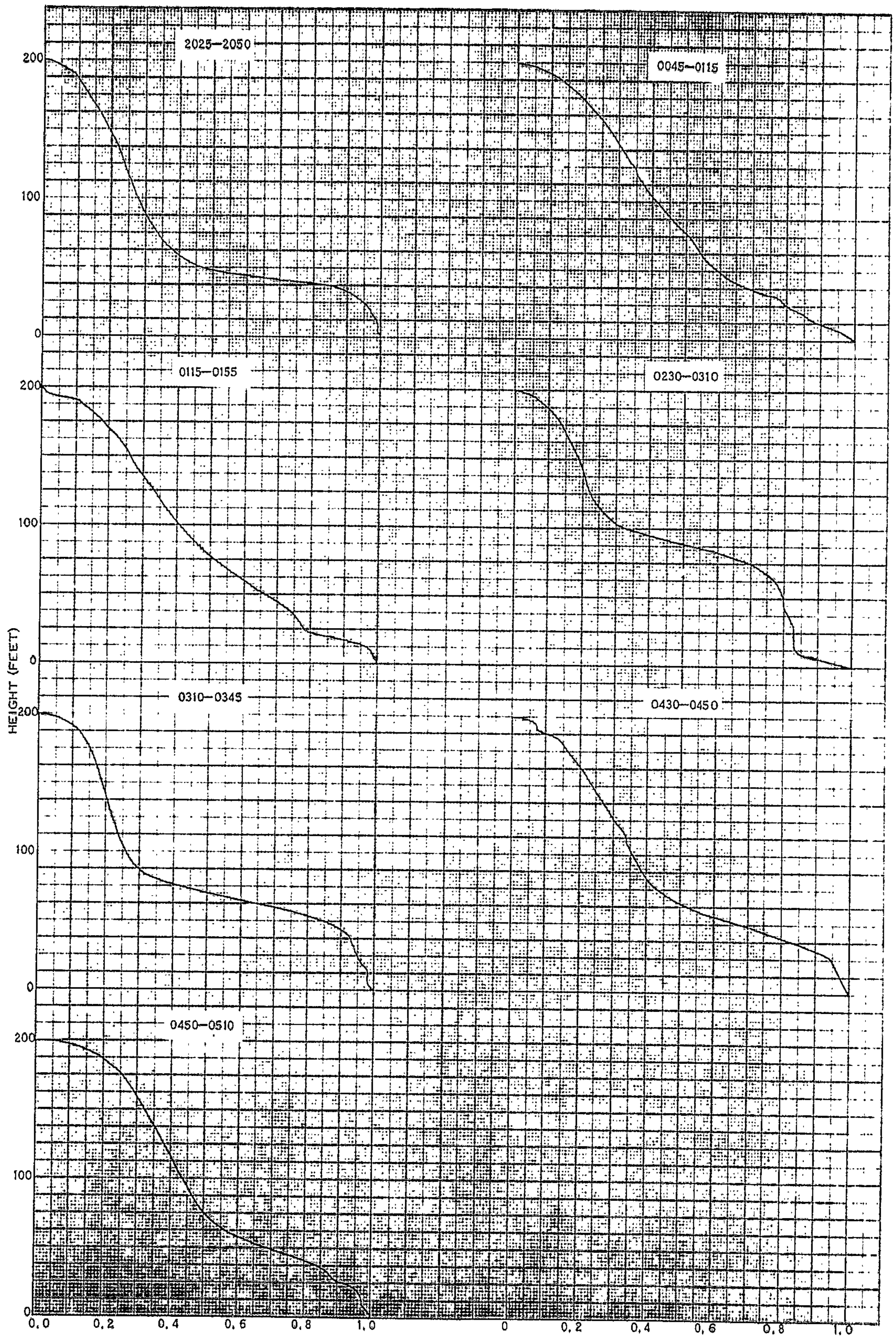


FIGURE 25. Height Above Ground vs. Normalized Microthermal Dispersion Parameter for 23 June 1961

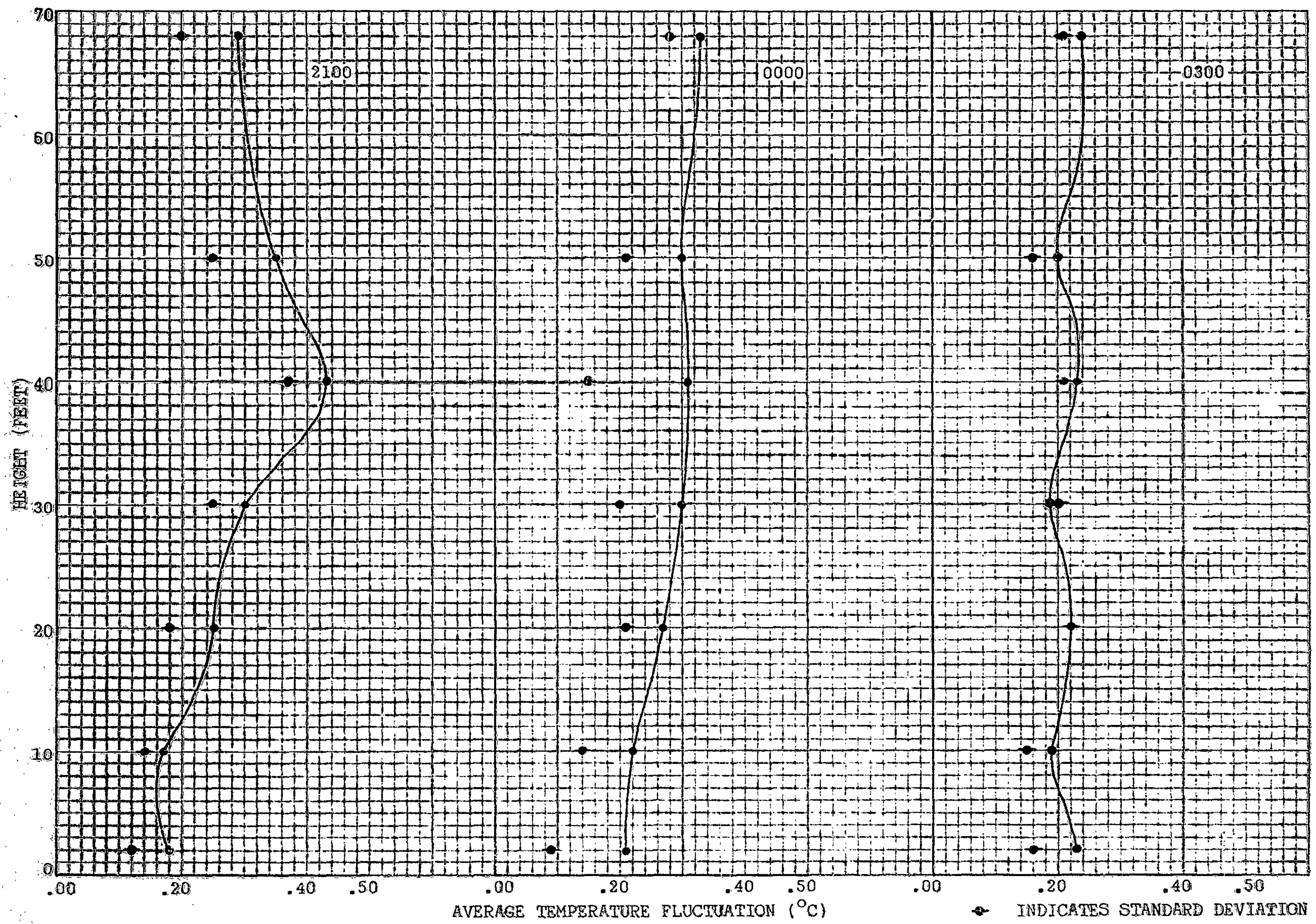


FIGURE 26. Height Above Ground vs. Average Microthermal Temperature Fluctuations for Three Hours of Night -- 8 August 1961 through 7 September 1961

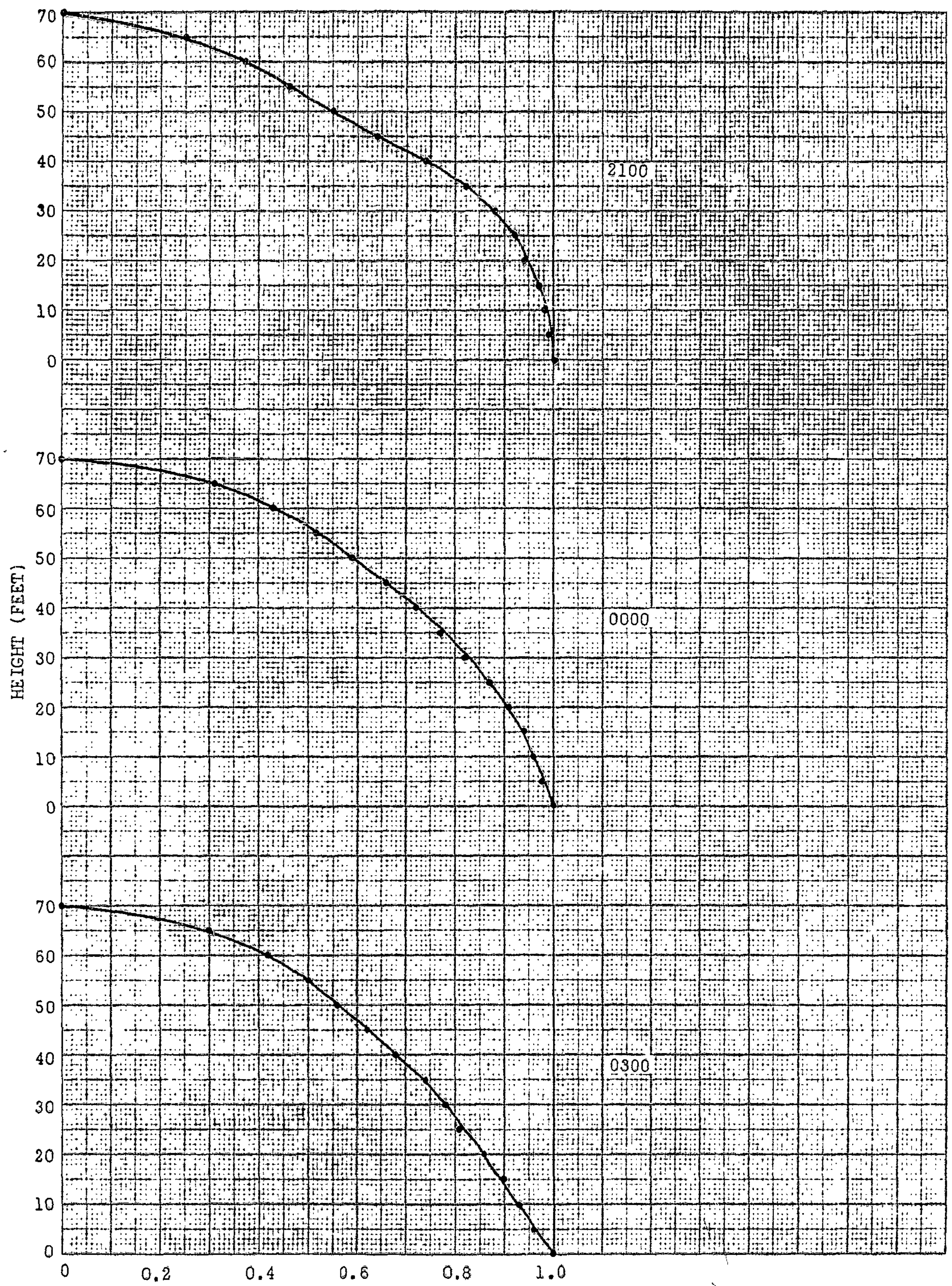


FIGURE 27. Height Above Ground vs. Normalized Microthermal Dispersion Parameter for Three Hours of Night -- 8 August 1961 through 7 September 1961

9.0 VISUAL OBSERVATIONS

9.1 Cloudcroft Survey

9.1.1 Double Star Observations

(a) Description

A significant evaluation of the Cloudcroft site is not possible without measurement of the quality of seeing at the site over an extended period of time.

The Cloudcroft double star program was essentially a duplication of the equivalent program carried out by AURA. Preselected double stars (Table VIII and Figure 28) of a nominal 2 arc-seconds of separation and confined to a zone between 0 and 20 degrees North declination, were observed at zenith angles of less than 45 degrees. The apparent diameters of the stars' seeing confusion disks were then estimated from the known separation of the double, identified with the appropriate value of the AURA seeing scale (Table IX), and entered in the observing log. Observations were made twice per hour, with each observation yielding a maximum, minimum, and modal value over an average interval of five minutes.

The Rhodes 16-inch gregorian reflector (Figure 30), which accounts for nearly all of the double star observations, was leased from W. H. Rhodes of Phoenix, Arizona. This instrument has an effective focal-length of 24 feet and is mounted on a portable equatorial-type mount. A more complete description of this instrument is give by Rhodes (1952). Upon its arrival at the Research Center, the Rhodes reflector was set up in proximity to the University's 12-inch Fecker reflector for purposes of comparison of optical performance. Although the optics were found to be of good quality, it was noted that the electric telescope drive produced considerable vibration of the telescope. After a week of unsuccessful attempts to reduce this vibration, the residual amplitude was still considered to be too high for seeing analysis, and it was decided to use the telescope without its drive. Snow storms and the delayed completion of the 16-inch telescope shelter at Cloudcroft prolonged the installation of the Rhodes reflector. This instrument was finally placed in operation at the site on 5 January 1961.

A 12-inch Newtonian reflector (Figure 31) was leased from C. F. Capen, Jr. for the period covered by the contract. This instrument, having a 96-inch focal length, was used primarily for planetary observations. Prior to the installation and operation of the Rhodes telescope, the 12-inch instrument was used for double star observations.

(b) Results

During the nine-month interval, December 1960 to September 1961, a total of 2,782 individual double star observations were made with the 12 and 16-inch reflectors.

TABLE VIII

DOUBLE STARS USED FOR VISUAL OBSERVATIONS

STRUVE NO.	RIGHT ASCENSION	DECLINATION	MAGNITUDES	SEPARATION	SPECTRA
Σ113	$01^h\ 17.7^m$	-00°49′	6.2-7.2	1.8″	G-G
Σ729	$05^h\ 28.9^m$	+03°15′	6.0-7.3	2.0″	B-O
Σ880	$06^h\ 13.2^m$	+10°36′	8.0-8.0	5.4″	G-G
Σ1348	$09^h\ 22.3^m$	+06°31′	7.0-7.5	1.8″	F-F
OΣ226	$13^h\ 26.5^m$	+15°55′	7.3-7.8	1.9″	F-F
Σ2375	$18^h\ 43.5^m$	+05°27′	6.2-6.6	2.2″	A-A
Σ2701	$20^h\ 35.1^m$	+11°54′	7.8-8.2	2.1″	K-K

TABLE IX

AURA SEEING SCALE

SEEING	RESOLUTION	POSSIBLE OBSERVATIONS
5+	0.3″-0.4″	Highest quality planetary photography
5	0.4″	Highest quality planetary photography
4	0.8″	Good for general planetary work, but not outstanding
3	1.2″	General coarse structure survey work
2	1.6″	Barely acceptable for survey work; useful for polarimetric or spectral studies
1	2.0″	Integrated studies only
0	>2.0″	None

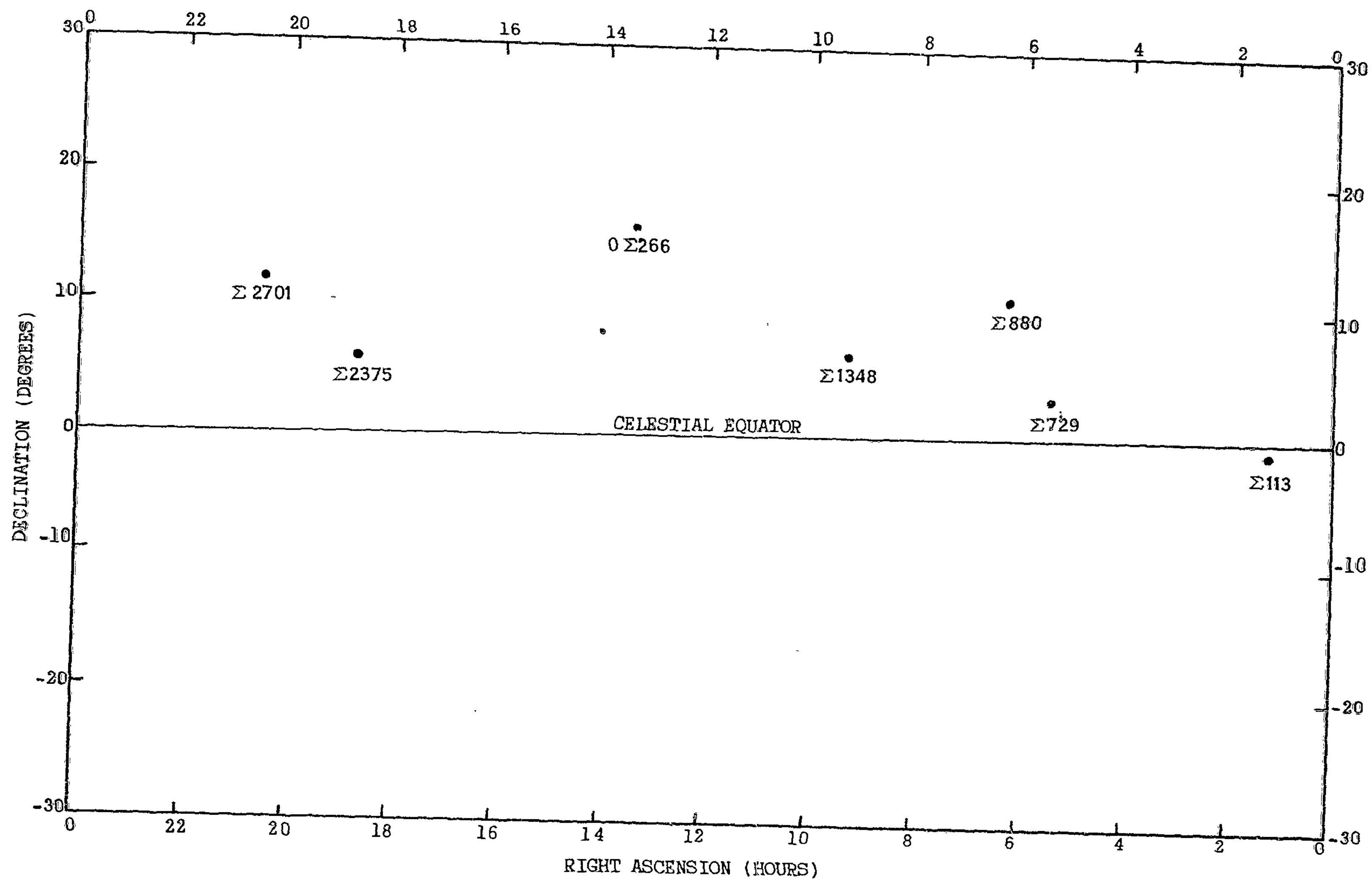
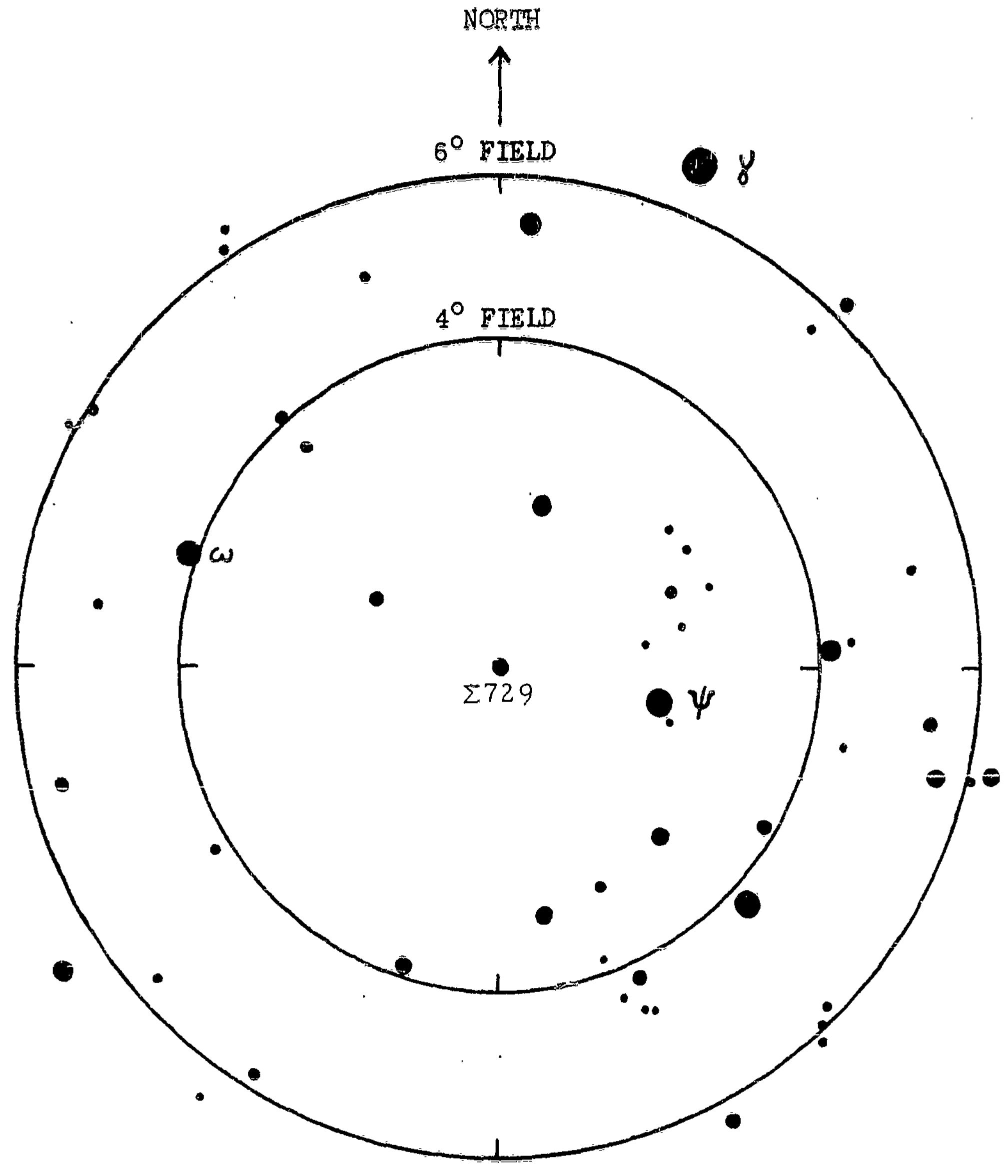


FIGURE 28. Stars Used at Cloudcroft Site for Double Star Observations



SAMPLE STAR FIELD IDENTIFICATION FOR THE DOUBLE STAR Σ729 IN THE CONSTELLATION ORION

FIGURE 29

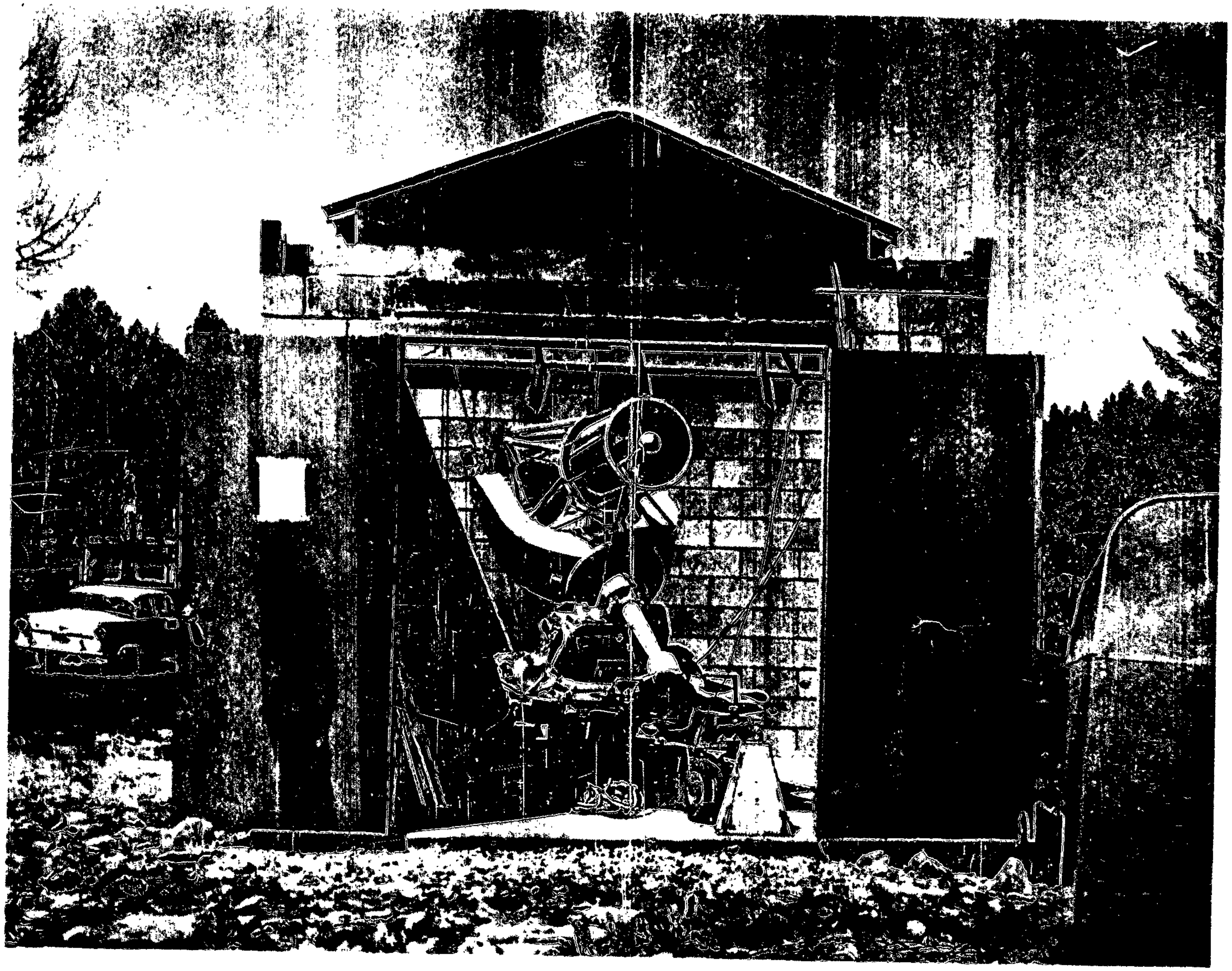


FIGURE 30. 16-Inch Telescope and Building Showing the Sliding Roof in a Retracted Position
(New Mexico State University Photograph)

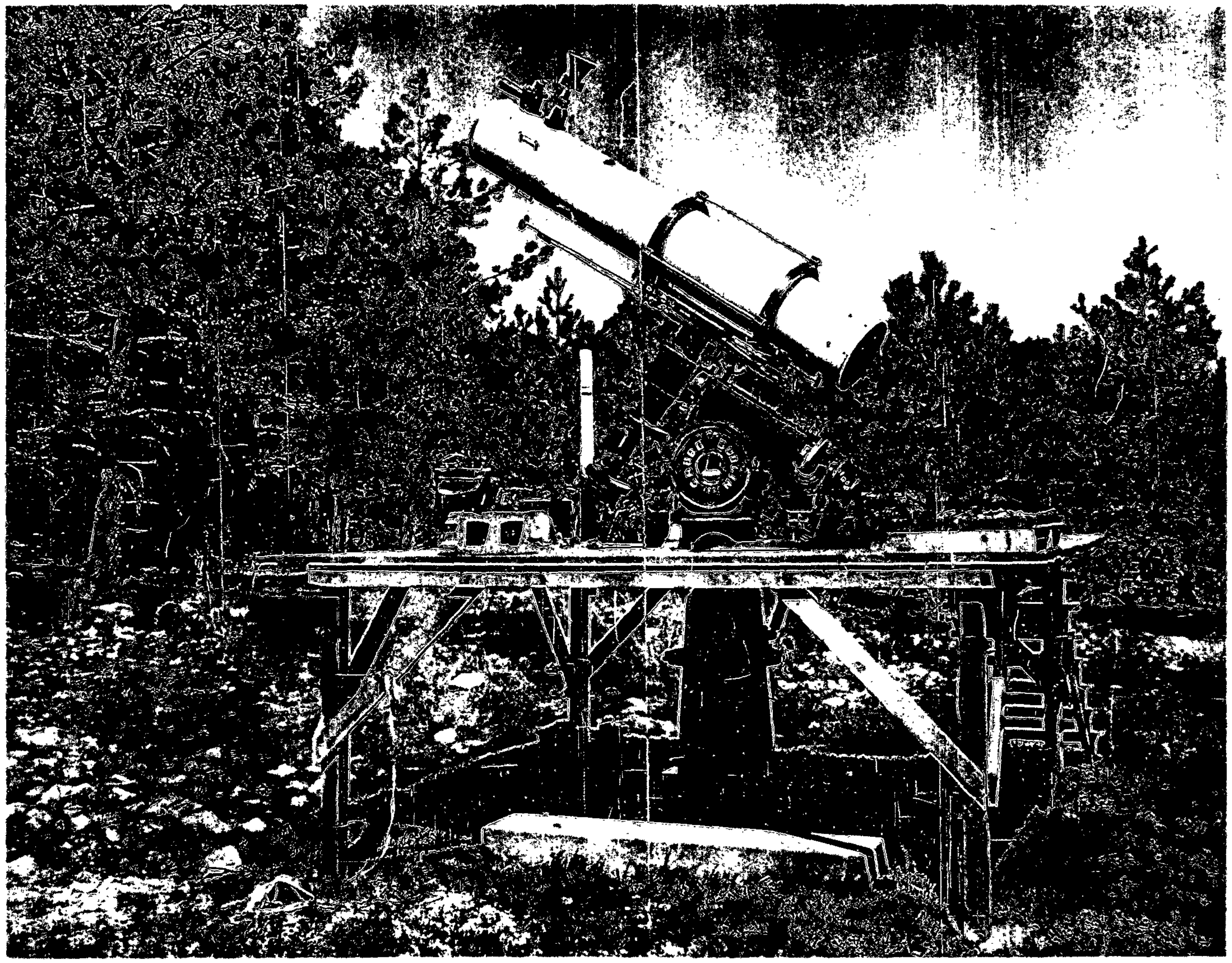


FIGURE 31. 12-Inch Telescope and Observing Platform.
(New Mexico State University Photograph)

During the period 5 January through 15 September, observations were made on every possible night. Observations were not possible during periods of strong or gusty winds, when the site was inaccessible because of snow, or when cloud cover was excessive.

Figure 32 shows the nightly total seeing range and the arithmetic means of the maxima, modes, and minima along a continuous time axis for each night of observation.

Figures 33 through 41 are representations of the arithmetic means of the maximum, modal, and minimum values versus hour of night for each of the nine months, January - September 1961. During the first and last observing hours of the night, the total number of readings per month is lower, because of the changing length of the night and the marginal observing conditions occurring at the end or beginning of twilight. Where this total is less than 4, dashed lines are used. Figure 42 gives the hourly arithmetic means of maximum, minimum, and modal values for the total interval December 1960 - September 1961. Although it will be noted that December 1960 contributes to the total interval, it is not presented as an individual graph because of the small number of observations (see Tables X through XII).

The normalized distributions of maximum, modal, and minimum values are given for each month and the total nine-month interval in Figures 43 through 46 and Tables X through XII. It will be noted in Table X that 13 readings listed as seeing value "5" are actually "5+" (see Table IX).

Figure 47 presents the monthly arithmetic average of the maxima, modes, and minima throughout the nine-month observing period.

Figure 48 presents a normalized distribution of best modal seeing recorded on a given night for each night of the Cloudcroft and Kitt Peak visual surveys. The Cloudcroft data are taken from the 189 dates on which observations were made between December 1960 and September 1961. The Kitt Peak data are taken from the published results, in the AURA final report, of 86 nights of observations between April 1957 and February 1958.

Since brief moments of good seeing are often useful to the planetary astronomer, the number of nights yielding at least some good resolution is of importance. Table XIII, then, indicates the percentage of nights per month, along with the nine-month total, on which seeing value "4" (AURA scale) was noted during at least one observing period at Cloudcroft. Since the AURA survey recorded only modes, no information is available on the maximum values for Kitt Peak.

Also included in Table XIII are monthly ranges of the nightly arithmetic means of the modes, and the total monthly arithmetic means of the modes. Similar data for Kitt Peak are given for the 1957-1958 AURA survey for all months during which observations were made on ten or more nights, along with a summary for all observations made during the survey. December contributes negligibly to the Cloudcroft data in Table XIII.

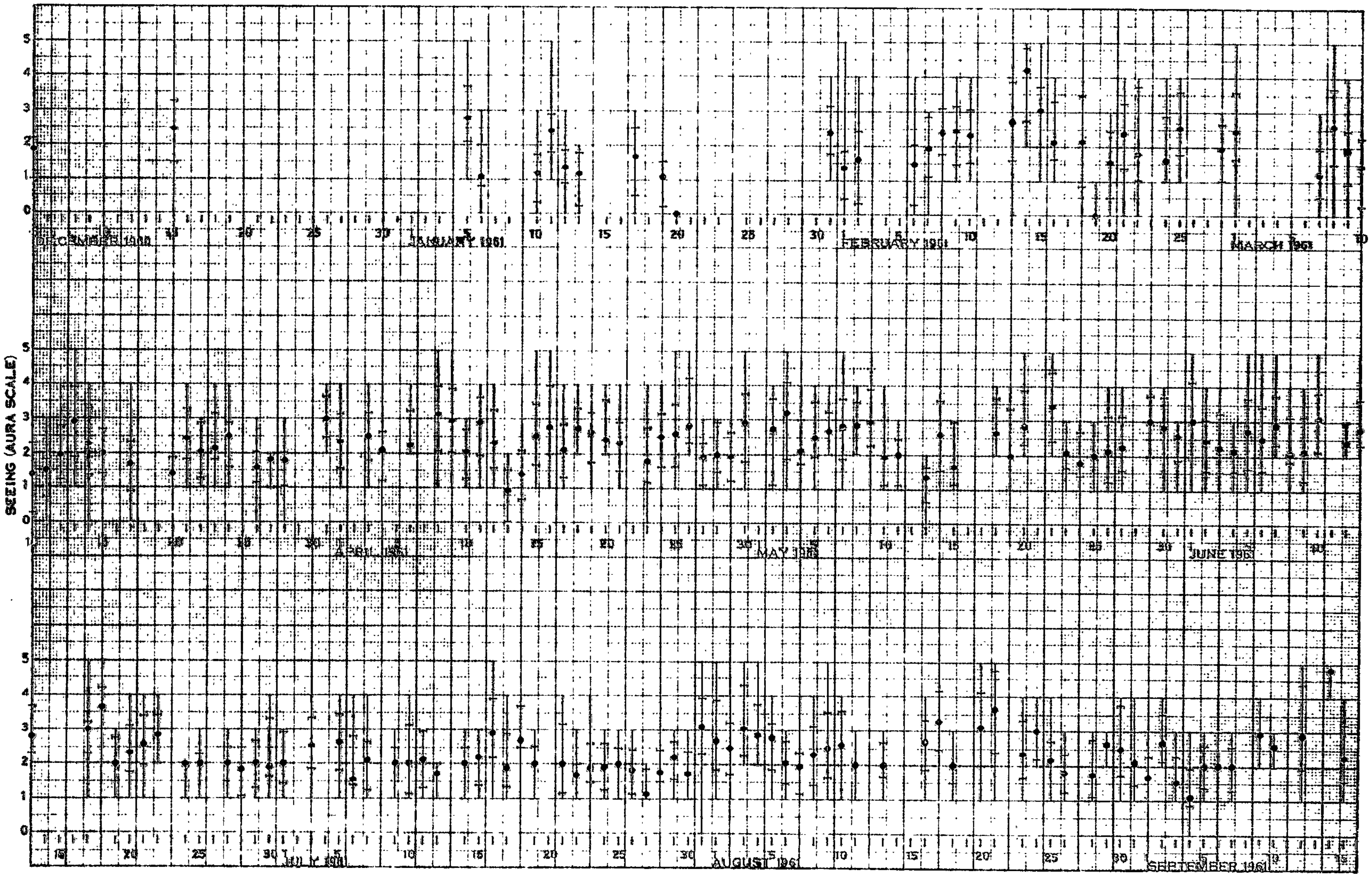


FIGURE 32. Daily Total Range and Daily Average of Maxima, Modes, and Minima of Seeing (Double Star Observations)

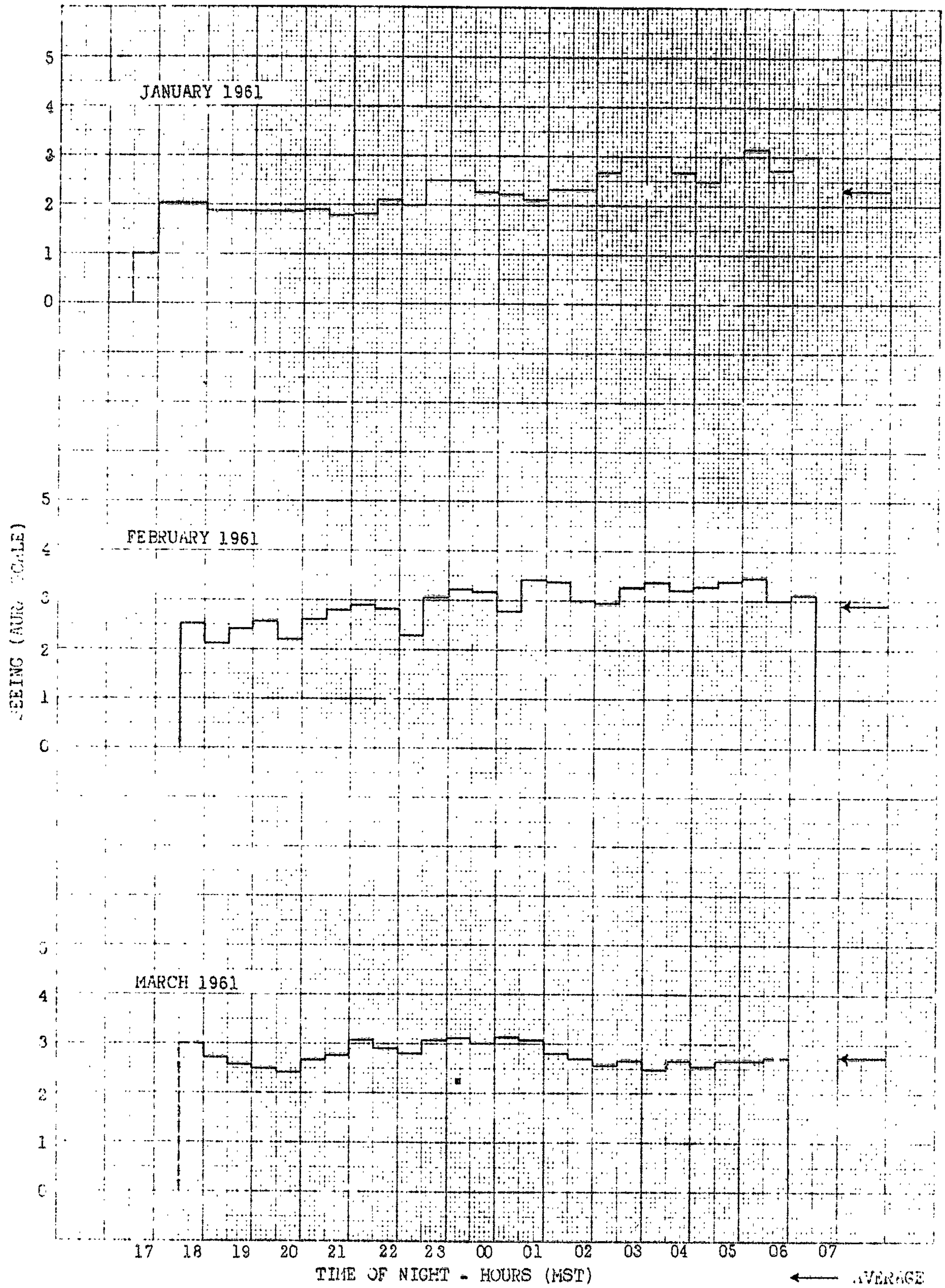


FIGURE 33. Average of Maximum Seeing vs. Time of Night (Double Star Observations)

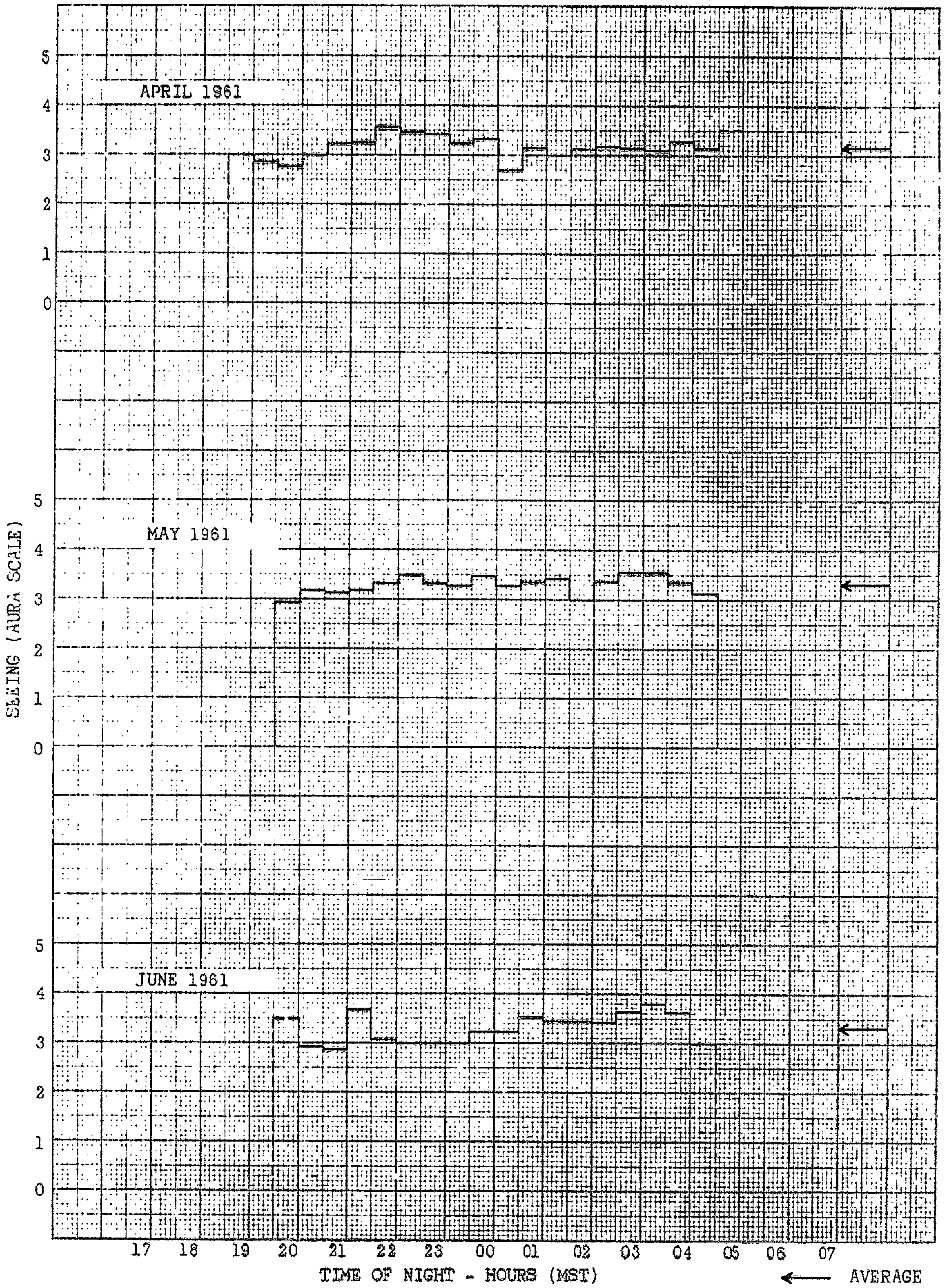


FIGURE 34. Average of Maximum Seeing vs. Time of Night (Double Star Observations)

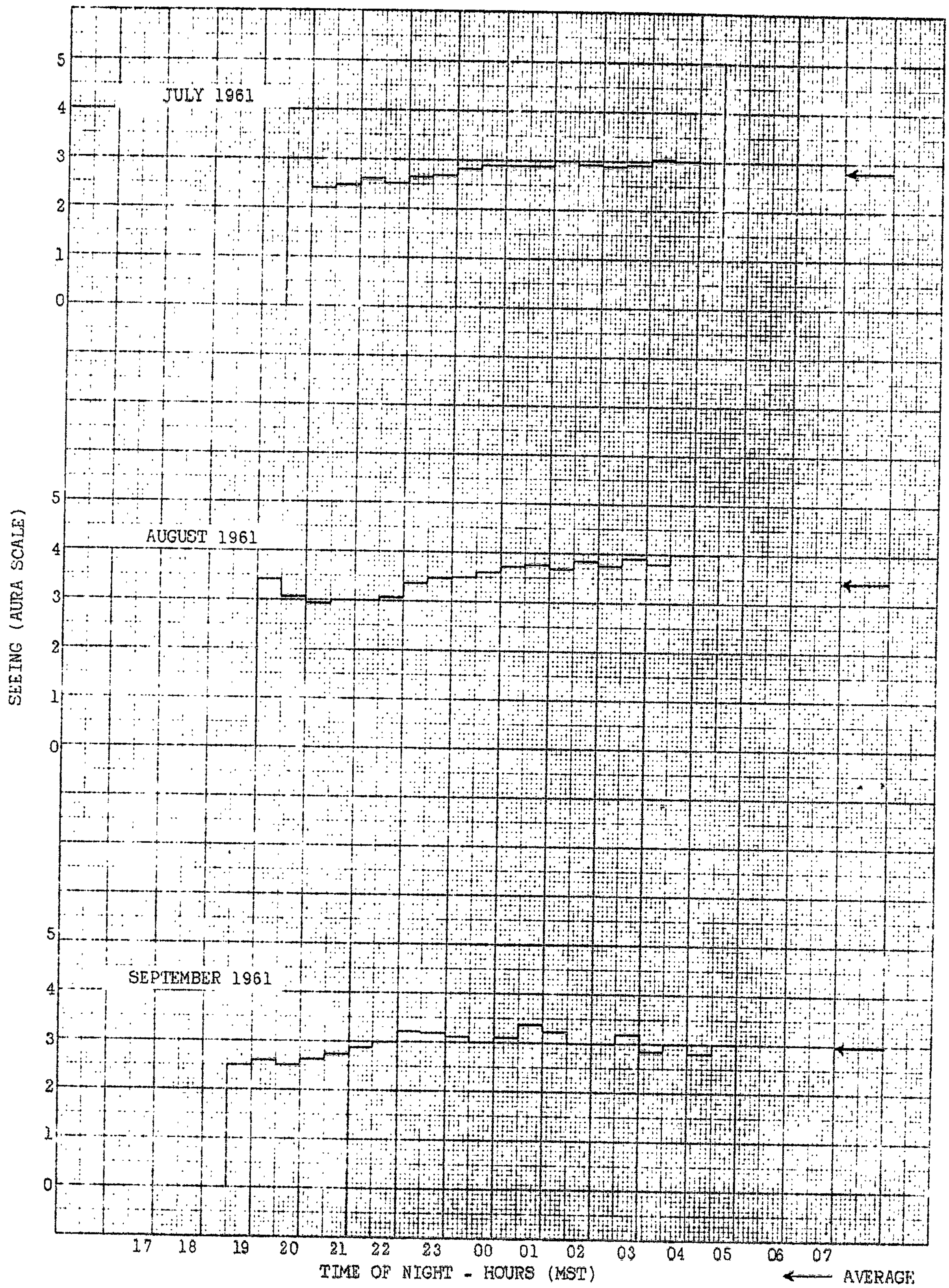


FIGURE 35. Average of Maximum Seeing vs. Time of Night
(Double Star Observations)

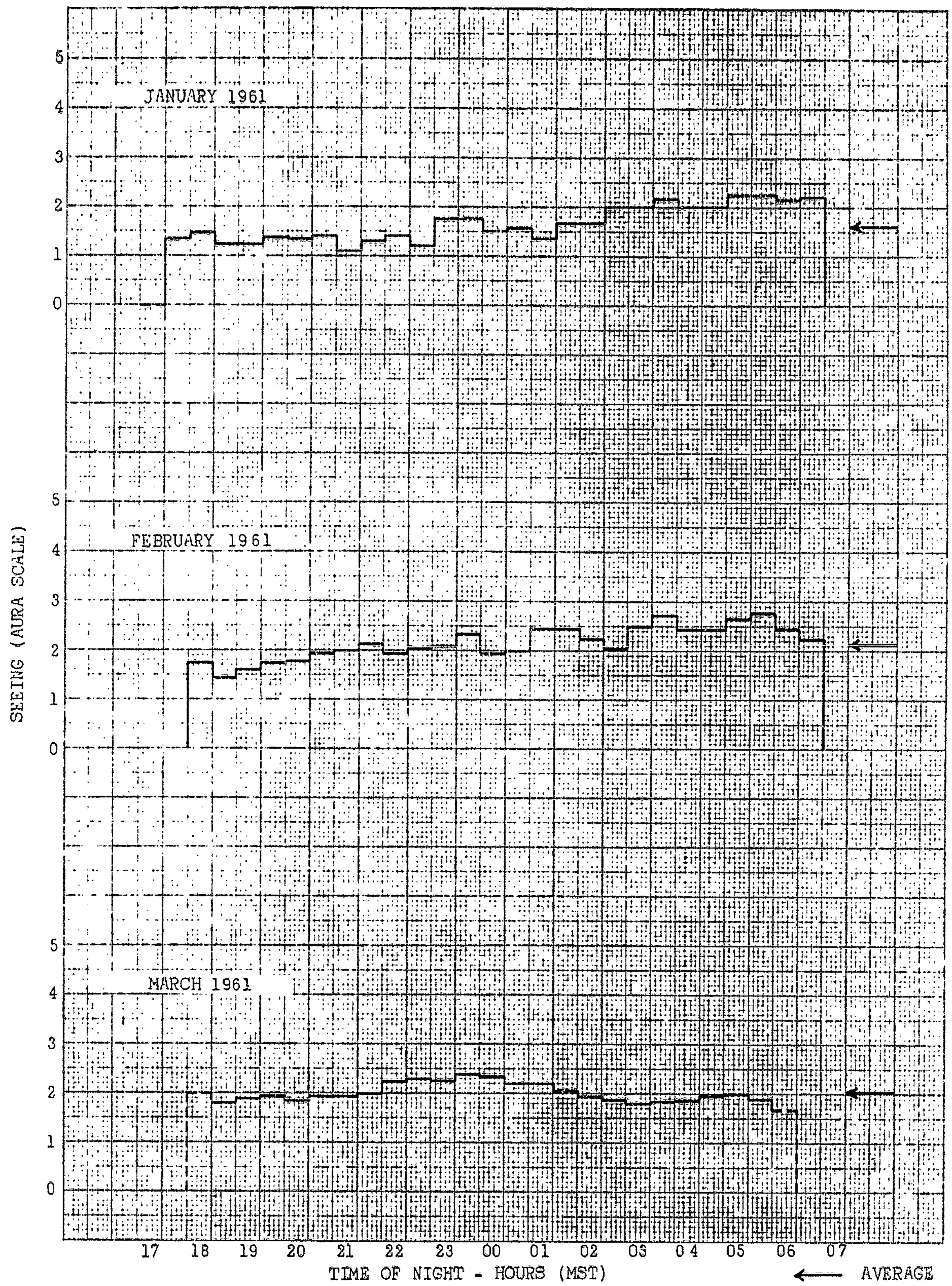


FIGURE 36. Average of Modal Seeing vs. Time of Night
(Double Star Observations)

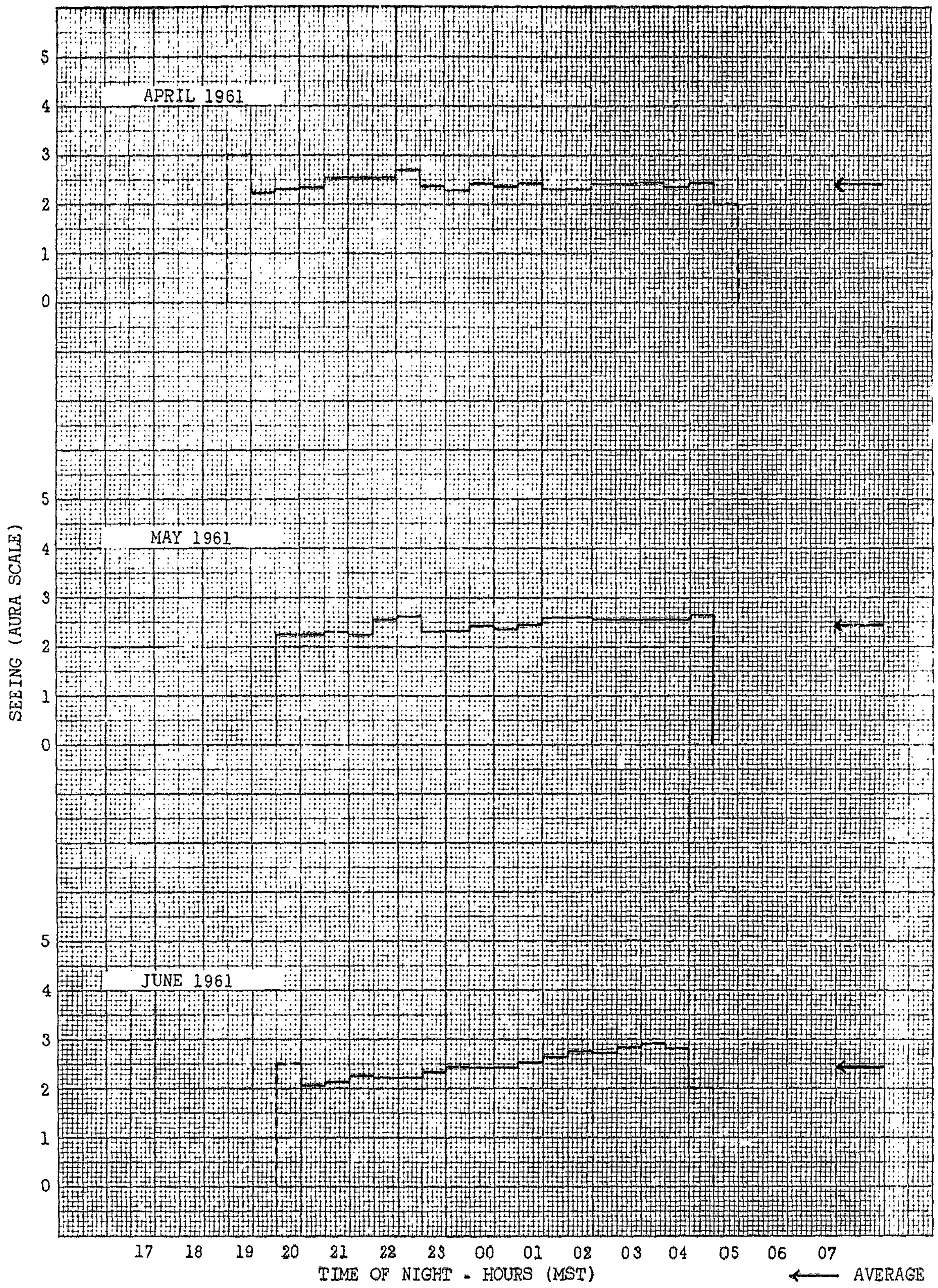


FIGURE 37. Average of Modal Seeing vs. Time of Night
(Double Star Observations)

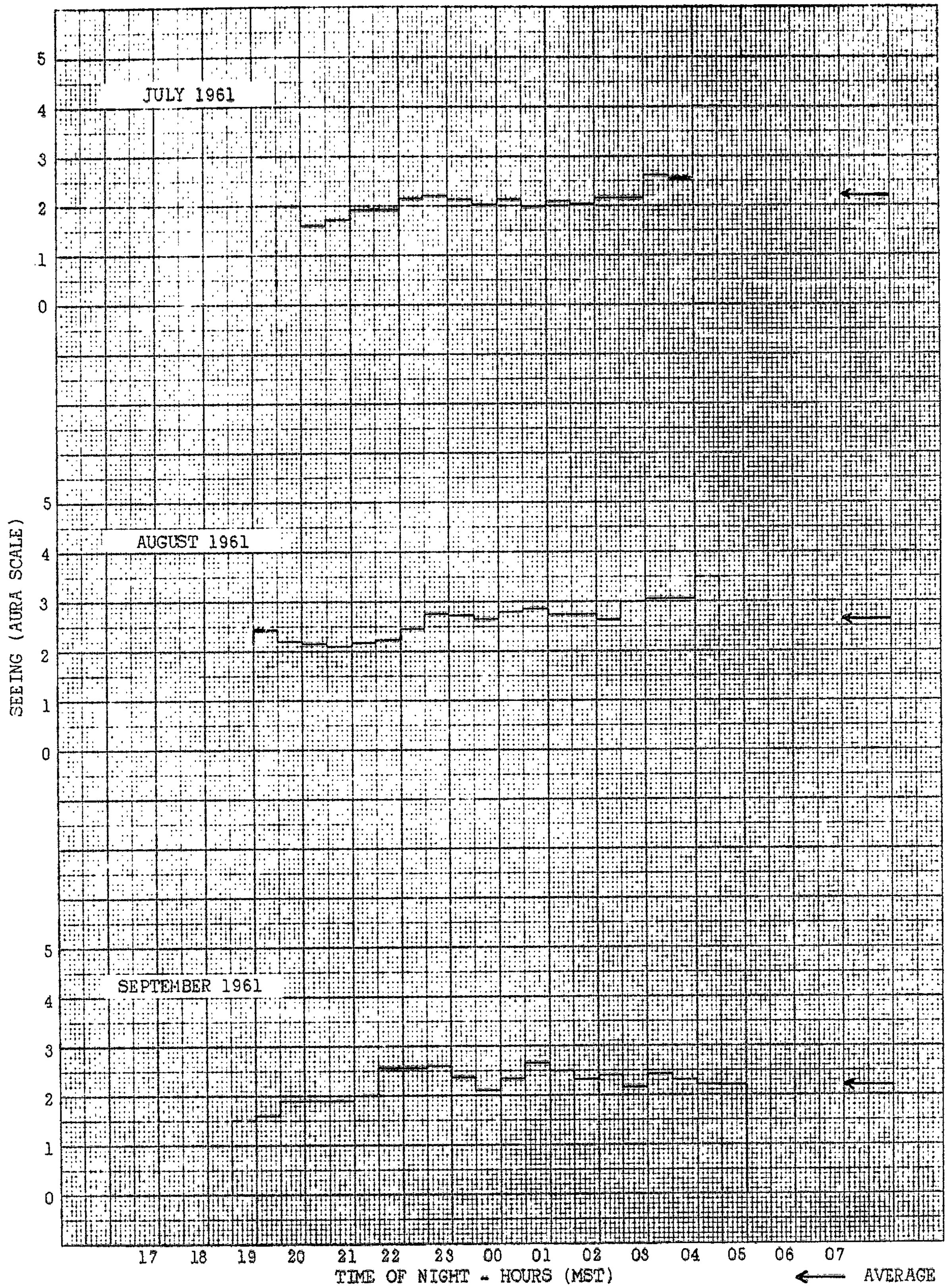


FIGURE 38. Average of Modal Seeing vs. Time of Night
(Double Star Observations)

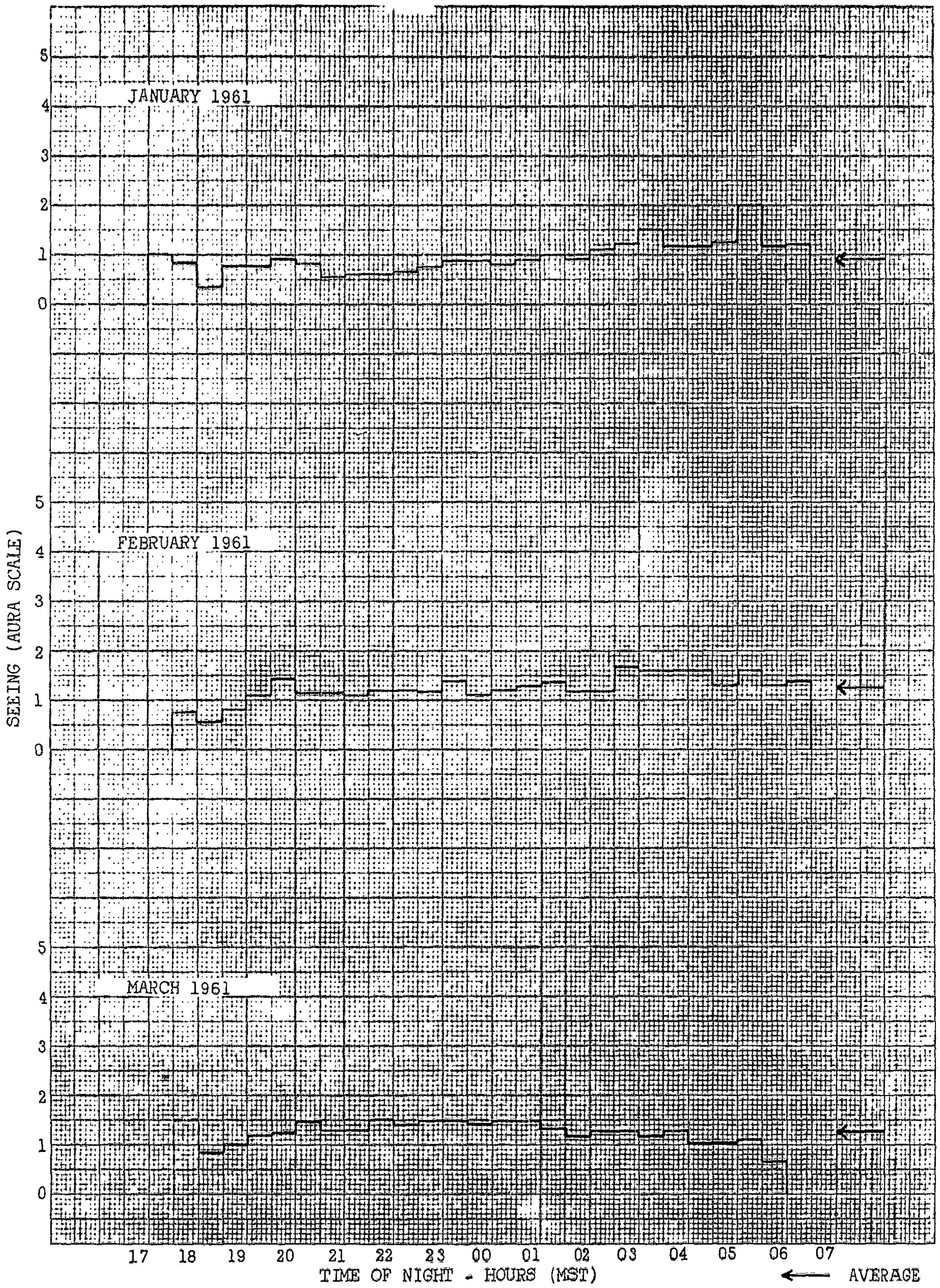


FIGURE 39. Average of Minimum Seeing vs. Time of Night
(Double Star Observations)

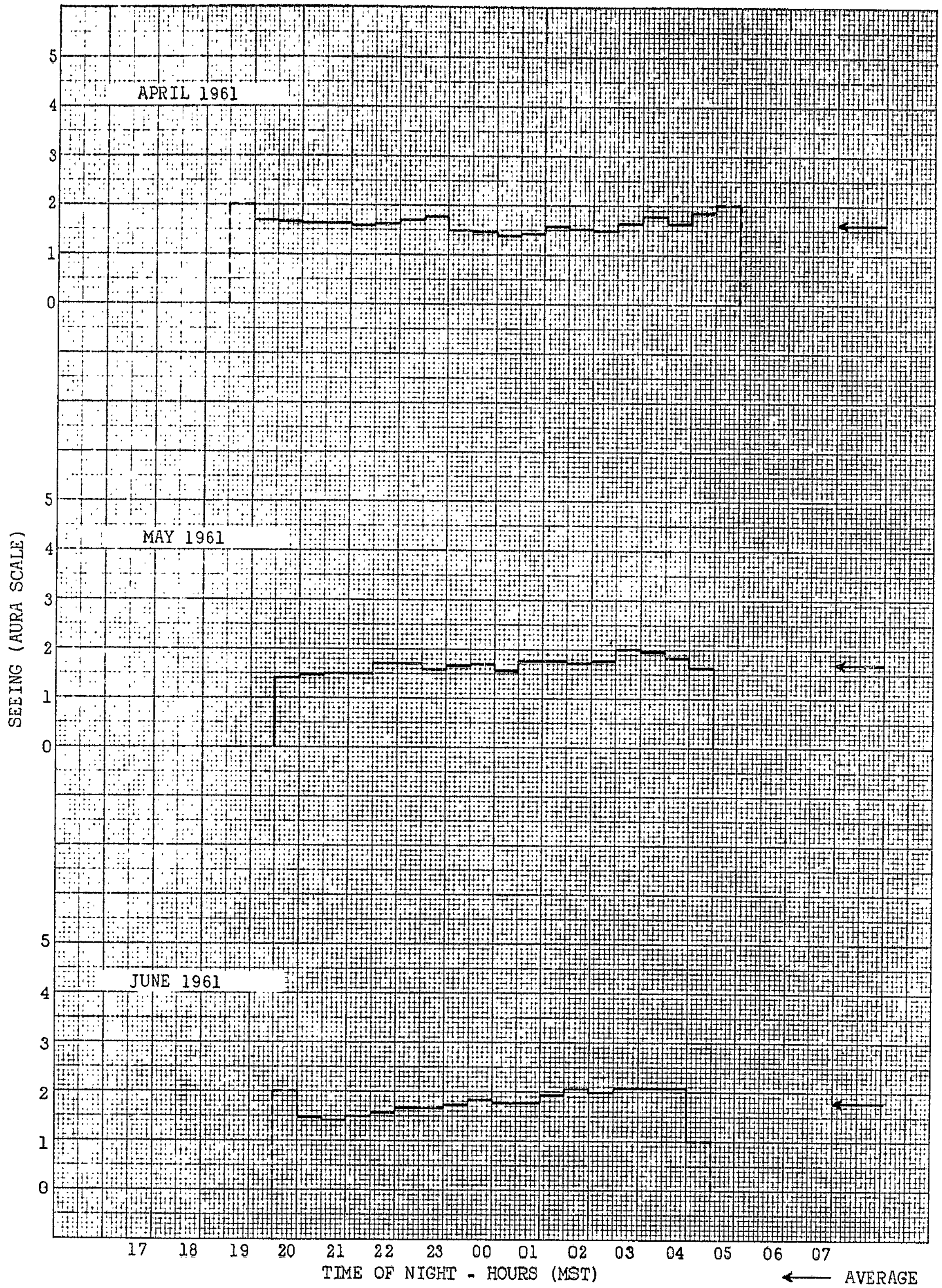


FIGURE 40. Average of Minimum Seeing vs. Time of Night
(Double Star Observations)

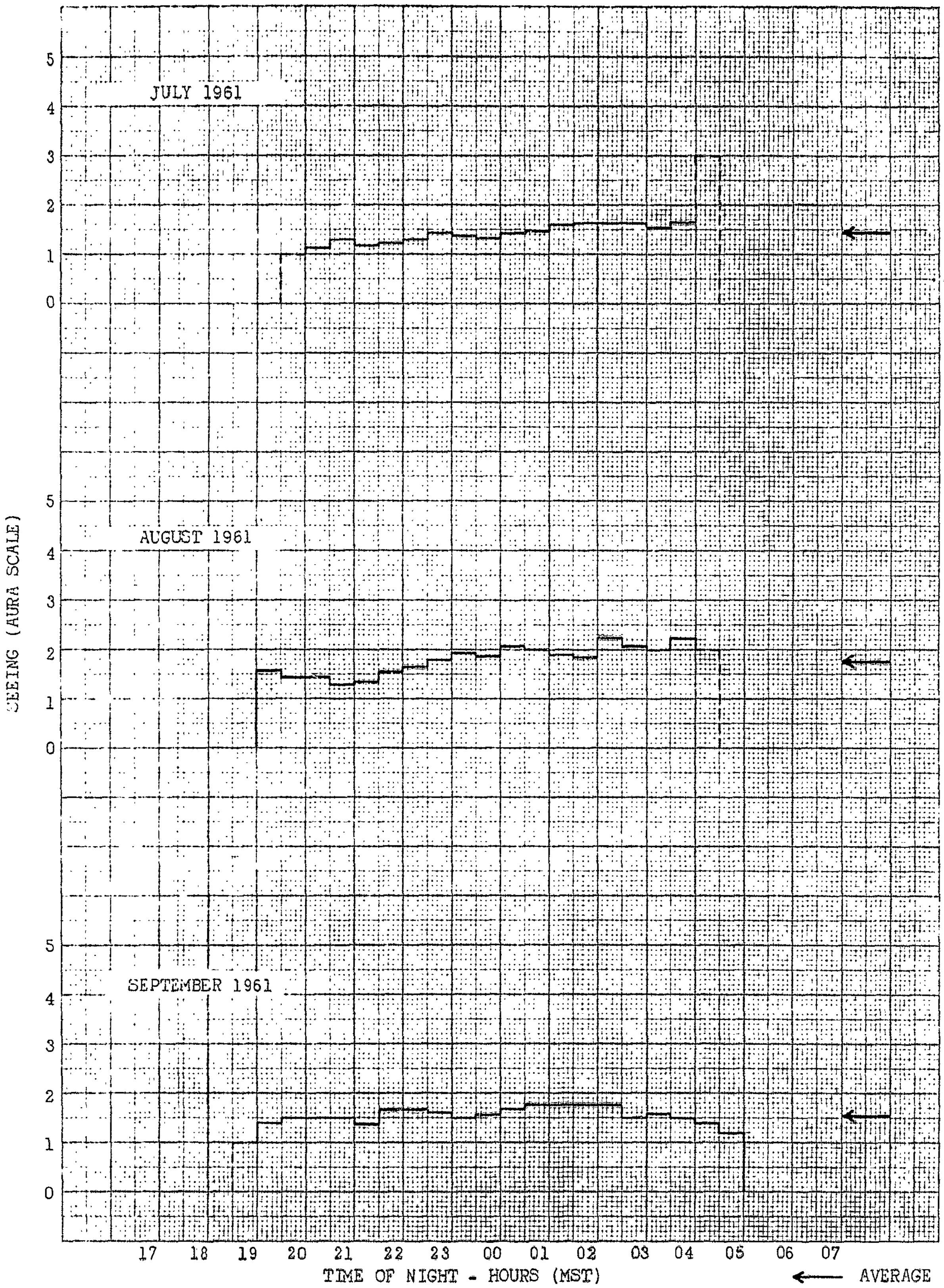


FIGURE 41. Average of Minimum Seeing vs. Time of Night (Double Star Observations)

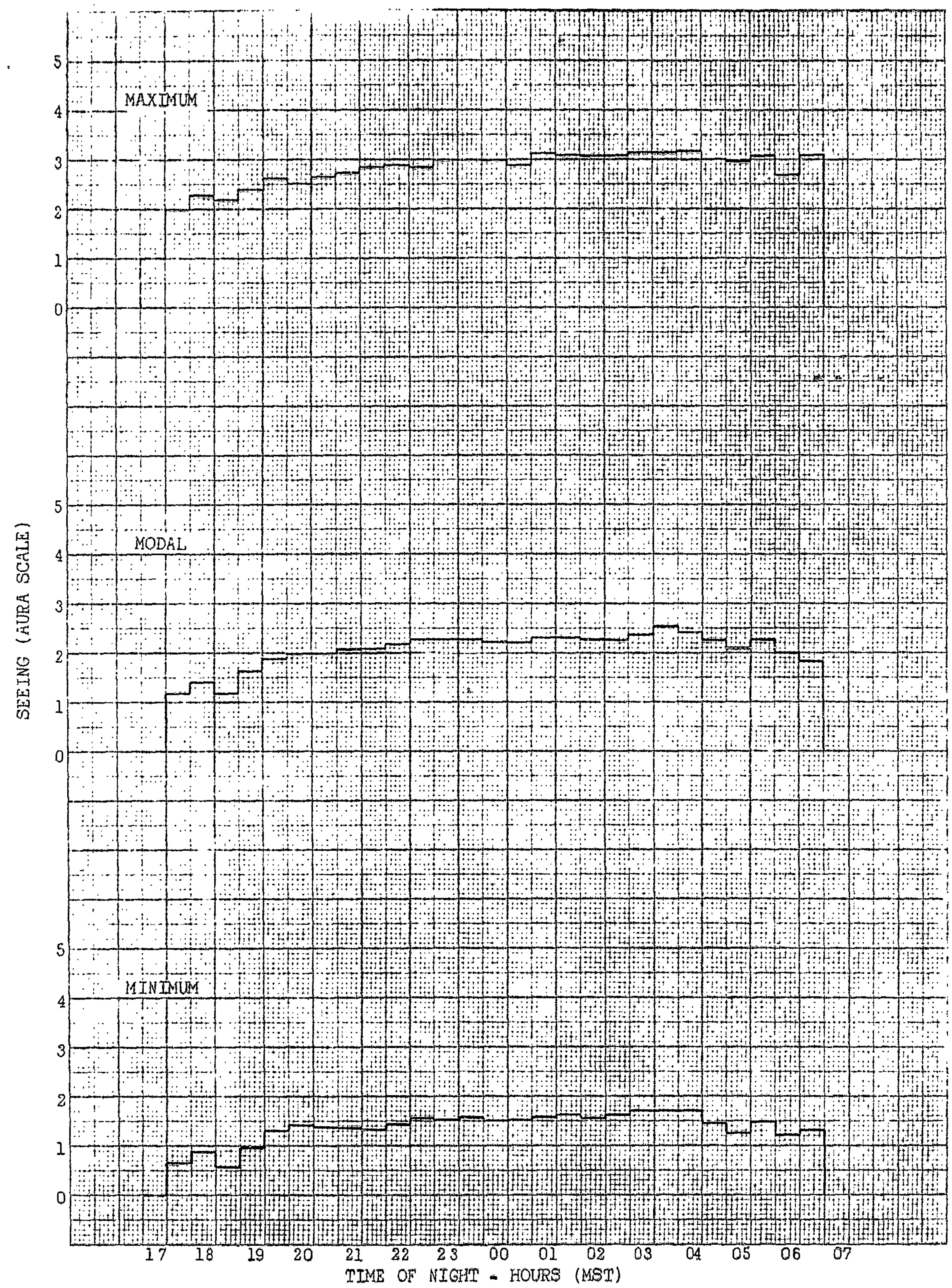


FIGURE 42. Total Nine-Month Average of Maximum, Modal, and Minimum Seeing vs. Time of Night-December 1960 through September 1961 (Double Star Observations)

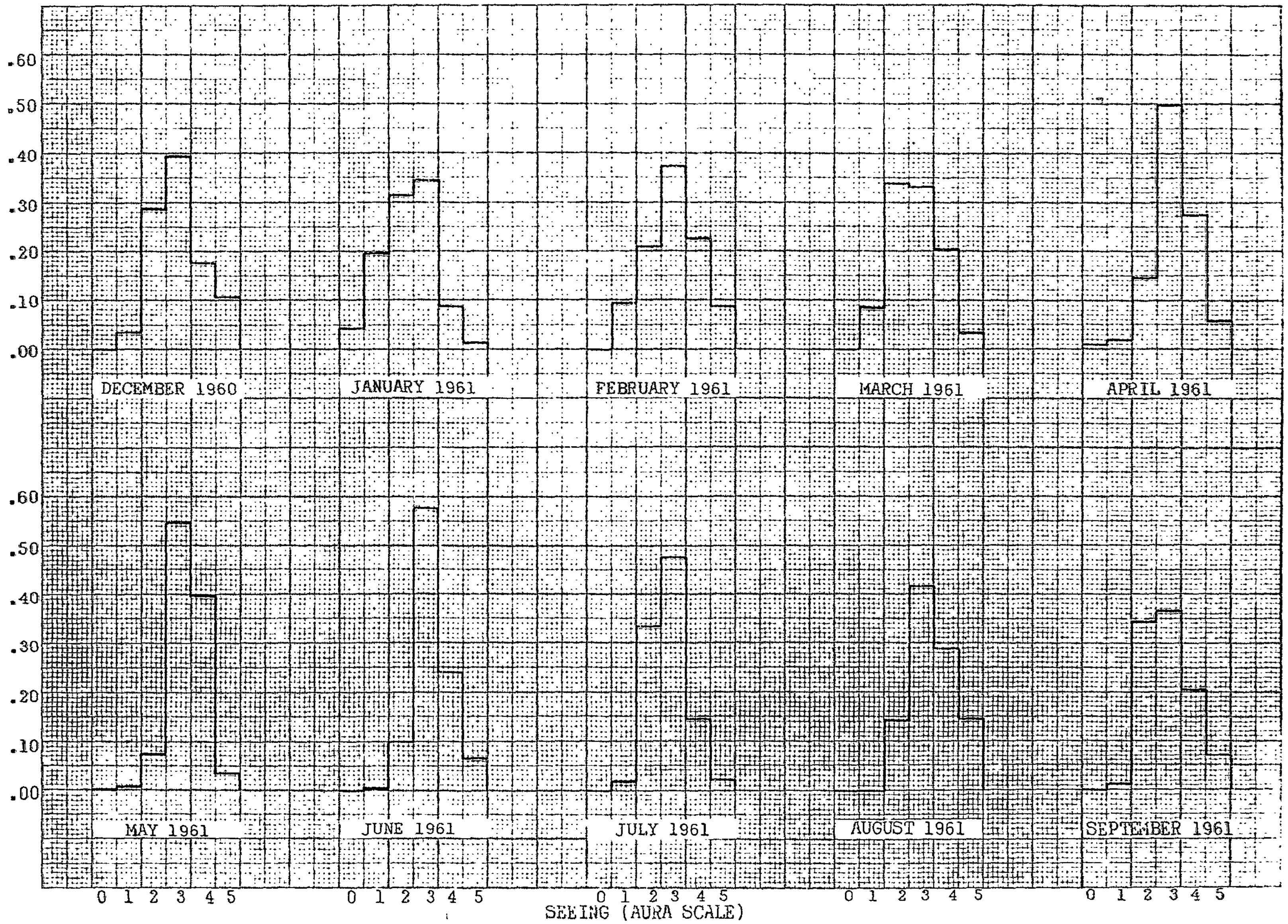


FIGURE 43. Normalized Distribution of Maximum Seeing (Double Star Observations)

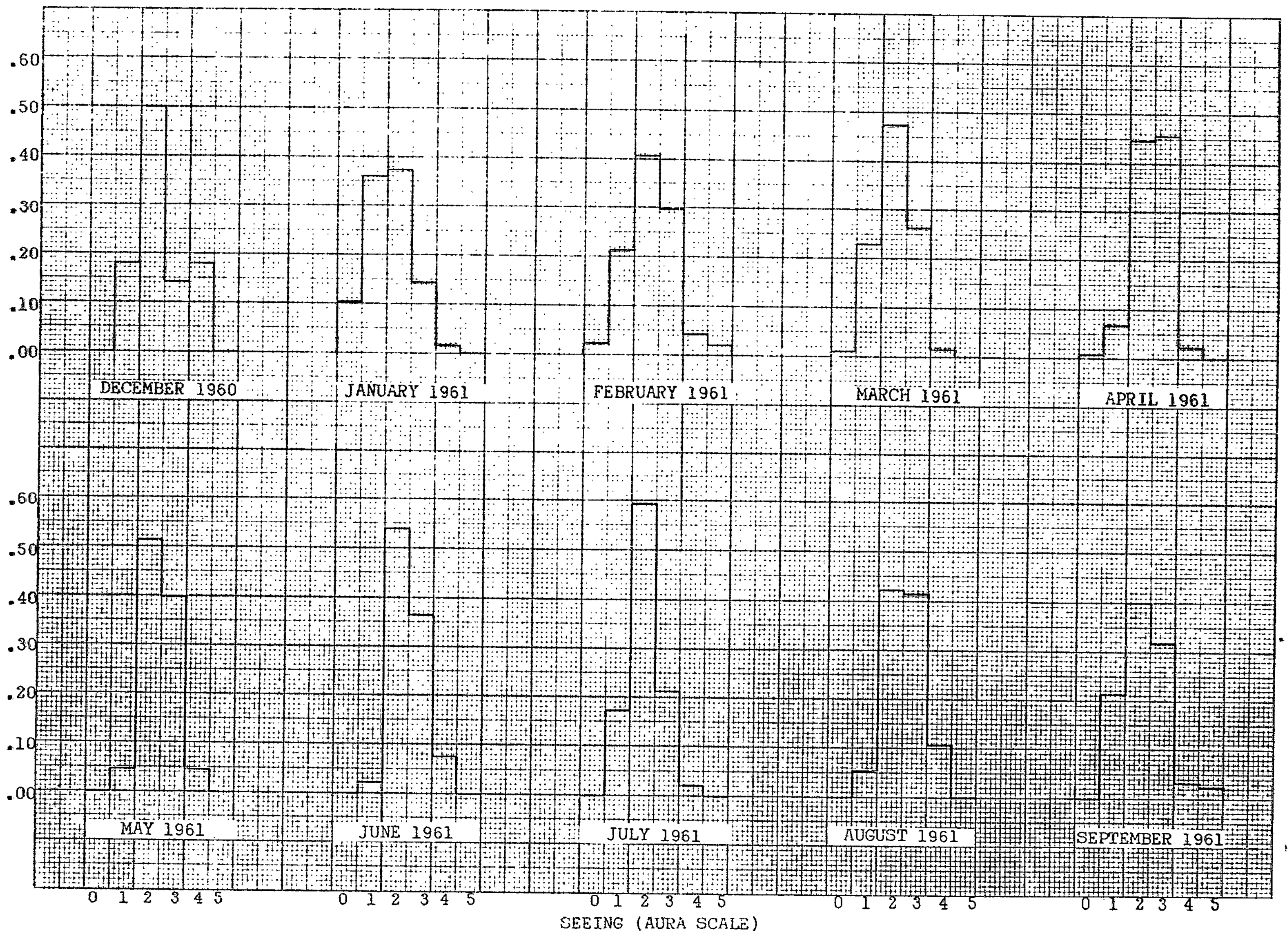


FIGURE 44. Normalized Distribution of Modal Seeing
(Double Star Observations)

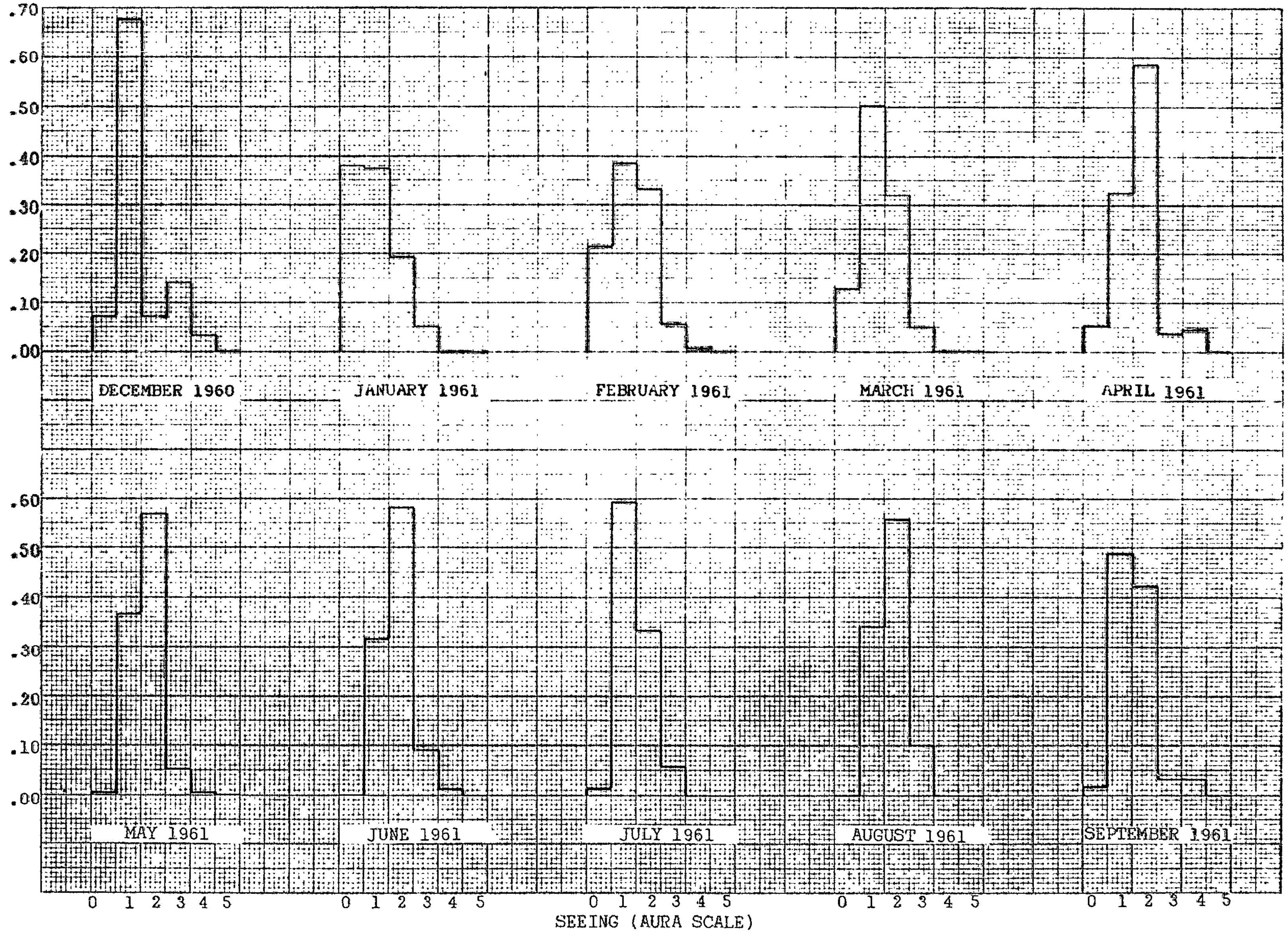


FIGURE 45. Normalized Distribution of Minimum Seeing (Double Star Observations)

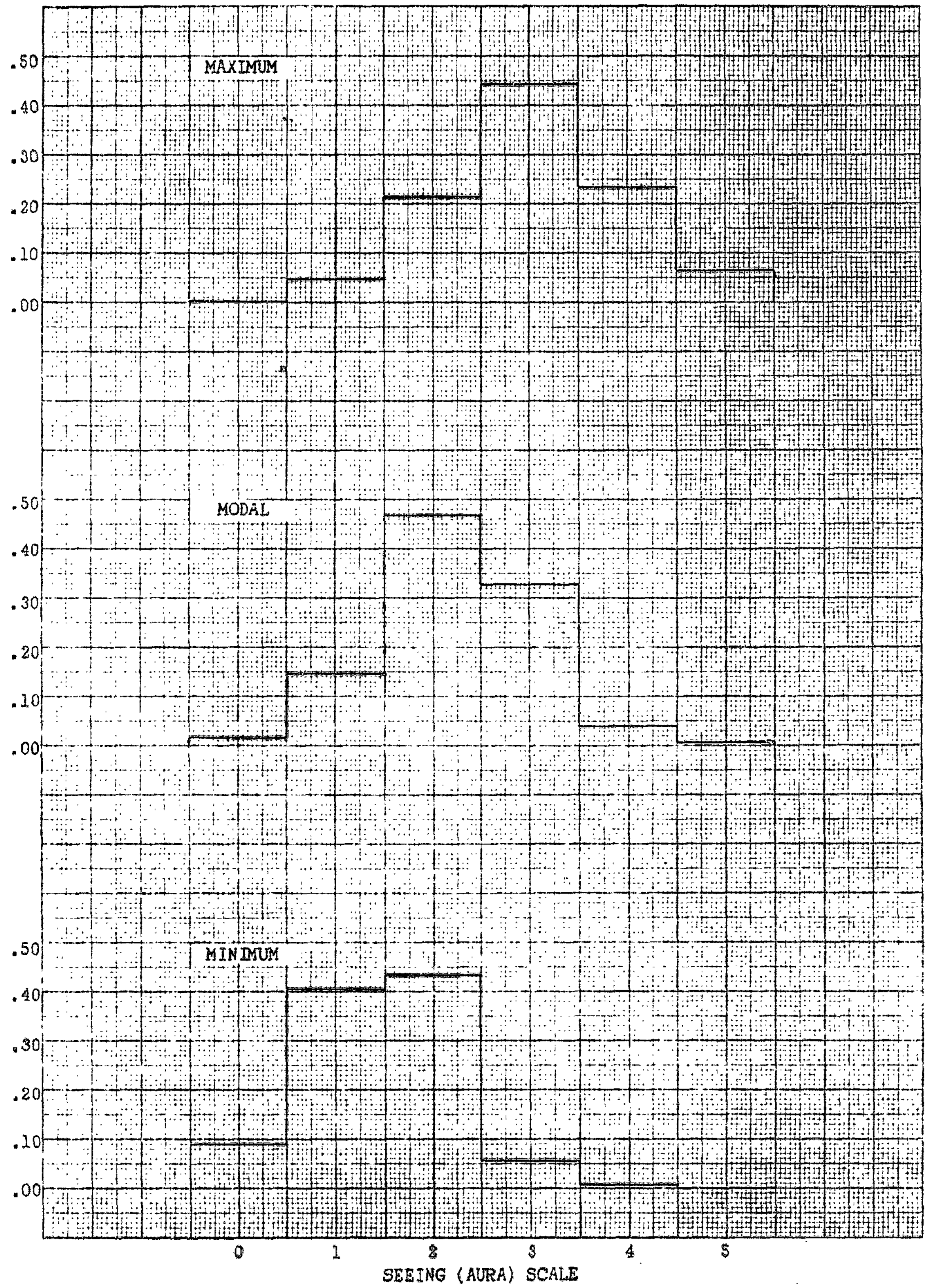


FIGURE 46. Normalized Distribution of Maximum, Modal, and Minimum Seeing for Nine-Month Period-December 1960 through September 1961 (Double Star Observations)

TABLE X

PER CENT OF OCCURRENCE OF
MAXIMUM SEEING

--Double Star Observations--

MONTH	0	1	2	3	4	5	TOTAL READINGS
DECEMBER 1960	0 0%	1 3.6%	8 28.6%	11 39.3%	5 17.9%	3 10.7%	28
JANUARY 1961	9 4.2%	42 19.7%	67 31.4%	73 34.2%	19 8.9%	3 1.4%	213
FEBRUARY 1961	0 0%	39 9.5%	86 21.0%	153 37.5%	93 22.7%	37 9.0%	408
MARCH 1961	0 0%	33 8.8%	127 34.0%	124 33.2%	76 20.3%	13 3.4%	373
APRIL 1961	1 0.2%	9 2.0%	64 14.7%	217 49.8%	119 27.3%	25 5.7%	435
MAY 1961	0 0%	2 0.6%	23 7.2%	174 54.7%	108 33.9%	11 3.4%	318
JUNE 1961	0 0%	1 0.3%	30 10.0%	173 57.8%	75 24.0%	20 6.6%	299
JULY 1961	0 0%	5 1.7%	98 33.6%	137 47.5%	42 14.5%	6 2.0%	288
AUGUST 1961	0 0%	0 0%	38 14.3%	111 41.8%	77 29.0%	39 14.7%	265
SEPTEMBER 1961	0 0%	2 1.2%	53 34.1%	57 36.7%	32 20.6%	11 7.0%	155
TOTAL	10 0.36%	134 4.82%	594 21.35%	1230 44.21%	646 23.22%	168* 6.04%	2,782

* Thirteen Readings are 5+

TABLE XI

PER CENT OF OCCURRENCE OF
MODAL SEEING

--Double Star Observations--

MONTH	0	1	2	3	4	5	TOTAL READINGS
DECEMBER 1960	0 0%	5 17.9%	14 50.0%	4 14.3%	5 17.9%	0 0%	28
JANUARY 1961	22 10.3%	77 36.1%	80 37.5%	31 14.5%	3 1.4%	0 0%	213
FEBRUARY 1961	10 2.4%	87 21.3%	166 40.6%	118 28.9%	18 4.4%	9 2.2%	408
MARCH 1961	5 1.3%	86 23.0%	177 47.4%	99 26.5%	6 1.6%	0 0%	373
APRIL 1961	3 0.7%	30 6.9%	194 44.6%	197 45.3%	11 2.5%	0 0%	435
MAY 1961	0 0%	14 4.4%	163 51.3%	127 39.9%	14 4.4%	0 0%	318
JUNE 1961	0 0%	7 2.3%	161 53.8%	108 36.1%	23 7.7%	0 0%	299
JULY 1961	0 0%	50 17.4%	171 59.4%	61 21.2%	6 2.1%	0 0%	288
AUGUST 1961	0 0%	15 5.7%	112 42.3%	110 41.5%	28 10.6%	0 0%	265
SEPTEMBER 1961	0 0%	33 21.3%	62 40.0%	51 32.9%	5 3.2%	4 2.6%	155
TOTAL	40 1.4%	404 14.5%	1300 46.7%	906 32.8%	119 4.1%	13 0.5%	2,782

TABLE XII

PER CENT OF OCCURRENCE OF
MINIMUM SEEING

--Double Star Observations--

MONTH	0	1	2	3	4	5	TOTAL READINGS
DECEMBER 1960	2 7.1%	19 67.8%	2 7.1%	4 14.2%	1 3.5%	0 0%	28
JANUARY 1961	81 38.0%	80 37.5%	41 19.2%	11 5.2%	0 0%	0 0%	213
FEBRUARY 1961	89 21.8%	158 38.7%	136 33.3%	23 5.6%	2 0.4%	0 0%	408
MARCH 1961	48 12.8%	187 50.1%	120 32.1%	18 4.8%	0 0%	0 0%	373
APRIL 1961	23 5.3%	141 32.4%	254 58.4%	15 3.4%	2 4.6%	0 0%	435
MAY 1961	2 0.6%	117 36.8%	181 56.9%	17 5.3%	1 0.3%	0 0%	318
JUNE 1961	0 0%	95 31.8%	174 58.2%	27 9.0%	3 1.0%	0 0%	299
JULY 1961	4 1.4%	171 59.4%	96 33.3%	17 5.9%	0 0%	0 0%	288
AUGUST 1961	0 0%	90 34.0%	148 55.8%	27 10.2%	0 0%	0 0%	265
SEPTEMBER 1961	3 1.9%	76 49.0%	66 42.6%	5 3.2%	5 3.2%	0 0%	155
TOTAL	252 9.1%	1134 40.7%	1218 43.8%	164 5.9%	14 0.5%	0 0%	2,782

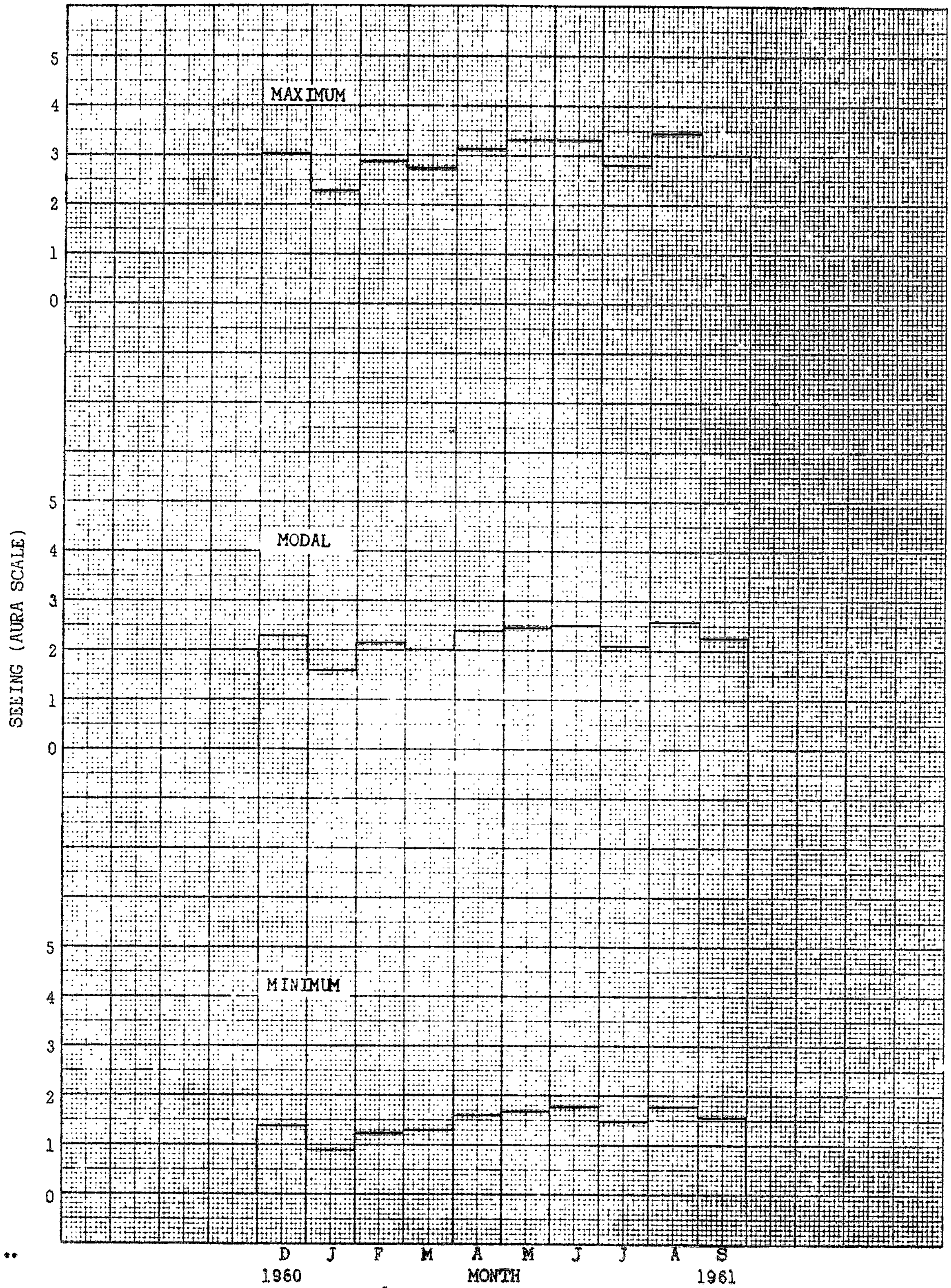


FIGURE 47. Monthly Average of Maximum, Modal, and Minimum Seeing vs. Month of Year (Double Star Observations)

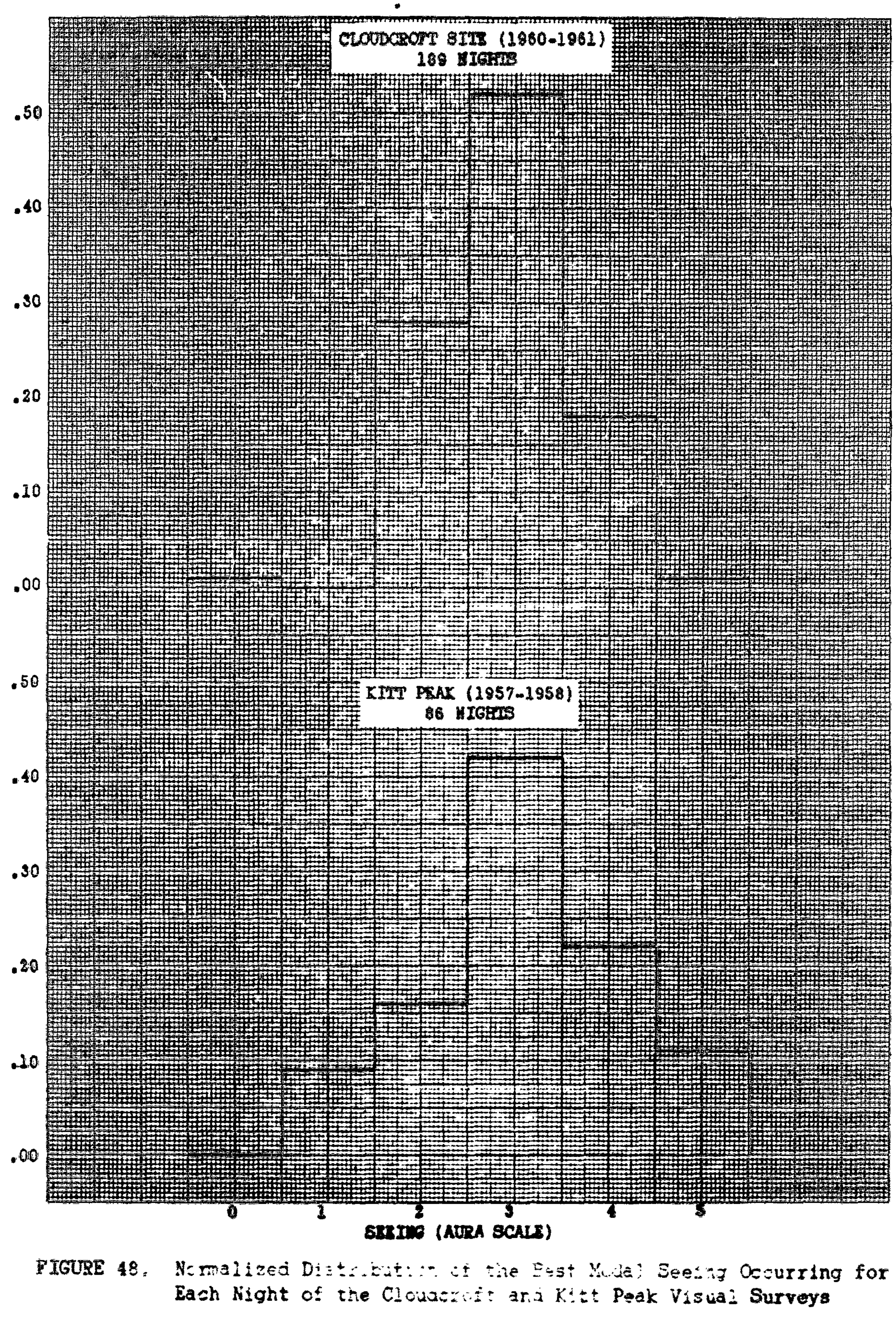


FIGURE 48. Normalized Distribution of the Best Modal Seeing Occurring for Each Night of the Cloudcroft and Kitt Peak Visual Surveys

TABLE XIII

SEEING RECORDS

	MONTH	NO. OF NIGHTS OF OBSERVATIONS	RANGE IN NIGHTLY MODES	AVERAGE OF NIGHTLY MODES	PER CENT OF NIGHTS HAVING BEST SEEING 4 OR BETTER
KITT PEAK 1957-1958	JUNE 1957	12	$2\frac{1}{2}$ - 5	4.0	no data
	AUGUST 1957	13	$1\frac{1}{2}$ - $4\frac{1}{2}$	2.6	no data
	DECEMBER 1957	17	$\frac{1}{2}$ - $4\frac{1}{2}$	2.4	no data
	ALL NIGHTS (1957-1958)	86	0 - 5	2.8	no data
CLOUDCROFT 1960-1961	DECEMBER 1960	2	1.8 - 2.5	2.3	50%
	JANUARY 1961	10	0.0 - 2.7	1.6	30%
	FEBRUARY 1961	19	0.0 - 4.2	2.1	79%
	MARCH 1961	20	1.2 - 3.0	2.0	60%
	APRIL 1961	26	0.9 - 3.1	2.4	77%
	MAY 1961	25	1.7 - 3.4	2.4	72%
	JUNE 1961	24	1.8 - 3.7	2.5	67%
	JULY 1961	26	1.1 - 3.1	2.1	46%
	AUGUST 1961	25	1.8 - 3.6	2.6	72%
	SEPTEMBER 1961	12	1.1 - 4.8	2.3	42%
	ALL NIGHTS DECEMBER - SEPTEMBER	189	0.0 - 4.8	2.3	64%

(c) Conclusions

There are many factors which make comparison of seeing between Cloudcroft and Kitt Peak most difficult. Among these are (1) that different observers were used, (2) that different observers may assign inconsistant seeing values especially when the seeing is erratic, and (3) that different telescopes were used with their mirrors located at different heights above the ground. Both surveys used 16-inch reflectors, but the effective height above the ground for the Kitt Peak telescope was approximately ten feet higher than that of the Cloudcroft instrument. Additionally, it is clear that the monthly coverage was not the same at both sites, and it is possible that neither survey is typical of the long-term seeing of its site. It is also clear, however, that the comparison of these surveys is the best yardstick available for the evaluation of the Cloudcroft site in terms of the acknowledged quality of AURA's Kitt Peak.

A normalized distribution of the modal value of the Kitt Peak seeing is given in the AURA report. This distribution, however appears to give equal weight to each day. Equal weighting could be justified only if an identical number of individual observations were recorded on each night for which the average modal values are given. This was certainly not the case for the Cloudcroft survey and it would also appear to be doubtful for the Kitt Peak survey. Since it is not certain just what the AURA distribution represents, no definite conclusions can be drawn, other than to say that the Kitt Peak average seeing appears to be somewhat superior to that at Cloudcroft.

Table XIII tends to substantiate the conclusion that average seeing is somewhat better at Kitt Peak. It also indicates, however, that for small apertures, some momentary good seeing can be obtained on nearly two-thirds of the nights at Cloudcroft. Since the AURA survey was conducted with concern for stellar rather than planetary observations, only modal seeing was recorded. There is, therefore, no basis for comparison of either the Cloudcroft maxima or minima with the AURA data. The photography of the moon and planets normally utilizes short exposures. Thus, a few images secured under good seeing conditions are often more useful than many images of mediocre quality. It is true, of course, that some planetary investigations require long exposures or continuous coverage throughout the night, and here the average seeing value becomes significant. The advent of electronic image intensification techniques, however, tends to place the emphasis more and more toward the best rather than the mean seeing. Menzel et al (1962), however have pointed out that the best seeing observed with a 16-inch telescope cannot be extrapolated to instruments in the 40 to 60-inch range.

Figure 48 indicates graphically that the best modal seeing per night runs substantially better at Kitt Peak than at Cloudcroft. Caution should be exercised in the interpretation of these distributions, however, since they only represent 86 and 189 nights respectively. In the Kitt Peak distribution, for example, 20 per cent of the "4" and 55 per cent of the "5" were recorded during the latter half of June 1957.

The magnitude of the diurnal effect on seeing appears to be greatest with maxima and least with the minima as might be expected. It will be noted that the best seeing occurs at different times of night for different months. Many months, however, show a gradual improvement as the night progresses, and this pattern can be observed in the nine-month averages.

A slight seasonal effect is noted in Figure 47. The poorest seeing occurs in January, with the best being recorded in August. Although it is probable that a real seasonal effect exists, it is felt that a single year is rather insufficient to determine the magnitude and phase with any meaningful accuracy. How far each month in 1961 departed from its long-term average will remain unknown, unless many years of data are eventually gathered.

In an effort to shed some light on the possible departure of the 1961 Cloudcroft seeing data from the long-term averages, a comparison might be made with 1961 daytime seeing conditions at the Sacramento Peak Observatory at Sunspot, New Mexico, approximately 14 miles SSW of the Cloudcroft site. Since the Sunspot data were taken during the daytime at a site having entirely different topographical surroundings, no quantitative comparisons may be made. A qualitative study of the Sunspot seeing would, however, permit a rough index of the departure from the average. This, then, might be applied cautiously to the Cloudcroft data.

Accordingly, Mr. Donald G. Carson at the Sacramento Peak Observatory was asked to prepare a qualitative appraisal. Mr. Carson kindly submitted the following data taken between sunrise and one hour before midday:

January through mid-March	seeing poor but typical.
Mid-March through May	seeing more erratic than usual, but in general better than average.
June	seeing erratic, but difficult to evaluate because of unusually early summer rains.
July and August	seeing usually is good during these months, but was even better than average this year.
September	seeing fair to good, typical.

Mr. Carson explained that the above comparison of the 1961 seeing with an 11-year average was made from a composite of available objective data, and the subjective estimates of the Sacramento Peak Observatory observing staff.

9.1.2 Planetary Observations

(a) Description

Although 100 per cent seeing correlation will often be observed between two points separated by only two arc-seconds, the correlation diminishes between points separated by angles equivalent to planetary diameters, i.e., 10-60 arc-seconds. The per cent of correlation as a function of angular separation will depend upon the aperture of the instrument and the linear distances of the disturbing asmospheric layers. Since these relationships cannot be predicted from the double star observations, planetary observations were made at Cloudcroft whenever possible so that a rough comparison between double star and planetary seeing could be made. These observations were necessarily obtained on a non-interference basis since the double star program was the prime objective of the visual seeing survey.

(b) Results

Throughout the nine-month observing period, 307 visual observations of the Moon, Venus, Mars, Jupiter, Saturn, and Uranus were made with the 12 and 16-inch telescopes. The blur of detail over the surface of the planetary disk was evaluated in terms of the known angular diameter of the disk or the known separation of features. The seeing blur was then corrected to conform with the AURA scale. The 16-inch telescope was used for 203 or approximately two-thirds of the observations. Figures 49 and 50 give the normalized distributions of maxima, modes, and minima over the nine-month survey for the 12-inch and 16-inch telescopes, respectively.

(c) Conclusions

A comparison of Figures 46, 49, and 50 reveals that the seeing distributions of double star and planetary observations are quite similar. The small differences are of the order that might be expected to arise from the relatively small sampling available from planetary observations. Since the personnel of the proposed observatory would be studying the moon and planets rather than double stars, this similarity is rather encouraging.

It must be pointed out, however, that seeing estimates derived from planetary observations are more subjective than those derived from double stars. Of the three full-time observers at the Cloudcroft site, only one (C. F. Capen, Jr.) is an experienced planetary observer. Mr. Capen made three-quarters of the total lunar and planetary observations personally.

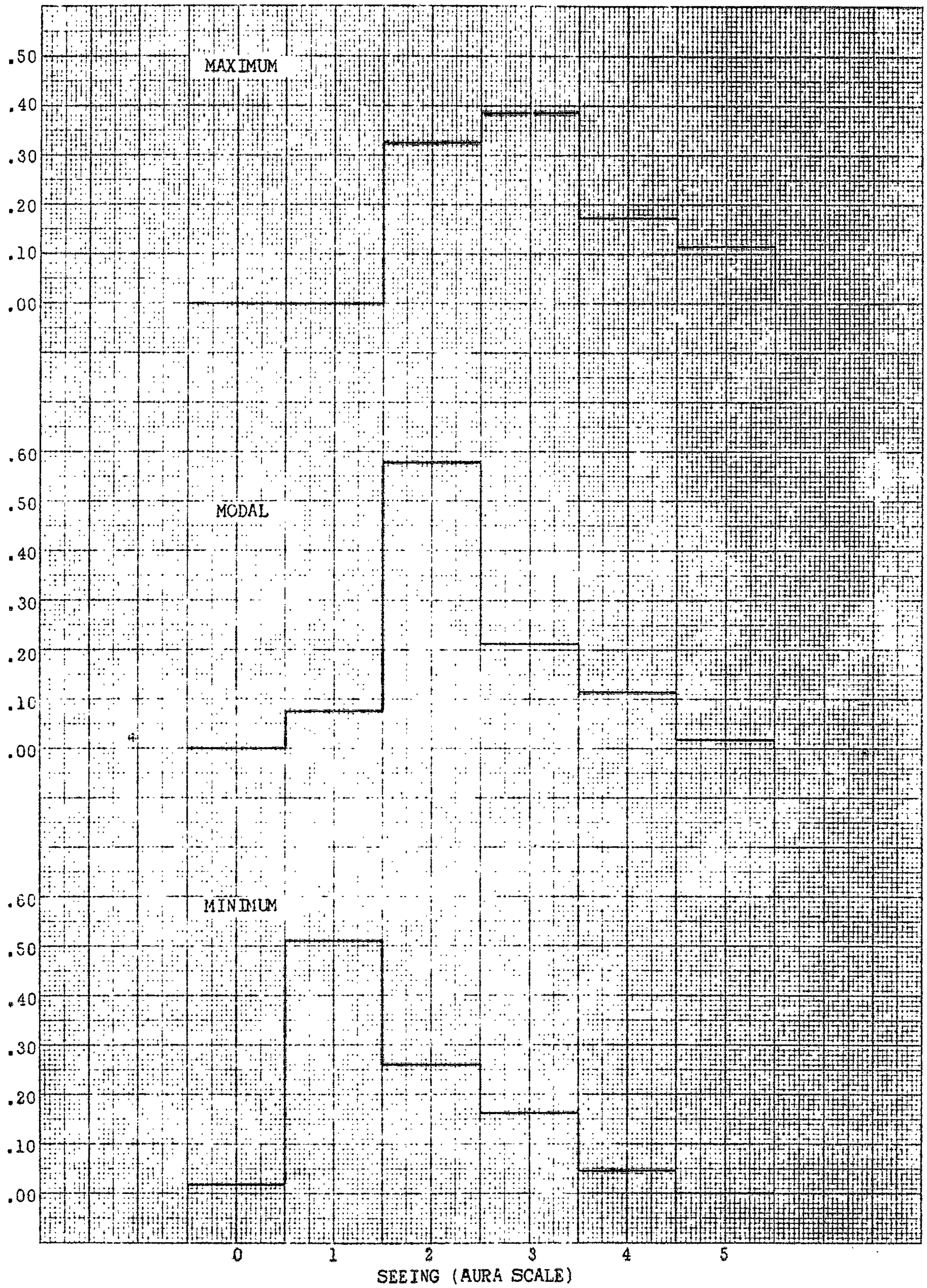


FIGURE 49. Normalized Distribution of Maximum, Modal, and Minimum Seeing for Nine-Month Period-December 1960 through September 1961 (Planetary Observations, 12-Inch Reflector)

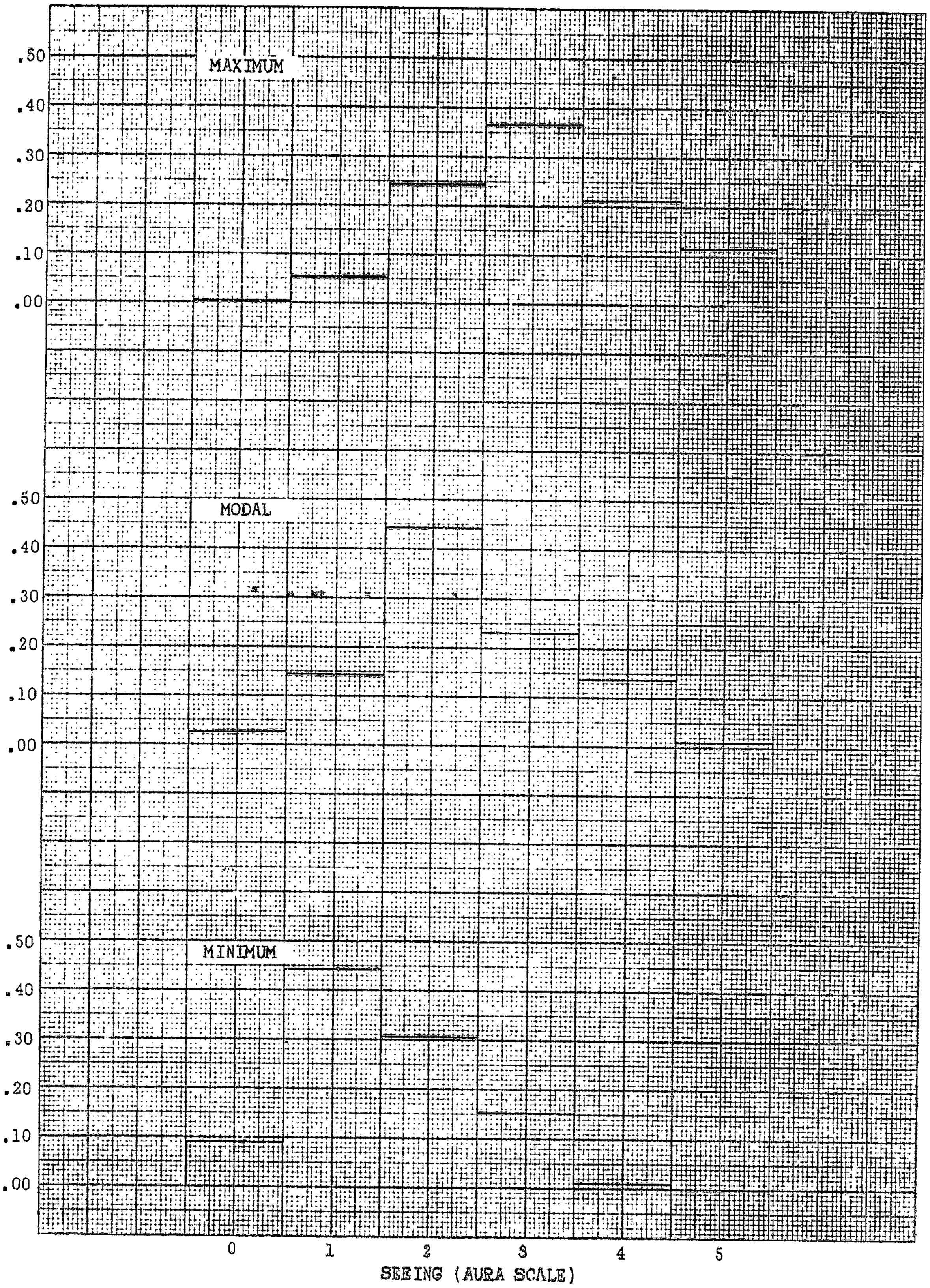


FIGURE 50. Normalized Distribution of Maximum, Modal, and Minimum Seeing for Nine-Month Period—December 1960 through September 1961 (Planetary Observations, 16-Inch Reflector)

10.0 POLARIS TELESCOPE ELECTRO-OPTICAL SEEING MEASUREMENTS

10.1 Cloudcroft Survey

10.1.1 Description

The Polaris telescope is an automatic electro-optical device which gives an indication of image quality by measuring the integrated distribution of light across the image over an interval of one second of time. The instrument is mounted in a fixed position with the optical axis coinciding precisely with the North Celestial Pole. Thus, the locus of the image of Polaris (α Ursae Minoris) is a circle in the secondary focal plane centered on the optical axis of the catadioptic optical system. As the image of Polaris traverses this circle at the sideral rate, a photomultiplier tube records interruptions of the light produced by a reticle located in the secondary focal plane.

The Polaris telescope, with its one-second time-constant, simulates an integration of the position of a seeing-disturbed image over a one-second time period. This near-Gaussian distribution is analogous to the light distribution in the seeing image produced by a large reflector.

The actual equivalent aperture represented by the Polaris telescope depends upon the linear distance moved by the surrounding air during a one-second time interval. The Polaris seeing is expected, therefore, to be generally poorer than that derived from 16-inch visual observations, since it usually represents a larger aperture. The reader is referred to Meinel (1960) for further information on this system.

Several Polaris telescopes were used in the AURA survey in an attempt to establish systematic differences in the stellar seeing diameters among the various sites under consideration. In an effort to determine the effects of height above the ground, two instruments were installed at each site; one located atop a ten-foot tower and the other on a sixty-foot tower. Tower instability precluded the usefulness of the sixty-foot instruments, and only the results of the ten-foot towers were published.

The Cloudcroft Polaris telescope records were taken from a single AURA Polaris system set upon a six-foot cinder-block pier with the optics standing approximately eight feet above the ground. This is somewhat lower than the AURA ten-foot tower, but it was decided to use caution on the installation so as to better insure freedom from the tower shake that plagued the AURA survey.

The equipment as received from AURA required some alterations and repairs. The most serious problem was that the mean distance of Polaris from the pole had decreased from 3360 arc-seconds in 1957 (when the AURA survey was being conducted) to 3295 arc-seconds in 1961. This meant

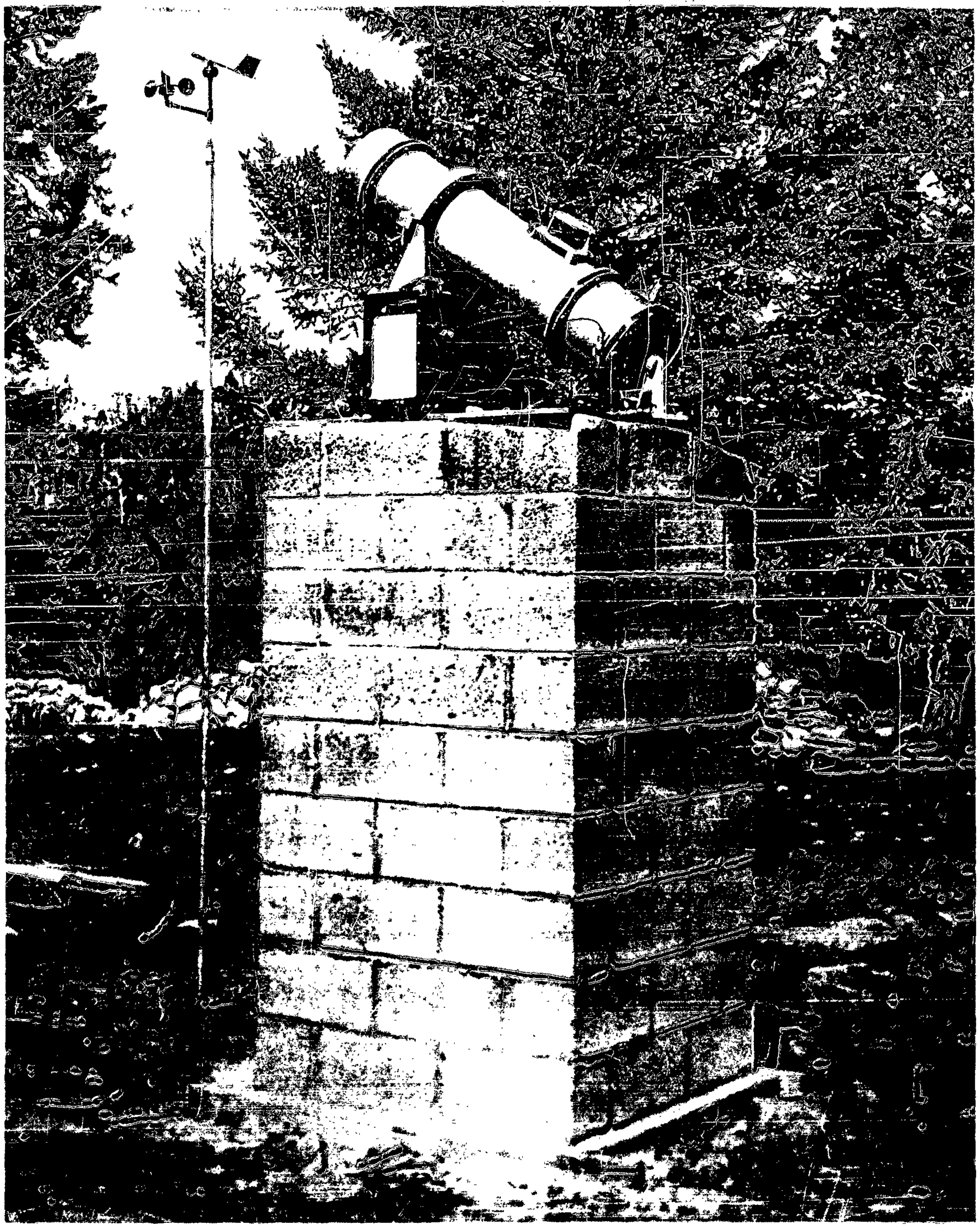


Figure 51 Polaris Telescope Showing the Recorder and Anemometer.
(New Mexico State University Photograph)

that the image of Polaris fell off of the circular reticle to the inside. To correct for this it was necessary to increase the focal lenght of the optical system by 2.0 per cent while necessarily maintaining the approximate physical positions of all optical components. This was finally achieved without destructive alteration of the instrument.

10.1.2 Results

The Polaris telescope was placed in operation near the end of March 1961. Some alignment difficulties were experienced initially and it was 9 April 1961 before continuous nightly records were obtained. The instrument operated reasonably well until the heavy thundershowers began in late June. From this time on, the moisture and dew played havoc with the high impedance circuitry of the Polaris telescope electronics. The dampness and a series of additional unrelated electronic failures terminated the Polaris telescope data at Cloudcroft. Had an adequate shelter been prepared for the relatively exposed Polaris equipment, moisture would not have been a problem and some additional data might have been obtained.

The Polaris telescope tapes yielded a single seeing value for a given occulting bar during each 12-minute cycle. The cycles ran continuously (with the exception of one or two twenty-minute interruptions per night caused by reticle supporting spars) throughout the night. When noticeable transparency changes had taken place within a given cycle, this cycle was omitted in the reduction of the tapes.

In the reduction of the Polaris telescope tapes, the occultation depths of the 1.0 arc-second bar only were measured, because this was the single parameter selected for measurement by AURA.

The radial summation of light distribution is considered by Meinel (Technical Report No. 7) to approximate a Gaussian or normal distribution along a tangential plane, with 0.4 arc-seconds as the dispersion parameter (σ) of the undisturbed image. This assumes that, in a completely undisturbed image, 68 per cent of the light falls within a width of 0.8 arc-seconds or 2σ. Meinel's assumptions, based on his theoretical study of the focal plane light distribution, are accepted without question in this reduction program.

The light distribution in the disturbed image is probably even more closely approximated by a Gaussian distribution. In determining the dispersion parameter due to seeing disturbances alone,

$$\sigma^2 = \sigma_T^2 - \sigma_o^2$$

where σ is the dispersion parameter due to seeing alone, σ_T is the total dispersion parameter determined from the occultation depth of the photo-electric record, and σ_o is the dispersion parameter for an undisturbed image.

In his analysis Meinel allowed 10 per cent as a reasonable value for the scattering of light from all causes. This analysis also uses 10 per cent.

From the above assumptions, Figure 52 was prepared and applied directly to the Polaris tape measurements. The ordinate A/B is the ratio of the occultation depth of the 1.0 arc-second bar to the occultation depth of the 60 arc-second bar. The abscissa, 2σ, is the effective diameter of the stellar image in an instrument sufficiently large such that the Airy disk is trivial in comparison.

During the 12-week interval between 9 April 1961 and 28 June 1961, the Polaris telescope operated on 55 nights, accumulating 967 reducible measurements for an average of about 18 measurements per night. Actually about 40 measurements per night are possible but transparency problems and trouble with a recorder kept this number lower.

Figure 53 gives the nightly maximum, minimum, and arithmetic mean of the effective diameters from all of the reduced cycles for each date of operation. Also included is the nightly range and arithmetic mean of the effective aperture as determined from wind speed.

When no ground winds were blowing, the effective aperture would not actually be zero as indicated in Figure 53 but some small aperture of perhaps six inches (Polaris telescope aperture). Disturbances resulting from higher level winds might slightly increase this and all other indicated effective apertures.

Figure 54 shows the normalized distribution of effective seeing diameters from all reduced cycles during the total operating time of the Polaris telescope.

10.1.3 Conclusions

Comparison of the Cloudcroft Polaris data with those obtained at AURA's Kitt Peak Observatory will immediately reveal that the effective stellar disk diameters are somewhat larger at Cloudcroft. It is difficult to estimate the actual effect of the Cloudcroft Polaris telescope being closer to the ground than the instrument at Kitt, but it can be said with certainty that seeing improves with height above the ground. McMath and Pierce (1960) state that microthermal fluctuations at Kitt Peak (presumably daytime measurements) decrease exponentially with height above the ground. Section 8.0 would also indicate that seeing quality is dependent upon height above the ground. The result of a lower tower, therfore, is that somewhat poorer seeing might possibly have been recorded. (For this reason alone, direct comparison of Polaris seeing between the Cloudcroft and AURA surveys should be made with some discretion.)

It should also be mentioned that the Kitt Peak instrument was often inoperative during strong winds, because of tower shake, at a time when seeing might normally be poor. For its period of operation, an average of four or five observations per night out of 25 were measured for use in the AURA report.

The Cloudcroft instrument, however, seemed able to give data even during strong winds. This generally poorer seeing is included in the roughly 18 out of 18 observations per night measured for this report.

It is perhaps unfortunate that a continuous record from the Polaris telescope was not obtained throughout the study interval. However, it is not felt that the survey has been seriously impaired by the lack of substantial Polaris telescope data. In a telephone conversation with one of the writers of this report (B. A. S.), Dr. A. B. Meinel (now with the University of Arizona) stated that the AURA survey also had considerable difficulties with the operation of the Polaris telescopes, and that they were used primarily during those times when it was impossible to have observing personnel at the sites. Dr. Meinel went on to say that the Polaris data were not sensitive to the best seeing and more weight was given to the records obtained by a trained observer using a 16-inch telescope. Their experience was that the most sensitive indicator of the local seeing was that afforded by microthermal data, although their survey terminated before much of this type of information could be secured.

The difficulties with the Polaris telescope experienced by Meinel during the AURA survey, and by Smith during the Cloudcroft survey, would suggest that little emphasis should be placed on a comparison of Polaris telescope data between Kitt Peak and Cloudcroft. As did Meinel, the writers of this report place relatively little confidence in the Polaris telescope records.

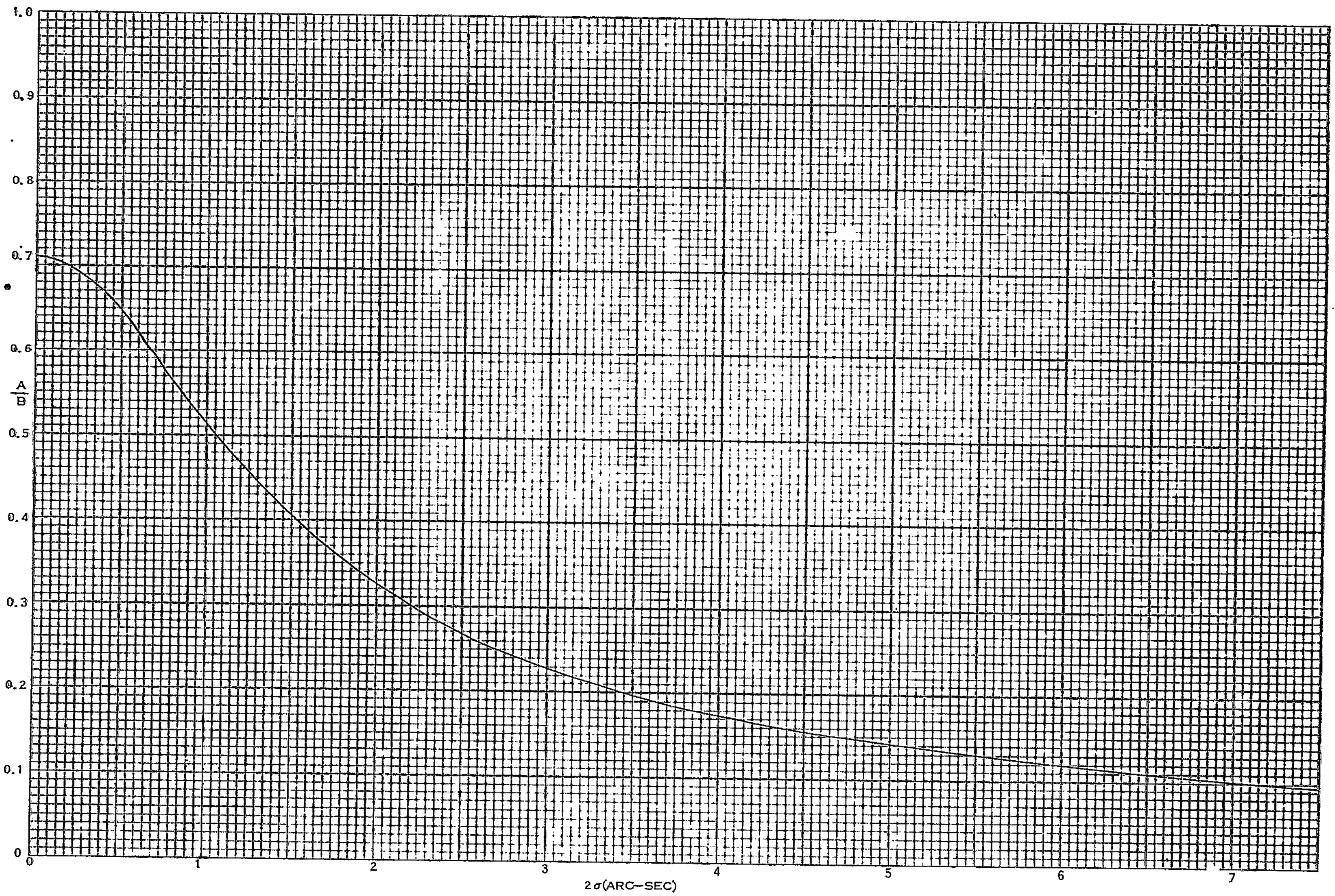


FIGURE 52. The Relationship of the Parameter $\frac{A}{B}$ to the Effective Stellar Disc Diameter 2σ for the 1.00 Arc-Second Bar of the Polaris Telescope

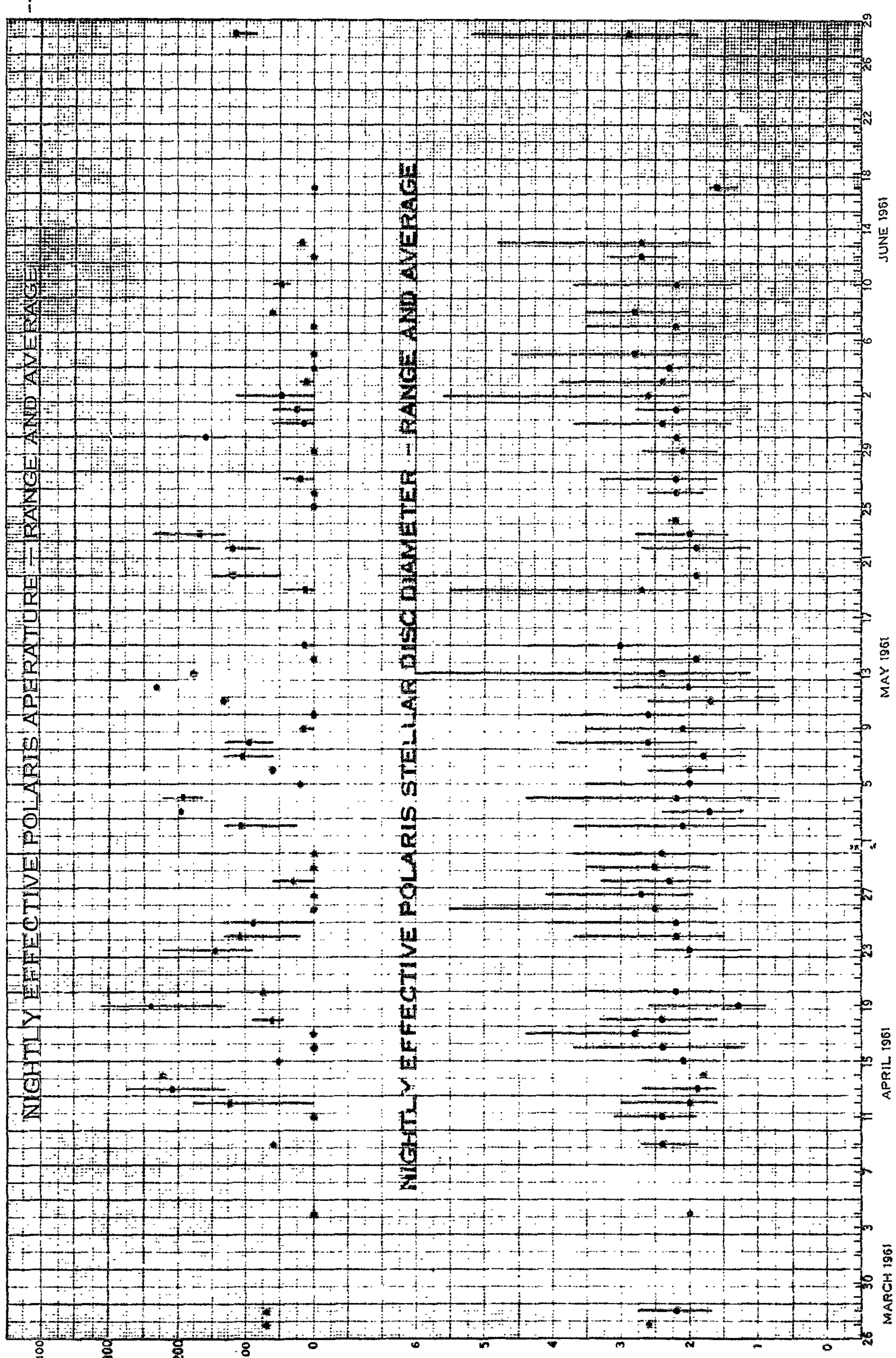

NIGHTLY EFFECTIVE POLARIS APERATURE — RANGE AND AVERAGE
NIGHTLY EFFECTIVE POLARIS STELLAR DISC DIAMETER — RANGE AND AVERAGE
INCHES
400
300
200
100
0
ARC-SECONDS
6
5
4
3
2
1
0
MARCH 1961
APRIL 1961
MAY 1961
JUNE 1961
26
30
3
7
11
15
19
23
27
1
5
9
13
17
21
25
29
2
6
10
14
18
22
26
29

FIGURE 53

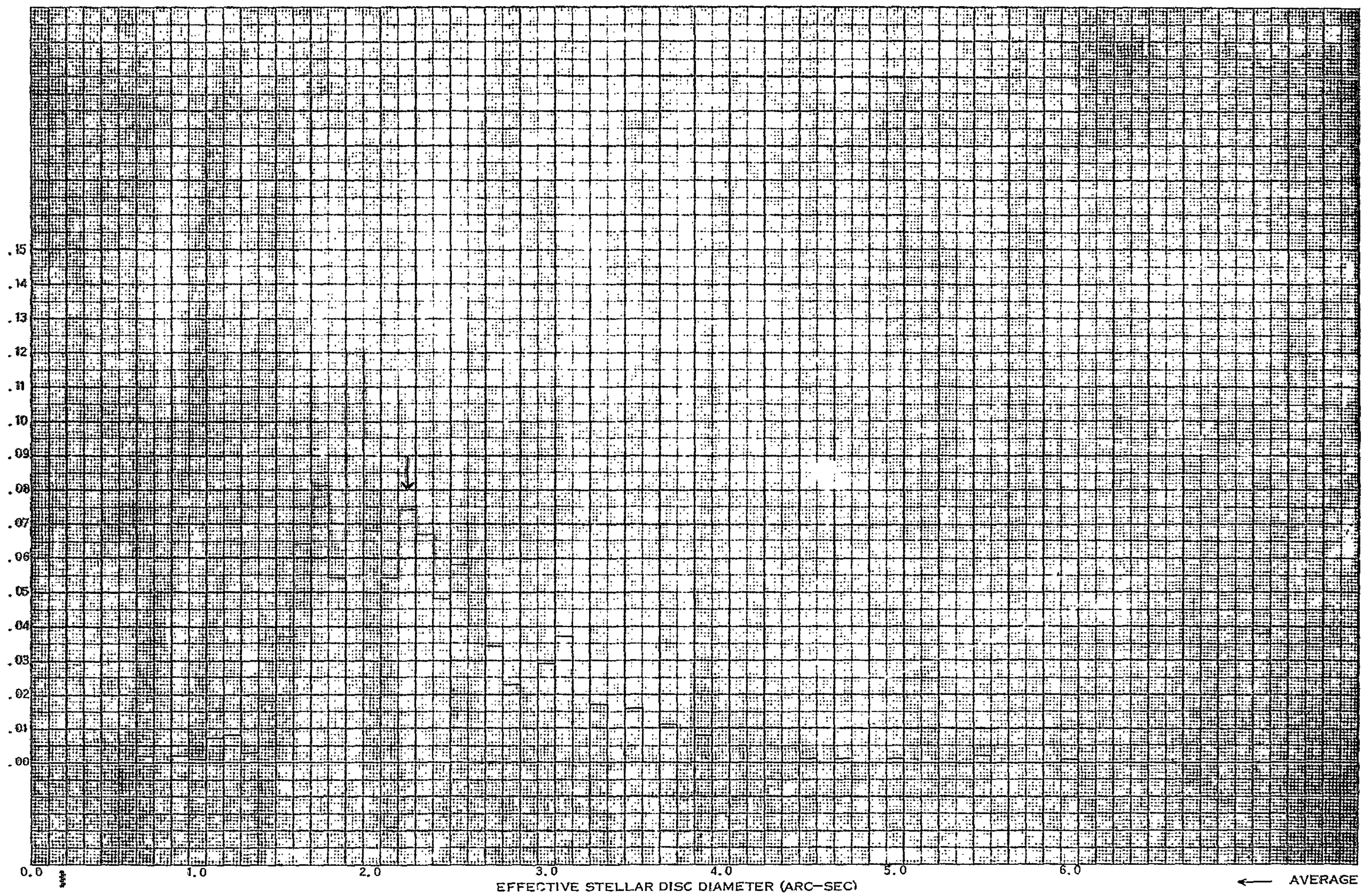


FIGURE 54. Normalized Distribution of the Effective Stellar Disc Diameter from Polaris Telescope

11.0 SITE PRACTICALITY

The practicality of a site, as distinguished from its scientific utility, may be measured by its ease of acquisition, ease of development, and habitability.

Site acquisition poses no problem for the Cloudcroft site, since 1360 acres have already been made available to the Air Force by the Lincoln National Forest Service.

Site development is favored by extreme ease of access. The site is located in Otero County, New Mexico, approximately three miles north of the town of Cloudcroft in the Sacramento Mountains (Latitude 32°59', Longitude 105°44'). The site is approximately 25 road miles ENE of Alamogordo, about 45 minutes by automobile. The road to the site is paved, and only roads within the site require paving. Alamogordo is served by airlines, with flights south to El Paso, and north to Albuquerque, Colorado Springs, and Denver.

Other phases of site development besides access are also favorable. Although most of the site is at an elevation of nearly 9,000 feet, the terrain is not rugged. It has a gently rolling topography situated on an uplifted plateau. The cover is largely Ponderosa pine and aspen, with large natural open parks. Thus, unlike some sites of limited area on mountain peaks, there is no practical limitation to the size of the facility that could be accommodated. There would also be no difficulty in conveniently locating the observational instruments and laboratories, not only because of the favorable terrain, but also because of favorable bedrock conditions for foundations.

Utilities could also be installed at the site with minimum difficulty. Tests by the Corps of Engineers indicate that wells dug in the area could each produce 25-50 gallons per minute. One such well would provide more than ample water for the Observatory and personnel housing. As for power, there is now a 14.4/24.9KV line with 2,000 KW capacity within 1-1/2 miles of the site. The Otero County Electric Co-op is prepared to run a 69 KV three-phase power line with a 5,000 KW maximum capacity to the site upon request. Maximum pwer demand for the proposed installation would be between 500 and 1200 KW. Sewage may be disposed of by means of spetic tanks or a treatment plant.

The final aspect of site practicality to be considered is habitability. As indicated above, there is easy access to the site on paved roads. There is also no question of long-term winter isolation of the site, despite the occasional heavy snow. Snow removal equipment is available at the town of Cloudcroft, and the road to Alamogordo is made impassable for only five to six hours during the severest winter storms.

The climate at Cloudcroft is cool and fairly dry. It is extremely pleasant during the summer, and not exceptionally harsh in the winter (see Tables I and XIV).

Due to the high elevation of the site, there are very few insects and no poisonous snakes, which make the attractive surroundings (see Figure 55) safe for recreation.

Adequate shopping facilities are available in the town of Cloudcroft, which is only four miles by road from the site. More complete facilities are available in nearby Alamogordo.

The practicality of the Cloudcroft site is, therefore, very good, and this would be reflected in the costs of construction and in the willingness of capable personnel to accept year-round employment at the site.

TABLE XIV

CLIMATIC SUMMARY - TEMPERATURES ($^{\circ}F$)

STATION	DATA	YEARS	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
CLOUDCROFT	MEAN	46	30.4	32.3	36.6	42.9	51.0	58.6	59.8	58.7	54.9	47.1	37.6	31.3	45.1
	MEAN MAX	46	40.4	42.3	47.1	54.2	63.2	71.1	71.3	69.6	66.2	58.2	48.7	41.4	56.1
	MEAN MIN	46	20.4	22.3	26.1	31.6	38.8	46.1	48.3	47.8	43.6	36.0	26.5	21.2	34.1
	RANGE	46	20.0	20.0	21.0	22.6	24.4	25.0	23.0	21.8	22.6	22.2	22.2	20.2	22.0
MT. HAMILTON (LICK)	MEAN	20	40.7	40.4	43.2	47.9	54.9	61.1	71.3	70.6	66.1	56.6	48.7	42.6	53.7
	MEAN MAX	20	46.4	46.1	50.0	56.0	63.7	70.5	80.4	79.7	75.0	64.6	55.3	48.5	60.9
	MEAN MIN	20	35.0	34.7	36.4	39.8	46.1	51.7	62.2	61.5	57.2	48.6	42.1	36.7	46.5
	RANGE	20	11.4	11.4	13.6	16.2	17.6	18.8	18.2	18.2	17.8	16.0	13.2	11.8	14.4
MT. WILSON	MEAN	26	42.6	42.5	46.2	50.8	57.5	66.6	73.7	73.1	67.1	58.1	51.5	44.9	56.2
	MEAN MAX	26	49.8	50.6	55.2	61.5	68.5	77.5	84.1	83.3	77.2	67.3	59.9	52.3	65.6
	MEAN MIN	26	35.4	34.4	37.2	40.1	46.5	55.7	63.3	62.9	57.0	48.9	43.1	37.5	46.8
	RANGE	26	14.4	16.2	18.0	21.4	22.0	21.8	20.8	20.4	20.2	18.4	16.8	14.8	18.8
MT. PALOMAR	MEAN	10	41.5	42.5	43.5	51.3	57.3	63.2	71.9	71.8	69.3	59.5	49.8	44.1	55.5
	MEAN MAX	10	50.7	51.9	52.9	61.8	68.4	74.6	82.9	82.7	80.5	70.2	59.4	53.1	65.8
	MEAN MIN	10	32.3	33.1	34.2	40.7	46.1	52.1	61.3	60.9	58.1	48.7	40.1	35.1	45.2
	RANGE	10	18.4	18.8	18.7	21.1	22.3	22.5	21.6	21.8	22.4	21.5	19.3	18.0	20.6
SELLS	MEAN	18	50.6	54.5	57.9	64.9	72.5	82.1	86.0	84.2	81.2	70.8	58.5	52.7	68.0
	MEAN MAX	18	65.5	69.7	73.8	81.7	90.6	100.1	99.8	97.7	95.6	86.0	73.6	67.1	83.4
	MEAN MIN	18	35.7	39.3	42.0	48.1	54.4	64.1	72.2	70.7	66.8	55.6	43.4	38.3	52.6
	RANGE	18	29.8	30.4	31.8	33.6	36.2	36.0	27.6	27.0	28.8	30.4	30.2	28.8	30.8
MT. LOCKE (McDonald)	MEAN	17	41.7	45.8	50.1	57.4	64.5	70.1	69.5	69.7	64.6	58.6	48.9	43.9	57.1
	MEAN MAX	17	51.6	56.7	62.0	69.8	76.7	82.3	80.6	80.7	75.1	68.5	59.0	53.3	68.0
	MEAN MIN	17	31.9	34.9	28.2	45.2	52.3	57.9	58.5	58.7	54.1	48.5	38.5	34.5	46.1
	RANGE	17	19.7	21.8	23.8	24.6	24.4	24.4	22.1	22.0	21.0	20.0	20.5	18.8	21.9

Figure 55 Area "E" of the Cloudcroft Site:
Looking east from the flagpole at one of the parks.
(Geophysics Research Directorate Photograph)

12.0 SUMMARY

The Cloudcroft observatory site has been evaluated from the points of view of rainfall, cloud cover, dendroclimatology, contrails, wind velocity, temperature, microthermal measurements, visual seeing records, and site practicality.

Cloudcroft is in a fairly advantageous position with respect to total rainfall, but has the greatest number of days on which some rain falls when compared to five major Southwestern observatories. Seventy days of rain per year are not, however, an unacceptable limitation on the operation of an observatory; especially in view of the fact that a large proportion of the rain falls during the day. The rainfall is a distinct advantage in that Cloudcroft has no water supply problem as has been experienced at Kitt Peak.

Studies of cloud cover by several different methods indicate that Cloudcroft is approximately equal to or better than most other Southwestern observatory sites with respect to nighttime cloudiness. Specifically, about two-thirds of all nighttime hours at Cloudcroft are expected to be clear (less than 4/10 clouds), and about one-half to be cloudless (less than 1/10 clouds). The relatively short-term study made during the survey at the Cloudcroft site agrees rather well with these predictions.

The dendroclimatological study indicates that, as is generally the case in the Southwest, the last 120 years have been drier than the 300-year mean except for the interval 1925-1945. Previous to 1840, the tree rings indicate alternating periods of wet and dry conditions of about 30-years duration. All summary rainfall data presented in this report are derived from measurements made during both wet and dry intervals, and are probably as representative of mean conditions as it is possible to obtain. It is not possible to draw conclusions as to the mean amount of cloud cover over the site from the tree-ring data. It is assumed that relative cloud-cover estimates are valid without regard to absolute cloud cover.

Because of their small number, contrails are of minor importance over the Cloudcroft site at present. The requirement to preserve this clear sky makes necessary a proscribed area for high altitude flights around the site. This area need measure only about 75 by 100 miles to prevent 90 per cent of all contrails formed in the vicinity from passing over the site.

High winds are in general no problem at Cloudcroft. Tall pine trees and surrounding hills provide protection from direct winds.

Temperature ranges at Cloudcroft are not unusually severe, and should not hamper men or equipment more than is normal for a high altitude observatory.

Microthermal measurements at Kitt Peak have been used by others to substantiate the theory that peaks are in general better sites for observatories than plateaus. This does not, however, seem to be a valid conclusion, and it is considered that seeing quality is the result of many variables, of which the purely local surroundings of a site are of great importance. Microthermal measurements are necessary to determine the important turbulence gradient at a site. The results of the survey suggest substantial seeing improvement by locating the telescopes about fifty feet above ground level.

A comparison of visual seeing records from Cloudcroft and Kitt Peak shows that the average nightly modal seeing is slightly lower at Cloudcroft (2.3 as opposed to 2.8 on the AURA scale). The best modal seeing per night appears to have a more favorable distribution at Kitt Peak than at Cloudcroft, subject to the precautions given in Section 9.1.1(c). There is no basis for the comparison of either the maximum or minimum seeing values at Cloudcroft with the Kitt Peak data since only the modes were recorded by AURA.

As far as site practicality is concerned, Cloudcroft is an extremely favorable position. This should be reflected in low cost of construction and in the willingness of capable personnel to accept year-round employment at the site.

It is obvious that many years of observations at a given site are needed for a flawless evaluation. This usually proves to be impractical and it becomes necessary to draw conclusions from data which can be assembled in a time interval consistant with the urgency of the project.

It is concluded, from the evidence obtained, that the Cloudcroft site has many factors in favor of its use as a location for a planetary observatory. These assets include adequate water, high number of clear hours, relative freedom from contrails, low wind speeds, and site practicality. Seeing, however, is a most important factor, and the modal value is somewhat poorer than at Kitt Peak. For a lack of comparison of the maximum seeing values, the conclusions must be drawn from a comparison of the modes.

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