THE CALIFORNIA SITE SURVEY*

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This paper summarizes the results of a two-year survey of potential dark-sky observing sites in California south of the latitude of San Francisco. This survey was undertaken in 1965 to locate a new site for future large optical telescopes since the growth of lights and smog near Mount Hamilton are increasingly limiting the usefulness of that site for observations of very faint objects and for photometry.

The best observing conditions appear to occur along the coast, very close to the ocean where the cold ocean current holds down the height of the inversion layer, and where there exists a laminar airflow off the ocean, minimizing the optical turbulence and placing the site upwind from sources of smog.

I. Introduction

In describing Mount Hamilton in 1879, S. W. Burnham (1887) wrote: "There can be no doubt that Mount Hamilton offers advantages superior to those found at any point where a permanent observatory has been established." In recent years, however, the quality of the observing conditions at Mount Hamilton has begun to deteriorate due to the increase in lights and smog in the San Francisco Bay area, and, in particular, in the Santa Clara valley. By the early 1960's it had become clear that while certain types of work, such as high-dispersion spectroscopy, could continue indefinitely at Mount Hamilton, a new site would have to be found for observations of very faint objects and for photometry. In 1965, the Regents of the University of California authorized the Lick Observatory to conduct a two-year survey of possible dark-sky sites for future optical telescopes. At the request of the Observatory Director, Dr. A. E. Whitford, I undertook the supervision of this survey.

The characteristics that a new site should possess include:

1. Dark sky.
2. High transparency.
3. High percentage of clear weather.
4. Minimum optical turbulence.

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5. Location such as to minimize future deterioration due to lights and smog.

The areas investigated were limited in the following ways:

1. Only sites within California were considered.

2. Sites north of the latitude of San Francisco were excluded because of the relatively high percentage of cloud-cover and rainfall in the northern part of the state, and because in these latitudes the interval between the end of astronomical twilight and dawn becomes very short during the summer months.

3. Sites in the Sierra Nevada range were excluded because they are subject both to severe storms in winter and to extensive thunderstorm activity in summer.

4. Only mountain-top sites with altitudes between about 5000 and 9000 feet were considered. The lower limit is set by the necessity of avoiding low-level haze and atmospheric turbulence, while the upper limit is set by the problems of heavy snowfall and low temperatures in winter and of the acclimatization of observers who come at infrequent intervals to work on the mountain.

5. Only sites accessible over existing roads or trails could be investigated, since funds for extensive road building were not available.

In preparing a list of sites to be investigated, only those at which the artificial illumination of the night sky is less than at Mount Palomar were considered. At Mount Palomar, the lights of Los Angeles and San Diego produce almost equal illuminations of the night sky, amounting to a brightening of $\leq 0^{m}.1$ at the zenith and $\leq 0^{m}.2$ at an altitude of 45° in the direction of the light source. Using a portable photoelectric photometer, the distance from the lights of San Jose, at which they produce this same illumination of the night sky, was found. Then, combining these data with those from Mount Palomar and assuming that the illumination of a center of population is proportional to the number of its inhabitants, a curve, shown in Figure 1, was constructed giving the distance from a city of a given population at which the illumination of the night sky will be $\leq 0^{m}.1$ at the zenith and $\leq 0^{m}.2$ at 45° altitude toward the city. Using this curve, the areas within which the sky is artificially brightened by more than the above limits could then be plotted on a map of California, as shown in Figure 2. On this map, present conditions are indicated by the solid lines, except that for

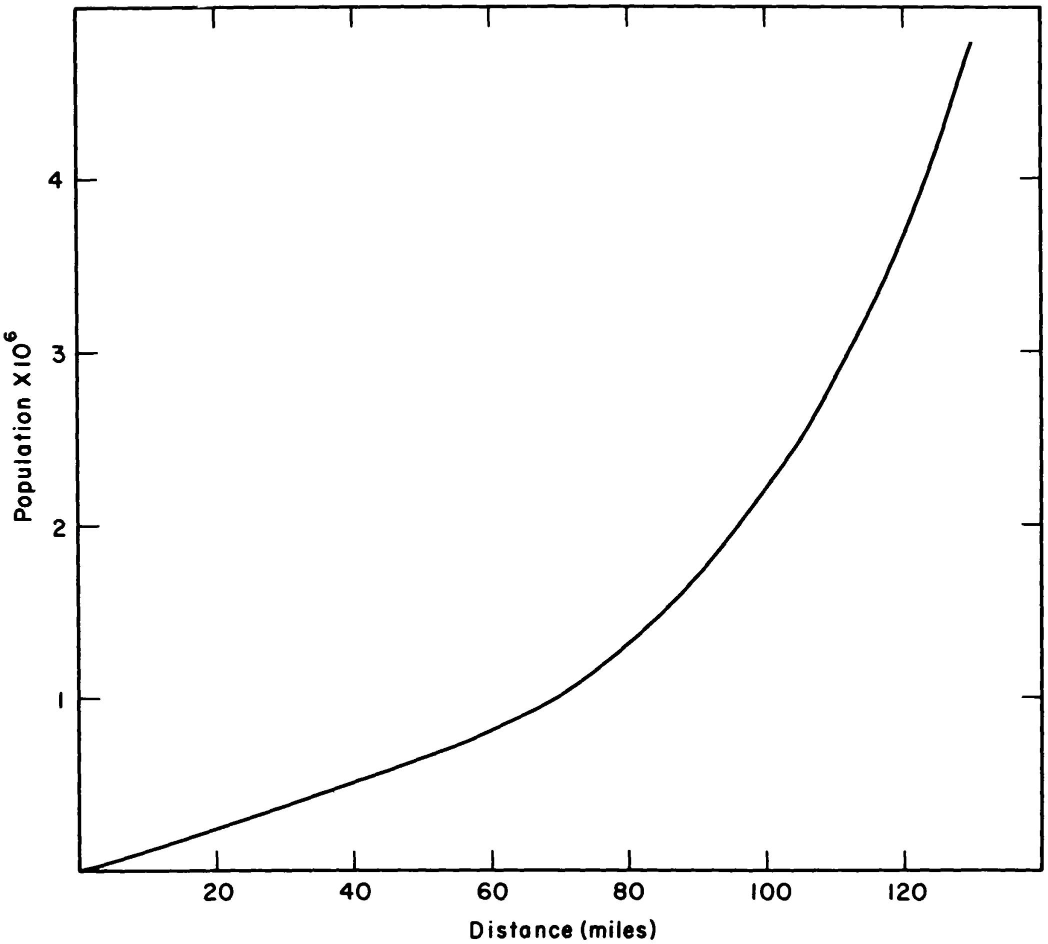

FIG. 1 — Distance at which the artificial sky illumination due to a city of indicated size will be $\leq 0^m1$ at the zenith and $\leq 0^m2$ at an altitude of 45° in the direction of the city.

all cities with present populations between 10,000 and 20,000 the circles have been drawn with radii of ten miles, instead of the smaller values predicted by the curve. The dotted lines indicate conditions expected in 1985 for a few cities for which projected population figures were available. For the larger centers, the areas of high population density are shown in black. A few cities of small population are shown simply as an aid in identifying the locations both of the sky illumination limits and of some of the sites investigated, as discussed later. It must be emphasized that the limits shown in Figure 2 are only approximate, being based on a limited amount of data, and were designed only to indicate in a general way those areas that are too close to sources of light to be considered as pos-

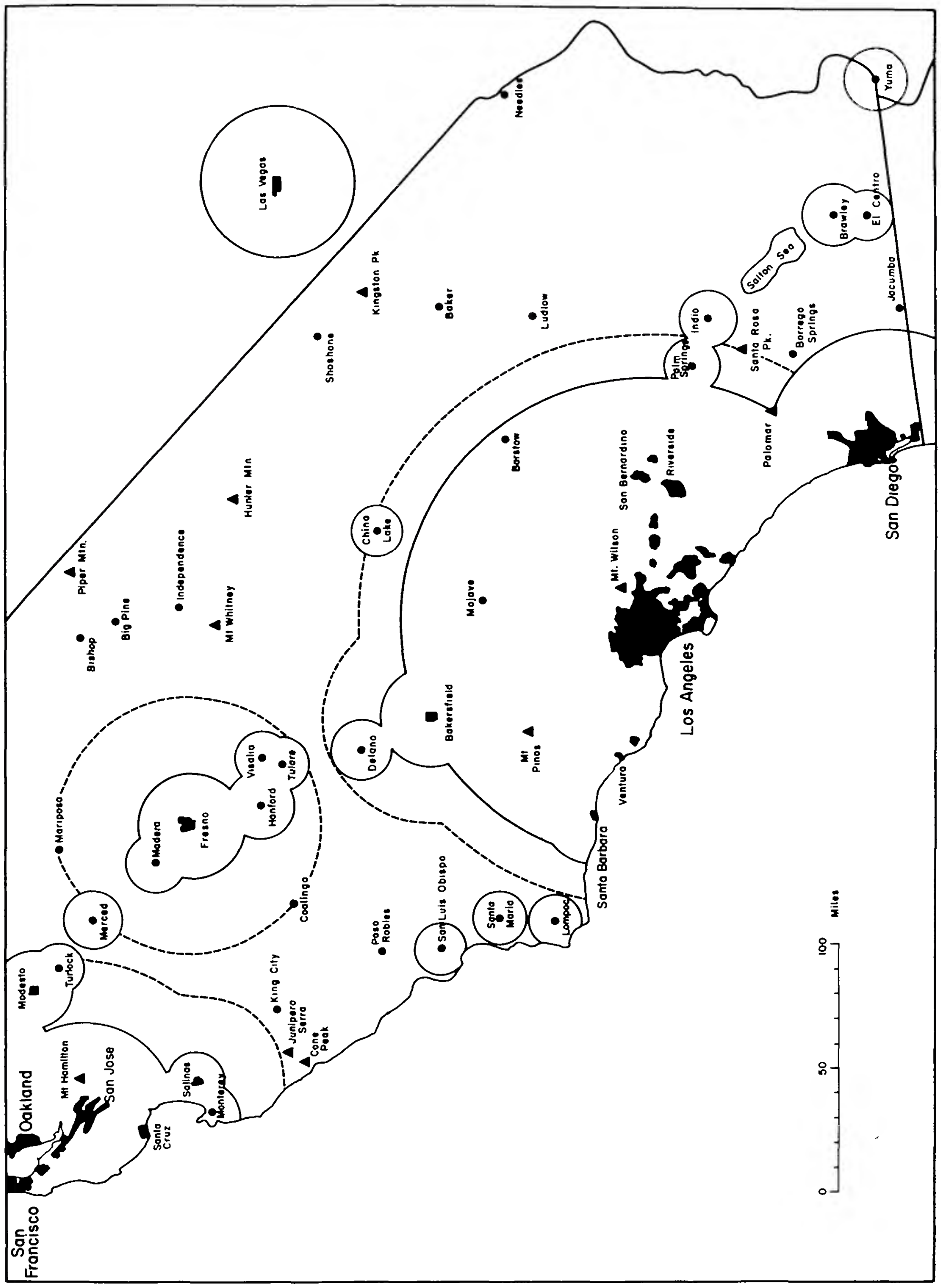

FIG. 2—Map of California showing regions having an artificial sky illumination $\geqslant 0\overset{m}{.}1$ at the zenith and $\geqslant 0\overset{m}{.}2$ at 45° altitude in the direction of the light source, calculated using the curve in Figure 1. Solid lines indicate present conditions; dotted lines, conditions expected in 1985.

sible long-term sites for future dark-sky observations. Some idea of the validity of the curve and of the effects of cities of different sizes and distances can be obtained from the observations of sky brightness discussed in Section II.

Examination of Figure 2 shows that south of San Francisco a surprisingly large area of the state is ruled out for dark-sky observing sites due to sky illumination caused by the large centers of population, or through the anticipated growth of these and of existing smaller centers. In the coast ranges, only peaks in the Santa Lucia range southeast of Monterey, in the Sierra Madre range northwest of Santa Barbara, and in the south end of the Diablo range northwest of Coalinga, are both sufficiently far from sources of light and of sufficient altitude to be considered. South of the latitude of Los Angeles almost no potential dark-sky sites exist due to the illumination from Los Angeles and San Diego and to the absence of high desert peaks east of the Salton Sea. In the trans-Sierra region, however, there are a large number of high desert peaks located well away from present or anticipated sources of light.

The question of the photometric quality of the prospective sites must next be considered. Atmospheric contamination by smog is now much more serious than is generally realized. Up to about 1950, the daytime sky at Mount Hamilton was often of "coronal" quality. Now, strong scattered light is almost invariably seen around the sun. Observations from the air and from Mount Hamilton and other peaks indicate that the smog from the Bay Area tends to drift in a southeasterly direction down the Santa Clara valley, rising and spreading as it goes. Consequently, peaks in the south end of the Diablo range are, like Mount Hamilton, usually submerged in the smog layer, at least during the daytime. On the other hand, peaks in the Santa Lucia range still have skies of extremely good transparency since this area is upwind from most sources of smog. In a similar way, smog from the Los Angeles basin flows eastward and southward, rising as it goes, so that by the time it reaches the Palm Springs area, only the peaks of the highest mountains (San Gorgonio, 11,485 feet, and San Jacinto, 10,805 feet) are usually above the smog layer. The flow spreads southward as far as Mount Palomar, covering that mountain at times. After passing Palm Springs, a part of the smog is drawn northward as the cooler coastal air moves in to replace the rising, hot air in the interior desert valleys. As a result, appreciable smog can be observed as far north as the Death Valley area, and up to altitudes of around 10,000 feet.

It is also desirable to avoid sites that lie under the flight paths of commercial airlines. Desert peaks northeast of Los Angeles—more or less along a line between Los Angeles and Las Vegas—thus appeared to be ruled out on this basis as well as by smog.

One of the important points to be investigated in the survey was the question of the effect of proximity to the ocean on the optical turbulence. It appeared likely that the good seeing observed at Mount Hamilton, Mount Wilson, and Mount Palomar could result from the effect of the cold ocean current along the California coast. The relatively low water temperature has the effect of lowering the height of the inversion layer over the ocean, and this condition persists some distance inland since the airflow during clear weather is usually from the northwest. Thus, near the coast, a site at an altitude of 4000 feet or more will usually be above the inversion layer, and in a layer of air in which the laminar airflow set up over the ocean still persists.

In view of all of the foregoing considerations, and since the available funding did not permit operation of more than two full-time observing stations, it was decided to concentrate on a comparison of the coastal and trans-Sierra regions. Along the coast, Junipero Serra Peak (5862 feet, T. 20 S., R. 5 E., M D B & M) was chosen since it is the highest peak closest to the ocean and at the greatest distance from present sources of lights and smog. Observations were made on the top of the peak near the bench mark, and at two locations on the south-southeast ridge of the mountain to investigate local seeing effects around the peak. These latter stations were located at distances of 1900 and 2700 feet from the bench mark at altitudes of about 5500 and 5465 feet, respectively. In the trans-Sierra region, several reconnaissance trips were made to investigate possible peaks. Most of these proved to be so precipitous that the installation of a field station was impractical with the limited budget available. Finally, Piper Mountain (7703 feet, T. 6 S., R. 37 E., M D B & M) was selected since it is an isolated peak, relatively far from the Sierra Nevada range, at a large distance from sources of light and smog, and with an existing Jeep road to near the summit. The observations were made on the highest point of the peak, near the bench mark.

Short series of observations were also made at Cone Peak, near Junipero Serra Peak, and at Hunter Mountain, about 70 miles south-southeast of Piper mountain. The observations at Cone Peak (5155 feet, T. 22 S., R. 4 E., M D B & M) were undertaken to determine whether any difference in seeing would occur on a peak that is both still closer to the ocean than Junipero Serra Peak and has an extremely sharp profile. The observations at Hunter Mountain (7454 feet, T. 16 S., R. 41 E., M D B & M) were undertaken to obtain some indication of how typical the seeing conditions observed at Piper Mountain were of the trans-Sierra desert peaks, and were made 0.10 mile east of the bench mark at an elevation of about 7200 feet. A few observations were also obtained on other peaks, including Santa Rosa Peak, Tule Mountain, Palomar Mountain, and Mount Pinos. However, these observations were too fragmentary in nature to contribute greatly to the results of the survey.

For the stations at Junipero Serra Peak and Piper Mountain, cabins were designed and prefabricated in the wood shop at Mount Hamilton and transported in sections to the sites for assembly. Daily radio communication was maintained with these two sites.

During the operation of the two field stations on Junipero Serra Peak and Piper Mountain, the survey employed two observers and one field supervisor, who also acted as a relief observer. The observers normally remained on the site for 20 days, followed by ten days off. During most of the survey, the field supervisor, who was charged with the construction and maintenance of the field stations, was Mr. Derrel Houdashelt. The principal observer at Junipero Serra Peak throughout the entire period of the survey was Mr. Winston C. Thompson. Other observers employed for various lengths of time during the survey include: Mr. John K. Bidlake, Mr. John Blankenship, Mr. Tom M. Gans, and Mr. Stuart R. Schulz. In addition, the survey utilized the part-time assistance of one regular observatory employee, Mr. Eugene Harlan. Mr. Harlan rendered especially valuable services to the survey including participation in the preliminary reconnaissance of possible sites, supervision of the instruments used at the sites, and preliminary analysis of the data obtained.

As indicated above, financial support for the survey was provided by a grant from the Regents of the University of California. The total cost of the two-year survey was approximately $80,000.

II. Observational Data

Observations of temperature, relative humidity, wind velocity and direction, and percentage cloud cover were made three times during the day, at 10:00, 14:00, and 17:00, Pacific standard time, and either three or four times during the night, depending upon the season. From May 1 through August 31, the nighttime observations were made at 21:00, 00:00, and 03:00 PST, and during the rest of the year at 20:00, 23:00, 02:00, and 05:00 PST. In addition, measurements of the transparency were made during the day and observations of the seeing were made at night, as described below. Publication of the detailed observations is impractical; in this paper only summaries of the data will be given. However, archive copies of the complete weather and seeing records have been prepared and placed in the libraries of the following observatories, where they will be available for inspection: Hale Observatories, Kitt Peak National Observatory, Paris Observatory, Royal Greenwich Observatory, and the U. S. Naval Observatory.

A. *Weather Observations*

The temperature and humidity were registered on recording hydro-thermographs, whose calibration was checked from time to time against laboratory thermometers and sling psychometers. These instruments were housed in regulation U. S. Weather Bureau-design louvered boxes mounted about five feet above the ground. A summary of the temperature and humidity conditions at Junipero Serra Peak and Piper Mountain is given in Tables I and II, together with the total precipitation for each month. Temperature and precipitation are observed regularly at Mount Hamilton and are published in *Climatological Data, California*, published by the U. S. Department of Commerce; they are therefore not included here. While the day-to-night range in temperature is similar at Junipero Serra Peak and Piper Mountain, the form of the diurnal variation is quite different. Figure 3 shows copies of thermograph records obtained simultaneously at Junipero Serra Peak, Mount Hamilton, and Piper Mountain. At both Junipero Serra Peak and Mount Hamilton the temperature falls during the afternoon and evening and then remains nearly constant all night. At Piper Mountain, on the other hand, the temperature continues to decrease until sunrise the next day. The constancy of the nighttime temperature at Mount Hamilton

TABLE I

WEATHER OBSERVATIONS AT JUNIPERO SERRA PEAK

	Temperature, °F				Average Δ Temp. During Night	Relative Humidity, % During Night			Total Precipitation, Inches	
	Maximum		Minimum							
	Highest	Average	Lowest	Average	°F	Highest	Lowest	Average	Rain	Snow*
1965										
Aug	77	72.7	58	60.6	3.8	33	0	20.1	0.00	0.0
Sep	72	60.0	37	51.9	3.6	100	12	64.7	0.00	0.0
Oct	84	69.3	31	54.8	3.3	95	2	29.9	0.02	0.0
Nov	64	48.6	24	39.0	2.1	97	15	65.9	13.35	4.0
Dec	64	39.9	16	31.0	3.4	97	10	57.4	3.63	11.6
1966										
Jan	50	39.6	22	31.5	3.6	100	2	51.4	0.63	12.6
Feb	54	38.6	19	29.6	3.4	98	0	55.4	1.69	0.9
Mar	74	50.8	13	38.4	3.3	98	0	43.7	0.06	7.5
Apr	76	60.0	29	44.4	2.9	100	4	43.4	0.40	0.0
May	76	63.6	35	47.5	2.7	100	11	43.9	0.00	0.0
Jun	85	69.5	39	54.4	2.4	100	2	37.1	0.10	0.0
Jul	84	73.3	44	57.2	2.6	90	13	38.8	0.80	0.0
Aug	86	78.7	43	62.5	2.7	95	8	33.0	0.01	0.0
Sep	81	68.0	39	52.7	3.4	98	12	44.2	0.16	0.0
Oct	76	63.4	32	49.5	3.9	92	10	36.8	0.00	0.0
Nov	71	47.4	24	38.0	3.8	100	14	61.0	6.66	1.0
Dec	62	45.6	19	36.0	3.5	97	2	45.3	15.79	Trace
1967										
Jan	61	45.2	19	36.4	4.2	99	11	47.9	8.78	10.0
Feb	63	49.6	20	38.0	5.4	100	4	35.8	0.00	6.1
Mar	59	41.2	17	30.1	3.2	100	2	69.4	6.31	34.1
Apr	42	32.3	17	24.4	3.0	100	14	86.7	0.00	68.0
May	81	57.3	28	44.5	2.8	98	8	49.9	0.69	0.0
Jun	84	64.8	31	51.4	2.2	96	6	46.1	0.15	0.5
Jul	84	78.9	58	63.9	3.0	77	11	33.9	0.14	0.0
Aug	86	81.5	63	67.6	1.6	50	15	33.8	0.00	0.0
Sep	78	70.3	47	56.8	3.0	96	23	50.8	1.83	0.0
Oct	72	64.0	38	51.5	3.4	98	5	37.5	0.64	0.0

*Includes sleet and hail

has been a well-known feature over the years and has been one of the great advantages of that site, since the effect of thermal change on the instruments is minimized. This temperature pattern is presumably related to the fact that near the coast the height of the inversion layer is low so that Junipero Serra Peak and Mount Hamilton are above it. In addition to the diurnal changes, Figure 3 also illustrates the slow variations in temperature with amplitudes of five or ten degrees and periods of the order of ten days observed at all three sites. Note that the variation of temperature during the night at

TABLE II

WEATHER OBSERVATIONS AT PIPER MOUNTAIN

	Temperature, °F Maximum Highest	Temperature, °F Maximum Average	Temperature, °F Minimum Lowest	Temperature, °F Minimum Average	Average Δ Temp. During Night °F	Relative Humidity, % During Night Highest	Relative Humidity, % During Night Lowest	Relative Humidity, % During Night Average	Total Precipitation, Inches Rain	Total Precipitation, Inches Snow
1966										
Mar	70	49.3	18	38.7	4.4	50	2	17.1	0.00	0.0
Apr	67	54.7	21	40.7	6.7	60	2	16.6	0.00	Trace
May	74	64.1	35	50.9	4.8	78	1	19.8	0.19	0.0
Jun	80	69.1	43	57.4	5.3	42	2	15.1	0.03	0.0
Jul	84	76.0	50	61.9	5.7	94	1	17.3	0.02	0.0
Aug	86	76.6	48	62.0	4.6	50	0	20.1	0.03	0.0
Sep	76	68.1	36	54.3	5.7	94	6	26.1	0.45	0.0
Oct*	66	62.0	41	47.0	7.9	54	17	34.0	0.00	0.0

*Observations from Oct. 1-9 only

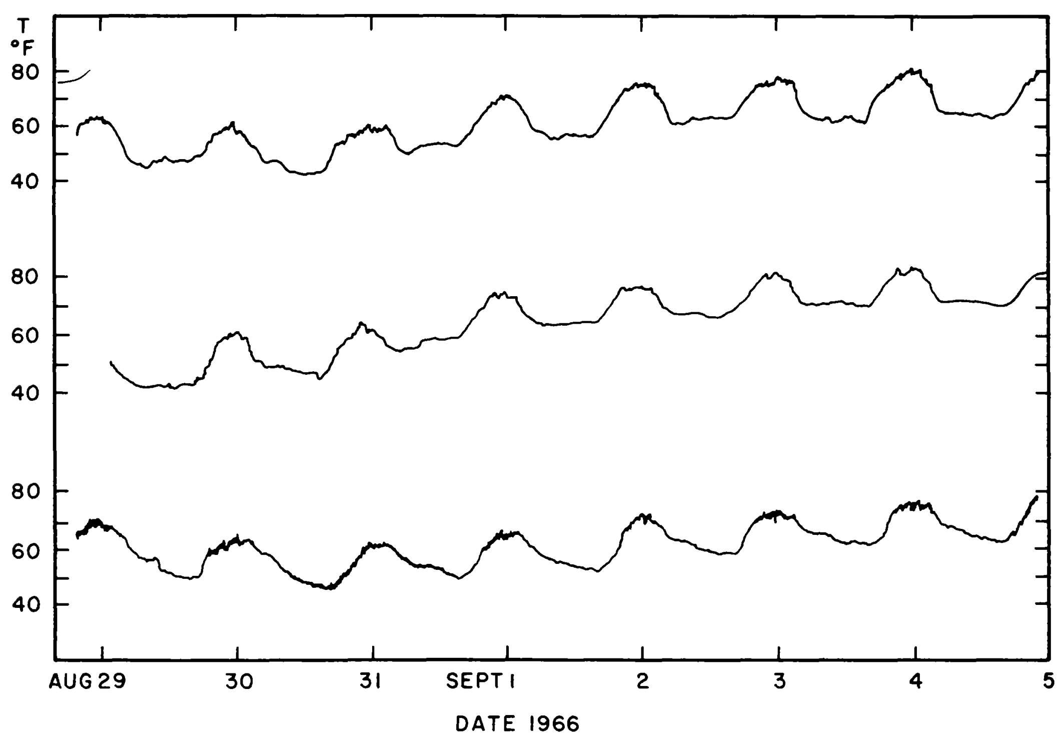

FIG. 3 — Simultaneous thermograph records obtained at (top to bottom): Junipero Serra Peak, Mount Hamilton, and Piper Mountain.

TABLE III

DAYTIME CLOUD COVER ABOVE 15° ALTITUDE

Date	Junipero Serra Peak No. Clear Days	Junipero Serra Peak No. Cloudy Days	Piper Mountain No. Clear Days	Piper Mountain No. Cloudy Days	White Mountain No. Clear Days	White Mountain No. Cloudy Days	Kingston Peak No. Clear Days	Kingston Peak No. Cloudy Days
1965								
Jul	-	-	7	10	5	12	4	12
Aug	-	-	12	19	10	21	16	15
Sep	7	11	19	11	13	16	21	9
Oct	7	22	20	11	11	20	23	8
Nov	1	29	7	23	5	25	4	22
Dec	3	28	8	23	7	24	10	21
1966								
Jan	6	25	9	15	6	25	10	21
Feb	4	24	8	20	6	22	11	17
Mar	8	23	11	18	6	25	11	20
Apr	9	21	14	16	9	21	17	13
May	12	19	16	13	5	26	14	17
Jun	19	11	14	11	13	17	17	13
Jul	19	12	18	13	21	10	18	13
Aug	16	15	14	17	19	12	19	12
Sep	19	11	19	11	13	16	12	18
Oct	13	18	4	5				
Nov	2	28						
Dec	2	29						
1967								
Jan	1	30						
Feb	4	24						
Mar	4	27						
Apr	0	30						
May	4	27						
Jun	9	20						
Jul	9	23						
Aug	10	11						
Sep	6	24						
Oct	4	24						

Junipero Serra Peak and Mount Hamilton tends to follow the trend of these long-period fluctuations.

Observations of the daytime cloud cover are summarized in Table III which gives the number of days with no cloud and the number of days with total or partial cloud above 15° altitude. Daytime cloud-cover observations were obtained during a one-year interval for a number of peaks in the trans-Sierra region by observers living in the vicinity of the peaks. In the table, observations of conditions at White Mountain (14,242 feet, located about 25 miles northwest of Piper Mountain) and at Kingston Peak (7320 feet, located—as shown in Figure 2—about 28 miles southeast of Sho-

TABLE IV

NIGHTTIME OBSERVING CONDITIONS AT JUNIPERO SERRA

Date	No. of Nights*	No. of Dark Hours*†	No. of Photometric Hours*†	No. of Nights* With ≥6h Cont. Photometric	No. of Hours*† With Cloud Cover: ≤ 60%	≤ 80%	No. of Nights* With Wind Velocity Consistently: $\geq 25\frac{mi}{hr}$	$\geq 30\frac{mi}{hr}$
1965								
Aug	5	40.1	39.9	5	40.1	40.1	0	0
Sep	17	152.5	133.9	15	140.5	144.9	0	0
Oct	31	305.2	197.9	18	300.8	303.8	1	0
Nov	29	310.7	57.3	5	193.7	211.5	1	0
Dec	31	345.8	104.1	10	210.5	226.6	3	0
1966								
Jan	31	338.1	126.0	9	206.0	248.2	3	0
Feb	28	286.5	107.5	10	158.3	173.8	1	0
Mar	31	285.5	109.5	11	188.1	211.2	0	0
Apr	30	239.4	125.1	15	171.3	180.8	0	0
May	31	207.8	124.1	14	164.2	170.7	1	1
Jun	30	179.3	124.7	12	153.1	155.8	2	0
Jul	31	195.4	165.4	24	183.8	188.6	0	0
Aug	31	229.4	169.8	21	212.6	219.2	0	0
Sep	30	261.2	179.1	19	234.0	256.4	4	2
Oct	31	305.2	212.5	21	269.4	277.1	1	0
Nov	30	321.4	70.6	7	180.9	187.1	5	3
Dec	31	345.8	98.9	9	232.1	246.5	6	4
1967								
Jan	31	338.1	82.3	7	190.2	205.6	8	3
Feb	28	286.5	80.6	7	207.7	219.2	3	0
Mar	31	285.5	56.0	3	120.7	142.5	2	2
Apr	30	239.4	34.4	3	57.2	77.3	1	0
May	31	207.8	86.9	9	144.5	160.6	0	0
Jun	30	179.3	115.0	8	156.4	161.6	0	0
Jul	31	195.4	113.4	14	167.2	180.8	0	0
Aug	20	152.3	113.9	14	144.6	153.5	0	0
Sep	30	261.2	153.0	17	231.4	237.9	0	0
Oct	28	111.3	151.3	15	247.5	256.4	0	0

*With Observer Present on Mountain

†Based on the interval from the end of astronomical twilight to the beginning of astronomical dawn.

shone) have been included in addition to those at Junipero Serra Peak and Piper Mountain.

Wind velocity measures were usually made on the tops of the peaks at ground level, using hand-held anemometers. In this report, only the nighttime wind velocities have been analyzed, as discussed below.

TABLE V

NIGHTTIME OBSERVING CONDITIONS AT PIPER MOUNTAIN

Date	No. of Nights*	No. of Dark Hours*†	No. of Photometric Hours*†	No. of Nights* With ≥6^h Cont. Photometric	No. of Hours*† With Cloud Cover: ≤60%	≤80%	No. of Nights* With Wind Velocity Consistently: ≥25 $\frac{mi}{hr}$	≥30 $\frac{mi}{hr}$
1966								
Feb	5	50.0	17.0	1	46.9	50.0	3	2
Mar	20	181.9	83.1	8	167.1	170.4	3	2
Apr	30	239.4	94.0	9	209.5	224.5	3	1
May	31	207.8	141.9	18	162.1	174.2	5	2
Jun	26	155.5	72.5	9	94.9	113.2	2	1
Jul	31	195.4	158.8	22	167.8	172.7	0	0
Aug	21	156.7	89.9	11	132.1	151.3	1	1
Sep	30	261.2	203.5	21	236.1	241.0	1	1
Oct	9	85.5	70.9	7	79.3	84.3	0	0

*With Observer Present on Mountain

†Based on the interval from the end of astronomical twilight to the beginning of astronomical dawn.

Nighttime weather and observing conditions for each month are summarized in Tables IV and V. In these tables, the first column gives the month, the second column the number of nights when an observer was present on the mountain, and the third column the number of hours between the end of astronomical twilight and the beginning of astronomical dawn for that month at the particular site when an observer was present. The fourth column gives the number of "photometric" hours between twilight and dawn, i.e., the number of hours with zero cloud cover above 15° altitude. The fifth column gives the number of nights in which an interval of more than six continuous photometric hours occurred. The sixth column gives the number of "spectroscopic" hours, that is, the number of hours with less than 60 percent cloud cover above 15° altitude, while the seventh column gives the number of hours with less than 80 percent cloud cover. Columns eight and nine give, respectively, the number of nights when the wind velocity was consistently greater than 25 and 30 miles per hour; velocities in this range represent about the limit for the operation of a large telescope, due to telescope vibration and to the transport of dirt and leaves into the dome.

B. *Astronomical Seeing*

The optical turbulence or astronomical seeing was measured using the Polaris-trail technique described earlier (Harlan and

Walker 1965). In this method, six-inch refracting telescopes are used to photograph the star trail of Polaris through an enlarging lens at a scale of about 15.″5/mm. The telescopes were individually calibrated at Mount Hamilton by photographing trails of Polaris simultaneously with visual observations of the apparent angular diameter of the faint companion of Polaris on the slit of the coudé spectrograph of the 120-inch reflector. A set of standard trails corresponding to different visual image diameters at the 120-inch was built up for each telescope. Owing to the limited time available for calibration of these telescopes, the sets of standard trails extended only to about 0.″75 in the direction of good seeing. The trails observed at the sites were then compared with the standards for the particular telescope used, to give values of the seeing in terms of the visual angular diameter the star image would have had if viewed through a 120-inch telescope. No attempt has been made to reduce these observations to the zenith, for two reasons. First, because one very often finds, in the course of routine observing, rather large departures from the usually assumed variation in image size with $(\sec z)^{1/2}$. Second, because in practice most observations are made at an appreciable distance from the zenith, so that the original observations of Polaris give a more realistic impression of the conditions that would be encountered in regular observing. Since the latitudes of all the sites are very nearly the same, no systematic corrections have been applied to the seeing observed at the different sites due to differences in the altitude of Polaris.

At all sites, the trail telescopes were mounted with their objectives about seven feet above the ground. At Junipero Serra Peak, a cement-block pier similar to that illustrated in the paper by Harlan and Walker (1965) was constructed. At the other sites, the telescopes were mounted on angle-iron frames that were loaded with rocks and sandbags. Mounted on the block pier, the trail telescope could be used for observations in wind velocities up to at least 53 miles/hour without difficulty due to telescope vibration. On the weighted frames, observations were possible in winds up to about 40 miles/hour. In order to avoid condensation on the objective, leading to possible changes in the transmission characteristics of the lens, no observations were made when the relative humidity exceeded 90 percent.

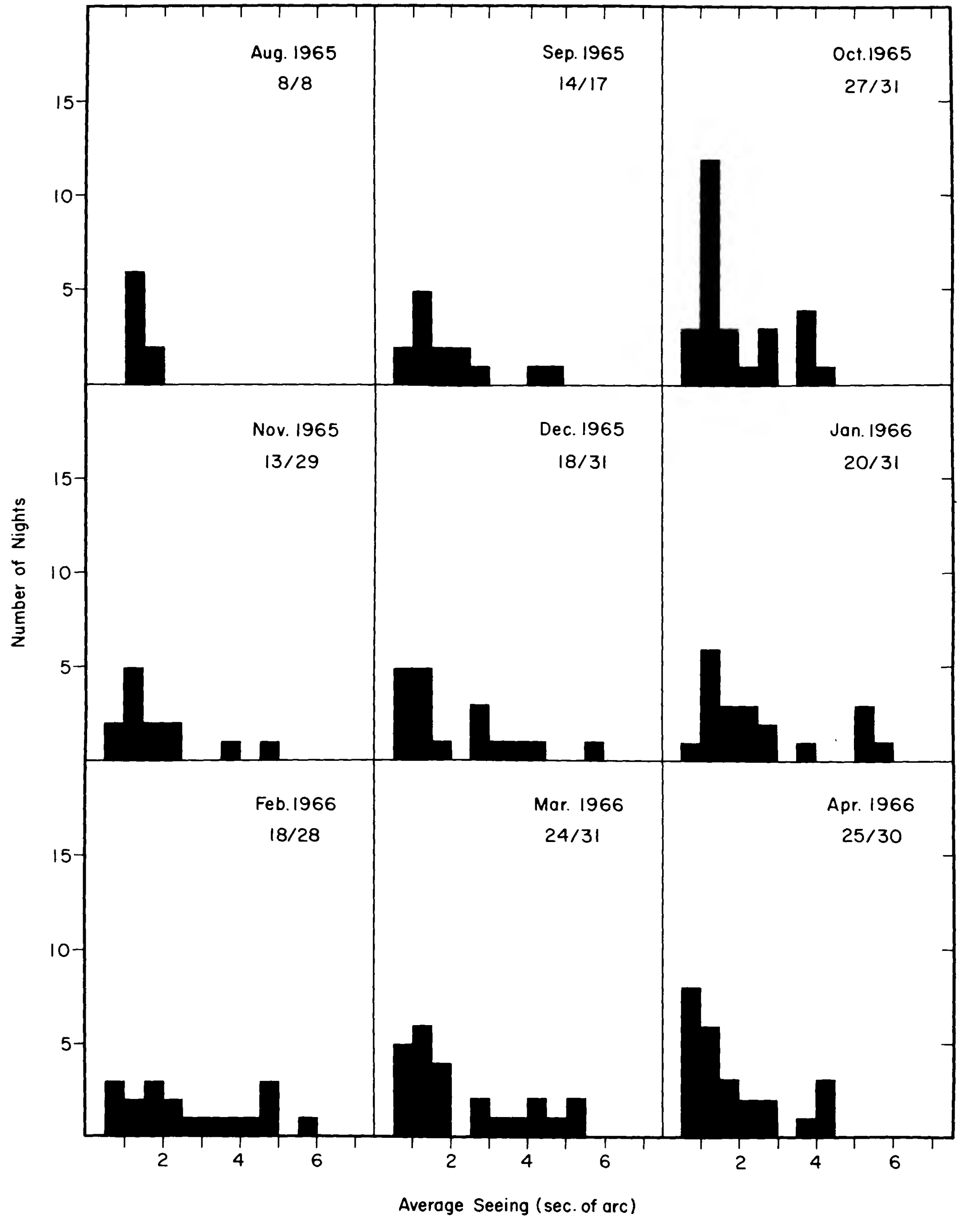

FIG. 4 — Frequency distribution of average nightly seeing observed at Junipero Serra Peak. Ordinate is the number of nights; abscissa, the average seeing for the night. The fractions given for each month indicate numerator, number of nights when at least one observation was made; denominator, number of nights with observer on site.

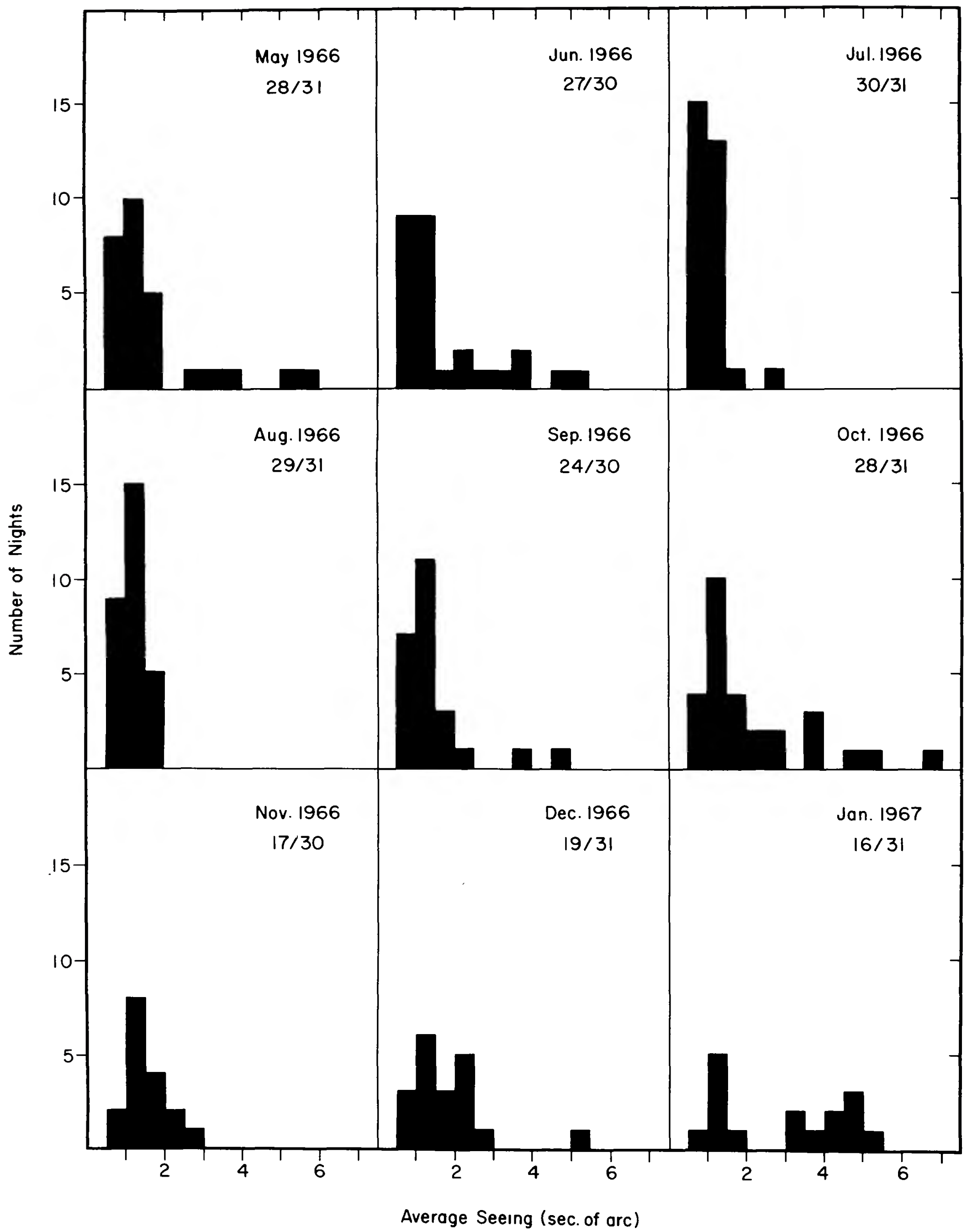

FIG. 5 — Frequency distributions of average nightly seeing observed at Junipero Serra Peak. Ordinate, abscissa, and notation as in Figure 4.

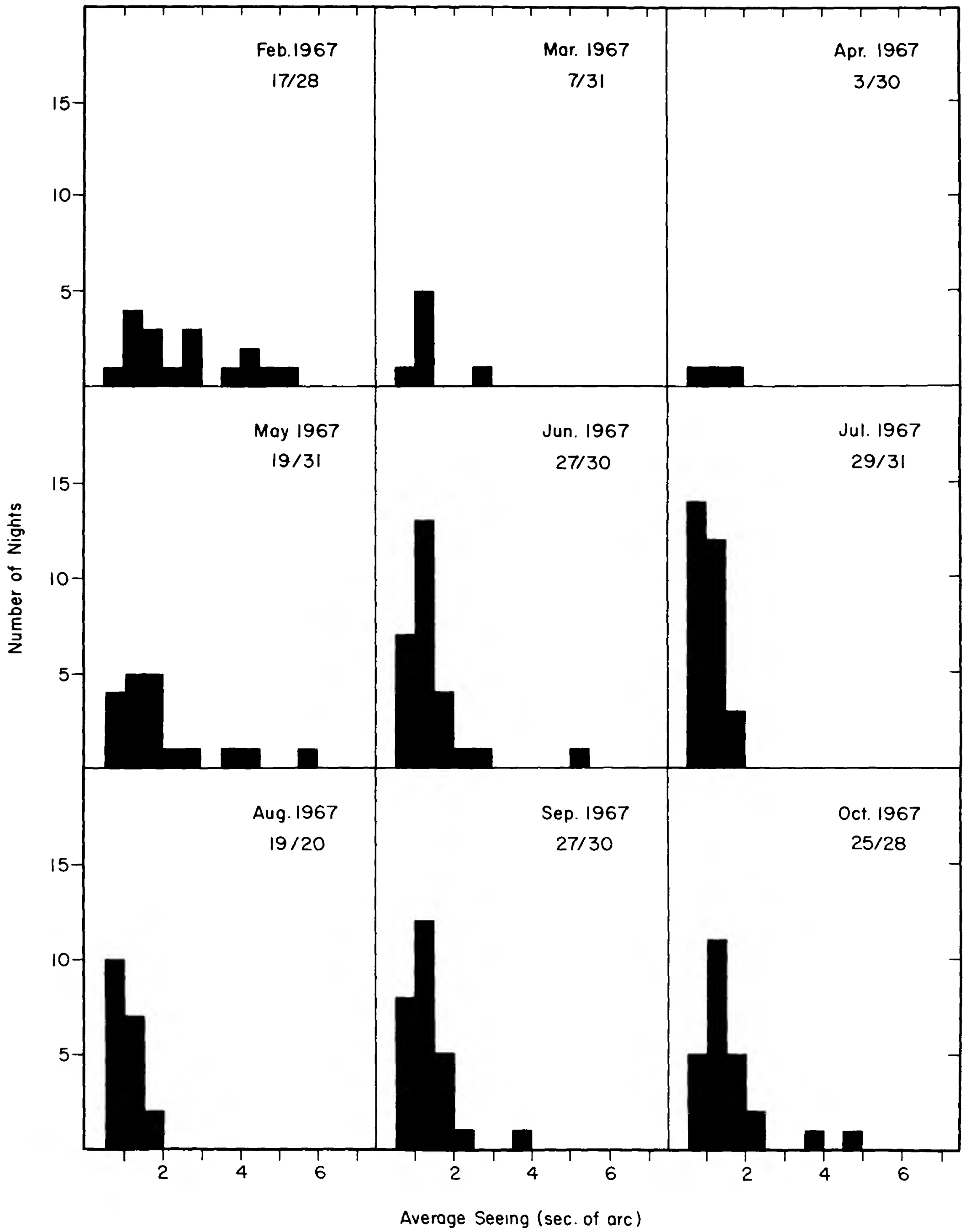

Fig. 6 — Frequency distributions of average nightly seeing observed at Junipero Serra Peak. Ordinate, abscissa, and notation as in Figure 4.

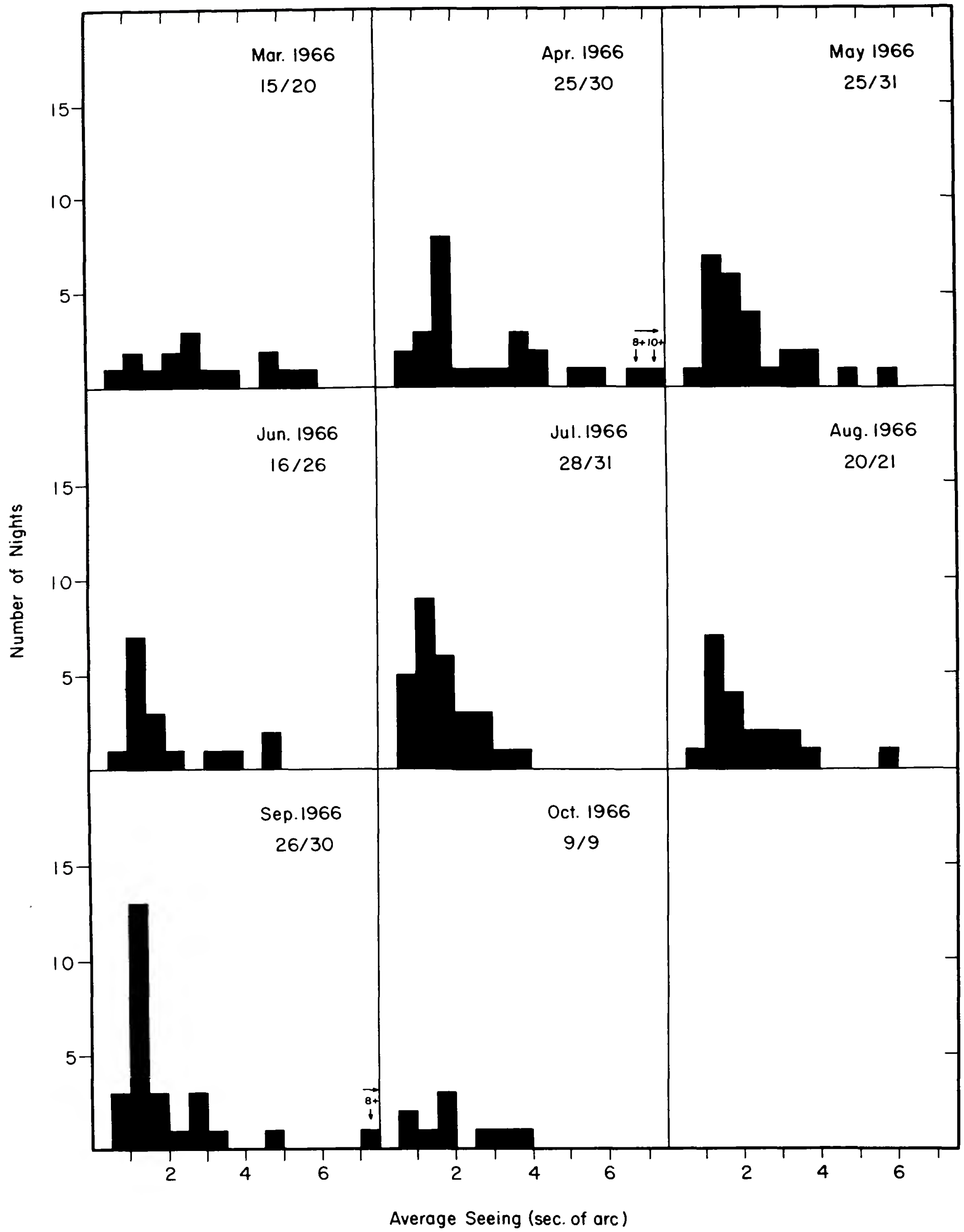

FIG. 7—Frequency distributions of average nightly seeing observed at Piper Mountain. Ordinate, abscissa, and notation as in Figure 4.

All available seeing observations were averaged to give the average seeing for the night at the particular site. Histograms for each month showing the frequency of nights with different average nightly seeing at Junipero Serra Peak and Piper Mountain are reproduced in Figures 4, 5, 6, and 7. The fractions given for each month indicate in the numerator, the number of nights on which some Polaris observations were made, and in the denominator, the number of nights when an observer was present on the site, ready to observe if conditions permitted. Inspection of the histograms shows that while good seeing occurs at both sites, it is much more frequent at Junipero Serra Peak. The best seeing observed at Piper Mountain was 0.″75. The best seeing at Junipero Serra Peak was considerably better than this, but since no standards for seeing better than 0.″75 are available, it is not possible to say how much better. In the reductions, it has been assumed that these best observations lie somewhere between 0.″5 and 0.″7.

The seeing observations at Junipero Serra Peak, Mount Hamilton, and Piper Mountain are further summarized in Table VI, which gives the number of nights per year with seeing in the indicated ranges. The observations for Mount Hamilton are based on the average seeing for the night reported by the observers using the 120-inch telescope. As discussed earlier (Harlan and Walker 1965), these observations are not too reliable, due to (1) the fact that the estimates were originally made on a number system of 1–5 which is subjective and differs from one observer to another, and (2) to the fact that seeing estimates at the prime focus are less reliable than those at the coudé, owing to the smaller scale. Thus, it is not certain that the seeing observations from Mount Hamilton are on the same system, or have the same accuracy as those from Junipero Serra Peak and Piper Mountain, and some caution must be exercised in comparing them with the values from the other sites.

Simultaneous observations were obtained at Cone Peak on a total of 17 nights in August and September 1967. These observations indicate that during the periods of observation, the seeing was essentially the same at the two sites, the average image diameter being 0.″3 larger at Cone Peak than at Junipero Serra Peak.

Simultaneous seeing observations on top of Junipero Serra Peak and at the site on the southeast ridge at 5500 feet altitude were obtained on 38 nights in June and July 1967, and on the peak and at

TABLE VI

NUMBER OF NIGHTS PER YEAR WITH INDICATED AVERAGE SEEING

	JUNIPERO SERRA PEAK				PIPER MOUNTAIN				MT. HAMILTON†			
YEAR	≤1".0	1".1 to 1".5	1".6 to 2".0	TOTAL NO. OF NIGHTS*	≤1".0	1".1 to 1".5	1".6 to 2".0	TOTAL NO. OF NIGHTS*	≤1".0	1".1 to 1".5	1".6 to 2".0	TOTAL NO. OF NIGHTS*
1965	14	32	10	80					1	11	16	77
1966	76	102	38	289	15	49	32	164	14	51	53	285
1967	53	77	26	189					15	50	24	182

*When readings were taken

†During those time intervals when an observer was present on Junipero Serra

the site at 5465 feet altitude on 23 nights in October 1967. At the 5500-foot station, the seeing was almost the same as on top of the peak, the average image diameter being 0."3 larger at the lower site. At the 5465-foot station, the seeing was decidedly poorer, the average image diameter being 1."1 larger than on the peak.

Observations of the seeing simultaneously with those at Piper Mountain were obtained at Hunter Mountain during two intervals totaling ten nights in May 1966. On these nights, the average seeing was the same at both sites; the average image diameter at Hunter Mountain was 0."1 less than at Piper Mountain.

C. *Daytime Sky Transparency at Junipero Serra Peak*

At Junipero Serra Peak, the daytime transparency was measured by observing the sky brightness with a Visual Sky Photometer (VSP No. 3) belonging to the Sacramento Peak Observatory. This photometer compares the brightness of the sky at a small angle from the sun to the brightness of the solar disk, and is similar to that described by Evans (1948), except that in the present instrument the internal occulting disk has a diameter of 0.0124 radian, and certain of the other dimensions are slightly different. According to Dr. Evans (1970) the sky is dark, or transparent, enough for coronal observations if the brightness measured with this type of photometer is less than 200×10^{-6} that of the solar disk, good if less than 100, and excellent if less than 50. Observations of this type were made at Mount Hamilton about 1950, at which time the sky brightness was $< 50 \times 10^{-6}$ on a good fraction of the days (Evans 1970). At Sacramento Peak, a brightness of $< 20 \times 10^{-6}$ is observed on about 30 days per year (Evans 1970).

The observations at Junipero Serra Peak are summarized in Table VII, which lists the date, the number of days each month on which observations were obtained, and the number of days when the sky brightness observed at approximately 09:00 or 10:00 PST was $\leqslant 200 \times 10^{-6}$, $\leqslant 100 \times 10^{-6}$, $\leqslant 50 \times 10^{-6}$, and $\leqslant 25 \times 10^{-6}$ that of the solar disk. The morning observations have been used as these are more nearly representative of nighttime conditions; the sky brightness usually increases later in the day as the level of the haze layer rises. The darkest sky observed at Junipero Serra Peak was 11×10^{-6}, measured at 14:00 PST on November 2, 1965.

TABLE VII

DAYTIME SKY BRIGHTNESS AT JUNIPERO SERRA PEAK*

Date	No. Days Observed*	Brightness in Units of the Solar Disk x 10^{-6} ≤200	≤100	≤50	≤25
1965					
Aug	3	2	2	0	0
Sep	8	8	7	4	0
Oct	25	22	21	14	4
Nov	9	8	8	5	2
Dec	9	8	6	3	1
1966					
Jan	19	15	15	11	2
Feb	12	11	11	11	4
Mar	16	9	7	3	0
Apr	20	16	7	0	0
May	22	19	5	1	0
Jun	26	24	20	12	3
Jul	27	27	24	21	7
Aug	28	28	28	23	16
Sep	26	24	18	15	7
Oct	26	26	22	16	10
Nov	12	12	11	9	3
Dec	16	16	16	15	1
1967					
Jan	17	16	15	13	0
Feb	14	13	12	7	1
Mar	7	7	6	5	0
Apr	0	0	0	0	0
May	21	19	12	6	0
Jun	21	21	8	1	0
Jul	24	23	18	12	7
Aug	17	16	10	4	1
Sep	18	18	8	1	0
Oct	22	22	18	11	5

*Based on observations at 09:00 or 10:00 AM PST.

D. *Daytime Sky Brightness at the Other Sites*

Estimates of the daytime sky brightness were made at all sites by occulting the disk of the sun and noting visually the absence or presence and extent of a halo of scattered light around the sun. Using this method, no brightening of the sky around the sun is observed when the sky is of excellent coronal quality. Unfortunately, these visual estimates varied considerably from one observer to another, so that no quantitative conclusions were possible. It appears, however, that the daytime sky brightness conditions at Cone Peak are similar to those at Junipero Serra Peak; while at Piper Mountain and Hunter Mountain, the daytime sky brightness conditions are good, but probably not as good as at Junipero Serra

Peak, probably due to smog, as discussed in Section I, and to dust carried up from the desert floor by convection.

E. *Nighttime Sky Brightness*

A few observations of the brightness of the night sky with no moon were made at Junipero Serra Peak, Mount Hamilton, Piper Mountain, Hunter Mountain, Santa Rosa Peak, Palomar Mountain, and Mount Pinos using photoelectric night-sky photometers designed by Dr. Whitford. These instruments consisted of short-focus three-inch aperture refractors with photoelectric photometers mounted at their foci. The photometers were equipped with color filters and with focal-plane diaphragms whose openings corresponded to one square degree on the sky. The night sky and the night sky plus a suitable bright star of known magnitude were then observed alternately through this diaphragm, using yellow and blue filters. In reducing the observations, the observed deflection of the sky was compared with that of the star, the magnitude of the star being taken as the catalog value of the star's brightness for no atmosphere diminished by the extinction at the time of observation, calculated using mean extinction coefficients. The resulting values of the sky brightness, in magnitudes per square second of arc, are approximately on the *B*, *V* system of Johnson and Morgan (1953).

Values representative of average good conditions at the principal sites in 1966 are given in Table VIII. Examination of the original observations indicates that there is little difference between Piper Mountain and Hunter Mountain, both of which are located very far from any significant sources of light. However, the sky at both of these sites appears to be significantly brighter than at Junipero Serra Peak. This difference could result either from auroral effects during the observations at Piper and Hunter Mountains, or from differences in the reflection of starlight from the earth's surface. Piper and Hunter Mountains are surrounded by extensive areas of light-colored rock and sand, while Junipero Serra Peak is surrounded by a dark forested area and by the dark surface of the sea. Thus, the lower albedo of the surface near Junipero Serra Peak, together with the somewhat greater transparency of the air, could cause less light to be reflected and a darker sky even though Junipero Serra Peak is nearer to sources of lights than are the sites in the trans-Sierra region.

TABLE VIII

REPRESENTATIVE VALUES OF THE NIGHT SKY BRIGHTNESS IN 1966

Site	Sky Brightness, mag./sq. sec. of arc V	B	Zenith Distance (deg)	Direction
Mount Hamilton				
a) San Jose clear	20.8	21.9	48	NW
	21.3	22.2	40	SE
b) San Jose fogged over	21.4	22.5	30	N
Piper Mountain	21.6	22.6	25	NE
Hunter Mountain	21.4	22.6	25	NNE
Junipero Serra	21.9	23.0	35	NW

One series of sky brightness observations of particular interest is shown in Table IX. These observations were made on nearly successive nights at Santa Rosa Peak (8056 feet), Mount Palomar (High Point, 6138 feet), Mount Pinos (8856 feet), and Junipero Serra Peak (5862 feet). The observations were made at the same time of night in each case, and thus represent about as good a comparison of sky brightness conditions on the different peaks as can be obtained without an extensive program of simultaneous measurements. This series of measures shows the effect of the illumination produced by the various centers of population surrounding the different sites, and they give an idea of the validity of the sky brightness limits on the map in Figure 2. The observations at Junipero Serra Peak toward the east and southeast are probably representative of conditions at a completely dark site. They indicate that even with no artificial lights, the sky brightens about $0^m.5$ in *B* and $0^m.8$ in *V* as one goes from the zenith to the horizon. Comparing these observations with those in other directions and at the other sites, the effects of the city lights are easily seen. The observations at Mount Palomar show the equality of the illuminations from Los Angeles and San Diego, discussed earlier, and indicate that the zenith sky is about $0^m.1$ brighter than at Junipero Serra Peak, while at a zenith distance of 45° towards the light sources it is about $0^m.2$ brighter. At Santa Rosa Peak, which is outside the circle in Figure 2, the zenith sky is darker than at Mount Palomar, but brighter than at Mount Pinos, which is inside the circle. This difference could be due either to differences in the albedos of the surfaces surrounding the peaks, or to the fact

TABLE IX
OBSERVATIONS OF NIGHT SKY BRIGHTNESS

Santa Rosa*

Zenith Dist. (deg.)	Dir.	Sky Brightness† Mag./Sq. Sec. V	B
12	NW	21.93	22.94
22	W	21.93	22.94
23	W	21.93	22.94
31.5	NW	21.85	22.86
56	N	21.54	22.58
60	WNW	21.34	22.53
73	ENE	21.25	22.36
73	SE	21.21	22.36
84	W	20.79	22.27
84	WNW	19.82	21.56
84	NW	20.04	21.66
86.5	SSW	20.08	21.77
88.5	WNW	18.82	21.06

Palomar* (High Point)

Zenith Dist. (deg.)	Dir.	Sky Brightness† Mag./Sq. Sec. V	B
12	W	21.88	22.89
22.5	W	21.80	22.85
25	W	21.80	22.85
30	NW	21.80	22.89
32	NW	21.73	22.81
45	NW	21.67	22.73
56	N	21.49	22.53
60	E	21.38	22.48
60	W	21.24	22.42
60	NW	21.29	22.48
72	ENE	21.24	22.42
72.5	ENE	21.20	22.42
73	SE	21.13	22.27
84	SSW	19.87	21.33
84	NW	19.70	21.32
86.5	SSW	19.62	21.21

Pinos*

Zenith Dist. (deg.)	Dir.	Sky Brightness† Mag./Sq. Sec. V	B
12	NW	21.96	22.97
23	W	21.96	22.97
24	W	21.92	22.97
31	NW	21.88	22.89
36	SE	21.49	22.53
45	SE	21.16	22.27
56	N	21.60	22.73
60	NE	21.43	22.51
60	E	21.34	22.48
60	SE	21.05	22.17
60	W	21.49	22.53
73	ENE	21.29	22.45
75	ENE	20.98	22.31
84	NNE	20.74	22.06
84	SE	20.50	22.09
84	S	20.43	21.87
84	SW	21.01	22.36
84	NW	20.88	22.17
86.5	NNE	20.56	21.94
86.5	SE	19.93	21.61
86.5	S	20.38	21.84
86.5	SW	20.98	22.42

Junipero Serra*

Zenith Dist. (deg.)	Dir.	Sky Brightness† Mag./Sq. Sec. V	B
12	NW	21.96	22.97
25	W	21.92	22.97
26	WNW	21.88	22.89
29.5	NNW	21.88	22.89
30	NNW	21.96	23.07
33.5	W	21.92	22.93
45	NNW	21.88	22.89
56	N	21.60	22.66
60	E	21.49	22.60
60	W	21.43	22.53
60	NNW	21.43	22.60
70	E	21.34	22.51
72	E	21.32	22.51
84	ESE	21.16	22.53
84	SE	21.13	22.53
84	NNW	20.36	21.94
84	NNW	20.54	22.09
86.5	NNW	20.15	21.87

*Dates of Observations:

Santa Rosa = 1966 July 14/15
Palomar = 1966 July 16/17
Pinos = 1966 July 17/18
Junipero Serra = 1966 July 19/20

All Observations Made Between 9:15 and 10:00 PM, PST.

†Sources of Sky Illumination:

Santa Rosa: SSW = San Diego; WNW = Los Angeles

Palomar: SSW = San Diego; NW = Los Angeles

Pinos: NNE = Bakersfield; SE = Los Angeles; S = Ventura; SW = Santa Barbara

Junipero Serra: E = King City + Fresno; SE = Paso Robles; NNW = Salinas that the Santa Rosa Peak is often under the smog layer while Mount Pinos is upwind from the smog generated in the Los Angeles basin. In general, the sky is brightened more in *V* than in *B* by the city lights, and it is interesting to note that at Junipero Serra Peak, the lights of Paso Robles (population 6677) are just detectable in *V* at a zenith distance of 84°, even though that city is some 60 miles distant. Visually, the lights of Paso Robles are readily seen as a very faint glow on the horizon. Thus, visual inspection of the horizon at a site is a very sensitive test for artificial sky illumination.

III. Conclusions

The results of the survey appear to support the hypothesis that the best astronomical seeing occurs very near the coast where one has an undisturbed air flow off the ocean and where the cold ocean current lowers the height of the inversion layer. Inspection of the seeing histograms in Figures 4, 5, 6, and 7 reveals a marked superiority of the seeing at Junipero Serra Peak over that at Piper Mountain. Since the seeing at Hunter Mountain was essentially the same as at Piper Mountain during the periods of observation, there is no evidence that the observations at Piper Mountain are not fairly representative of conditions to be found in the trans-Sierra region. As indicated in Table VI, the seeing at Mount Hamilton was somewhat poorer than at Junipero Serra Peak, although the exact difference is uncertain, as discussed above. This difference suggests that the zone of best seeing along the coast may be quite narrow, and that Mount Hamilton is already too far inland and/or at too low an altitude to be in this zone.

The tests at Cone Peak indicate that no improvement in the seeing resulted from observing on a peak that was closer to the coastline than Junipero Serra Peak and that had a very sharp profile. The tests at the secondary locations on Junipero Serra Peak indicate the desirability of locating telescopes on or near the top of the peak; the seeing was about the same or slightly worse at the 5500-foot staion, but quite definitely worse at the 5465-foot site.

Atmospheric transparency is very good at Junipero Serra Peak, and probably Cone Peak, a large number of the days being of "coronal" quality, as shown in Table VII. Transparency at Piper Mountain is also good, but not as good, due to smog and dust, as discussed above.

Wind velocities at Junipero Serra Peak are significantly lower than at Piper Mountain.

Comparison of Tables IV and V indicates that Junipero Serra Peak tends to have more observing hours than Piper Mountain only during June, July, and August. Table III indicates that in general the trans-Sierra desert peaks have less cloudy weather during the fall, winter, and spring than does Junipero Serra Peak.

Cloud conditions at Junipero Serra Peak are slightly better than at Mount Hamilton, as shown in Table VI. Junipero Serra Peak is just enough further south that several nights per year are clear at that site when Mount Hamilton is under the extreme southern edge of a more northerly storm.

Of the sites tested, Junipero Serra Peak is clearly the best. Cone Peak is probably comparable in quality, but lacks the large amount of space (about 10 acres) available on the top of Junipero Serra Peak. In time, sky illumination could be a problem if a very large population growth occurs in the Salinas valley near King City. Fortunately, both sites are well protected against growth of lights to the south and west by the rugged nature of the terrain, and both are likely to remain upwind from sources of smog, so that the atmospheric transparency should remain quite good.

On the basis of what was learned during the survey concerning seeing, transparency, cloud cover, and smog flow, it seems likely that good sites may exist in the mountains northwest of Santa Barbara. However, these sites lie further from the ocean and are less well protected against eventual sky illumination than are Junipero Serra Peak and Cone Peak.

Finally, the survey indicates that while trans-Sierra sites such as Piper Mountain are inferior to coastal sites such as Junipero Serra Peak, they are nevertheless of sufficiently high quality to be of interest at some future time as alternatives to sites along the coast when these are fully occupied or if their quality should deteriorate due to the growth of city lights.

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