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THE SEASONAL VARIATION OF NIGHTGLOW NaI 5890–96 A, (OI) 5577 A AND (OI) 6300 A IN THE TROPICS

L. L. SMITH and R. W. OWEN

U. S. DEPARTMENT OF COMMERCE
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THE SEASONAL VARIATION OF NIGHTGLOW NaI 5890-96 A, [OI] 5577 A AND [OI] 6300 A IN THE TROPICS

by

L. L. Smith and R. W. Owen

A study is presented of one year (July 1961-July 1962) of systematic zenith observations of the nightglow emissions [OI] 5577A, [OI] 6300A, and NaI 5890-96A at the Haleakala Observatory (latitude N 20.7°). Observed seasonal variations are shown and compared with previous investigations.

Key Words: Nightglow, Seasonal, Zenith, [OI] 5577A, [OI] 6300A, NaI 5890-96 A.

I. INTRODUCTION

During the year July 1961 to July 1962, airglow data were obtained on Mount Haleakala (altitude 10,000 feet A.S.L., geographic latitude N 20°.7, and longitude W 156°.3) through the cooperative efforts of the National Bureau of Standards, Boulder, Colorado, and the Hawaii Institute of Geophysics of the University of Hawaii, Honolulu, Hawaii. A photometer having a built-in, absolutely calibrated standard light monitored the zenith sky brightness using interference filters centered on 5300, 5577, 5893, and 6300 A [Purdy, Megill, and Roach, 1961].

II. OBSERVATIONS

Observations were made on moonless nights with skies of photometric quality between astronomical twilight and astronomical dawn during each lunation for a two-week period centered on the date of new moon. A total of 128 nights of useful data was obtained during the year July 1961 to July 1962.

The method of operation of the photometer is fully described by Purdy, Megill and Roach [1961]. Figure 1 is an illustration of the strip chart recording from the zenith photometer.

III. CALIBRATION AND DATA REDUCTION

The calibration of the recordings from the turret photometer requires a determination of the absolute brightness of the standard source. The data reduction involves a method for the elimination of the background contaminations in the 5577, 5893, and 6300 A filters.

The absolute calibration of the standard source in the turret photometer was obtained by comparison with a laboratory-calibrated standard source, as described by Smith and Alexander [1963]. The two-color method [Roach and Meinel, 1955] was used to eliminate the background contamination from the turret emission line filters by the equation:

$$R = [(DE - F \cdot DC) \cdot W \cdot I \cdot O] / T, \qquad (1)$$

where R is the emission line intensity in rayleighs,

DE is the ratio of sky reading to standard light reading of the emission filter,

DC is the ratio of sky reading to standard light reading of the 5300 A background filter,

F^* is the factor to be multiplied by DC to determine the background to be subtracted from DE,

W is the 100% equivalent transmission of the filter in angstroms,

I is the absolute brightness of the standard light in rayleighs per angstrom,

O is the correction factor to refer the reading inside the earth's atmosphere to outside the earth's atmosphere,

and T^{**} is the transmission of the interference filter DE at the wavelength of the emission line.

The two-color reduction method to eliminate the background intensities (airglow continuum, zodiacal light, and starlight) must be considered only as an approximate technique. The contamination of the

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*The F factor was computed by taking the ratio of the brightness of the standard light for the control filter to the brightness for the emission filter [Davis and Smith, 1964].

**For the sodium filter which includes both wavelengths of the doublet (5890-96 A), allowance was made for a relative intensity difference between the 5890 and 5896 A lines of two-to-one.

observations, due to the OH band emissions, the assumption that the background co-varies from 5300 through the 6300 A wavelength region, the uncertainties in the corrections for the extinction and scattering of the earth's atmosphere, and the uncertainty in the absolute calibration of the standard source contribute to the inaccuracy of the reduction method. However, over the past few years, this method has been significantly improved through the availability of extremely narrow band interference filters and low noise - high sensitivity photomultiplier tubes and through the improvements achieved in calibrating low light level sources.* Table 1 is a summary of the constants used for the reduction of the turret photometer observations by (1) for the observing period during the month of September, 1961. A change in the I and F constants of (1) was necessary from one observing period to the next due to the deterioration of the radium isolite source [Smith and Alexander, 1963]. The average luminosity deterioration of the isolite source at the four wavelengths utilized in this study was 8 percent for the year, and to a first approximation, the F's remained constant since they were computed by taking ratios of the luminosity of the isolite source. The total effect upon R in (1) if allowance had not been made for the luminosity deterioration of the isolite source would have resulted in the computed intensities at the end of the year being too low by approximately 10 percent.

Tables 2, 3, and 4 include the hourly average reduced zenith intensities from the two-color reduction method for [OI] 5577 A, NaI 5890-96 A, and [OI] 6300 A emission lines in rayleighs, the extreme values, and the average value for each night and for each standard time of the observing period. The negative intensities in table 3 result from the low intensity of the 5890-96 A emission and the inaccuracy of the two-color reduction method. The background intensities from the 5300 A filter for the turret photometer have been previously published [Roach and Smith, 1964].

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*A study of the two-color reduction method and its limitations has been made by Davis and Smith [1964].

IV. ANALYSIS AND INTERPRETATION

A first approach in the analysis of the data of tables 2, 3, and 4 for seasonal effects is simply to plot the zenith intensities as a function of the date during the calendar year. Figure 2 is a plot of the average zenith intensities, the probable errors* and the extreme values for each observing period for NaI 5890-96 A, [OI] 5577 A, and [OI] 6300 A. Maxima in May and October for [OI] 5577 A, May and November for NaI 5890-96 A, and in October for [OI] 6300 A of figure 2 are quite pronounced. Table 5, based on the averages for each observing period, gives the least-squares solutions (treating each emission as equally independent) for the covariance of the three emissions, assuming a linear relationship.

A useful technique for combining seasonal and diurnal variations of the emissions is shown in figures 3, 4, and 5 for 5577, 5890-96, and 6300 A emissions, respectively. The 5577 A emission (fig. 3) exhibits a well-defined maximum in May, and a broader maximum extends over the observing periods of September, October, and November. The maximum of the 5577 A emission in May occurs in the evening hours and the fall maximum near midnight. The diurnal variations (fig. 3) display the following: (1) The maximum is at the beginning of the night (May, June, and December), (2) the maximum is near local midnight (July, August, September, and November), and (3) the maximum is at the end of the night (January, February, March, April, and October).

The 5890-96 A emission (fig. 4) has a definite seasonal maximum at the November observing period and a broader maximum including the April and May observing periods. The November seasonal maximum takes place during the early evening hours, and the April-May maximum near and after midnight. Two types of diurnal variations are apparent for the 5890-96 A emission: (1) a maximum at the beginning of the night (June,

*The probable error computation in this study is used as a convenient method to express the intensity fluctuations about the mean and does not infer "errors" in the measurement of the mean.

November, and December) and (2) a maximum at the end of the night (March, April, August, and September). For January, February, May, July, and October no distinct maximum is ncted.

The 6300 A emission (fig. 5) has a well-defined seasonal maximum during the October observing period occurring during the early evening hours. For the other observing periods, the maximum is also at the beginning of the night probably due to the post-twilight effect.

It is interesting to note that characteristic diurnal variations seem to be associated with the seasonal maximums. In figure 4, for 5890-96 A, the diurnal maximum at the end of the night appears as both seasonal maximums are approached and, in figure 3, 5577 A does likewise for the spring maximum. The diurnal maximums at the beginning of the night occur for 5577 and 5890-96 A when both seasonal maximums have been reached and a decrease in intensity begins. The 5577 and 5890-96 A diurnal variations for the months December, 1961, and January, February, March, and April, 1962, are similar. The correlation coefficient for the linear least square solution based on the hourly averages of each of the five observing periods is 0.84. In figures 4 and 5, the diurnal maximum near local midnight takes place for 5577 and 6300 A as the fall maximum is approached.

The annual average diurnal variation and the probable errors for the three emissions are given in figure 6. The probable errors in figure 6 for all three emissions are very large. The 5577 A annual diurnal variation result suggests a broad maximum centered near midnight, but as has been noted from figure 3, this is representative of only 4 observing periods of the calendar year. The 5890-96 A annual diurnal variation exhibits no significant variations, but in figure 4 there definitely is evidence of diurnal variations as has been discussed. Obviously, there is no single type of diurnal variation for 5577 A and 5890-96 A emissions which is representative for a period of one year. The post-twilight effect of the 6300 A emission is apparent in figure 6 and is present during the entire year.

The average intensity of 5890-96 A and 6300 A relative to 5577 A is

$$5577 : 6300 : 5893 = 1 : 0.39 : 0.22.$$

Figure 7 displays the ratios of monthly average intensity of 5890-96 A and 6300 A relative to 5577 A.

Chamberlain [1961] discusses airglow annual variations and makes the following summary statements describing the results of several investigators:

(1) For 5577 A it is most difficult to establish a yearly variation due to the night-to-night fluctuations and the apparent sensitivity of any yearly variation if it does exist upon the latitude of the observations.

(2) The 6300 A emission probably possesses very little seasonal variation after post-twilight and pre-dawn effects are eliminated. It seems likely that earlier results which reported a maximum in winter and minimum in summer were contaminated in various degrees by OH.

(3) Several observers have found for NaI 5890-96 A a maximum in winter and a minimum in summer similar to the seasonal variation of NaI 5890-96 A in the twilight airglow. However, the OH contamination is also serious for these measurements at 5893 A.

Roach [1955] gives a review of observational results in airglow photometry. A part of this publication is a summary of the seasonal behavior of [OI] 5577 A, [OI] 6300 A, and NaI 5890-96 A emissions from two important investigations at mid latitudes [Pettit, et al., 1954, and Dufay and Tcheng Mao-lin, 1946 and 1947]. Figure 8 includes the monthly average values, the probable errors, and the extreme values for 5577, 5890-96, and 6300 A emissions from the study by Pettit, et al. [1954] at the Cactus Peak Observatory (geographic latitude 36°N) for the period from November 1948 to March 1954. Figure 9 is the comparison by Roach [1955] of the smoothed results of Pettit, et al. [1954] (CP) with the results of Dufay and Tcheng Mao-lin [1946] and [1947] for the period 1941-1943 at Haute Provence (HP) (geographic latitude 44°N) normalized to the Cactus Peak results.

Roach [1955] summarizes the seasonal results of Pettit, et al. [1954] as follows:

(1) For 5577 A the sporadic variations of intensity are so great as to cast doubt on the reality of any seasonal variation. If a straight line representing the overall mean intensity (259) is drawn through the 5577 A plot of figure 8, it departs only very slightly from the shaded portion in three parts of the plot in March, September, and December, corresponding to a minimum, maximum, and minimum, respectively.

(2) In the case of 5893 A (NaD), the seasonal variation is well established with a maximum in November and minimum in July.

(3) The 6300 A emission shows a seasonal variation roughly similar to that of NaD, but with smaller amplitude.

(4) The seasonal variation of CP and HP are strikingly similar.

It is apparent from these reviews by Roach [1955] and by Chamberlain [1961] that it is difficult to determine seasonal trends from photometric observations, since considerable night-to-night fluctuations tend to obscure seasonal variations and the spectral purity of the deduced emission intensities is in question due to the OH contaminations. Also, care must be taken in comparing results from other investigations because of the possible latitude dependency of the seasonal trends.

Probable errors and extreme values have been given in this study to substantiate our described trends. The seasonal variations, from our results, are within the probable error of each of the emission's night-to-night fluctuations. However, the annual average diurnal variations of this study for 5577 and 5890-96 A are not representative of even the monthly average diurnal variations. The 6300 A annual average diurnal post-twilight characteristic unquestionably is a general feature of its diurnal variations, but any other maximum is a function of the season.

The OH contaminations of deduced emission intensities from photometric data have been treated quantitatively by Roach [1963] and Davis and Smith [1964]. The 5577, 5890-96, and 6300 A emissions can be significantly contaminated by the OH bands (7 - 1), (8 - 2), and (9 - 3) with the band heads near 5562, 5886, and 6256 A. Krassovsky, Shefov, and Yarin [1962] give estimates of the mean zenith intensities for the OH bands (7 - 1), (8 - 2), and (9 - 3) as 20, 60, and 140 rayleighs, respectively. Also, they tabulated the relative intensities for the R, Q, and P branch lines for the OH bands. An estimate of the OH contaminations for the three airglow emissions under consideration was determined by utilizing these absolute intensities for the OH bands, the relative intensities for the Q branch at the Q_1 and Q_2 lines, for the R branch at the peak line, and for the P_1 and P_2 branch lines, and the transmission characteristics of the interference filters. The OH contamination computed in this way was 5, 7, and 17 rayleighs for the 5577, 5890-96, and 6300 A emission data, respectively. According to Bates [1960] and Chamberlain [1961], several investigators have found little or no seasonal variation in the OH emission intensities. However, night-to-night variations may occur by as much as a factor of two. Since the annual average deduced intensity of 5577, 5890-96, and 6300 A was approximately 190, 40, and 70 rayleighs, the OH contamination at these wavelengths could be, on average, 3 percent for 5577 A, 18 percent for 5890-96 A, and 24 percent for 6300 A. The 5890-96 and 6300 A contaminations are serious for the low intensities, but it is not likely that the contaminations could have seriously affected the seasonal trends indicated in figure 2 since the maximums are several times larger than the minimum intensities. It is the opinion of the authors based upon the above discussion that the seasonal variations described from figures 2, 3, 4, and 5 for the three emissions are valid.

The airglow data reported in the IGY Annals, Volume 24 (1962) includes 5577, 5890-96, and 6300 A data for the calendar year 1958 at Tamanrasset (geographic latitude 22.8°N) which provides additional information for seasonal variations in the tropics. Figure 10 shows the average monthly intensities for 5577, 5890-96, and 6300 A emissions at Tamanrasset for the calendar year 1958 and the results of this study. The Tamanrasset observations were obtained in the direction of the celestial pole and referred to the zenith. Consequently, assuming a height of

100 km for the 5577 and 5890-96 A emissions, the observations would be for an effective geographic latitude of 25°N and geomagnetic latitude 27°N and assuming a height of 300 km for the 6300 A emission gives an effective geographic latitude of 28°N and geomagnetic latitude of 31°N. The agreement is very good between the seasonal variation at the two tropical stations, Tamanrasset and Haleakala, for 5577 and 5890-96 A emissions. However, the Tamanrasset seasonal variation for the 6300 A emission is not similar to the results of this study. Figure 11 shows the good agreement between the mean diurnal variation of Tamanrasset for the year 1958 and the mean diurnal variations of this study (1961-62) for the three emissions.

In comparing the absolute intensities of one station with another, it is difficult to rationalize the agreement as real or as a coincidence. Each station's absolute intensities may be significantly affected by errors in the absolute calibration, different geographic or geomagnetic positions or because the data were obtained at different epochs of the solar sunspot cycle. Table 6 summarizes the information that may be pertinent to this study for the two mid-latitude and two tropical stations being considered.

One similarity in the seasonal variation of the three emissions at all four stations is an apparent fall maximum. The tropical seasonal variation for 5577 and 5890-96 A emissions exhibits a spring maximum which is not conspicuous in the mid-latitude results. The 6300 A emission seasonal variation in the mid-latitude stations suggests a minimum in summer and maximum in winter. The Tamanrasset tropical station also indicates a winter seasonal maximum and summer minimum, but the contrast is much more pronounced than the mid-latitude results. The Haleakala tropical station indicates only a fall maximum for the 6300 A emission. Possibly the difference in the two tropical stations for the 6300 A emission is because the data from Tamanrasset were obtained near sunspot minimum.

The mean diurnal variations for the tropical stations are similar. Both tropical stations indicate a second broad maximum for the 6300 A emission after local midnight. This tropical 6300 A emission maximum in the mean diurnal variation after the post-twilight effect is due to the tropical 6300 A emission activity observed and reported by several investigators [Barbier, Weill, and Fafiotte, 1961; Roach, Steiger, and Brown, 1964; and Davis and Smith, 1964]. For the Haleakala station, it has been shown to be associated with the equatorial (geomagnetic) anomaly in the ionosphere [Roach, Steiger, and Brown, 1964].

V. SUMMARY

During the year July 1961 to July 1962, at the Haleakala Observatory, evidence from this study suggests that the tropical [OI] 5577 A, [OI] 6300 A, and NaI 5890-96 A emissions exhibited seasonal variations. All three emissions indicate maximums in the fall and the 5577 A and 5890-96 A emissions suggest maximums also in the spring. From the comparison of the results of this study and those from Tamanrasset with the mid-latitude results from Haute Provence and Cactus Peak, it appears that the fall maximums are not dependent upon geographic latitude but the spring maximums for 5577 and 5890-96 A emissions do appear to be only a tropical phenomenon.

The covariance in the seasonal trends of the three emissions, table 5, seems to be statistically significant and due primarily to the common fall maximum. However, it is difficult to rationalize a physical significance in the statistical covariance of table 5 between the three emissions. A possible explanation could be that the atomic oxygen abundance at heights from approximately 80 to 300 km covary, on a gross scale, with season. Reactions involving atomic oxygen [Chamberlain, 1961] could then result in emissions at these three wavelengths. The NaI 5890-96 A emission seasonal variation is very similar to that found by other observers, and there is little doubt that the fall maximum is a common feature reported by almost everyone who has monitored this emission in the northern hemisphere, regardless of the observer's latitude. The spring maximum found by this study and indicated in the Tamanrasset results, however, may have a latitude dependence since the mid-latitude stations considered did not have this second maximum.

The apparent seasonal diurnal dependency for 5577 A and 5890-96 A is an interesting result of this study. The 5577 A and 5890-96 A high correlation coefficient in the covariance of the hourly averages for observing periods December 1961 through April 1962 could be significant because this suggests a common effect somewhere in the chain of events which ultimately results in the emission at these wavelengths.

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Table 1

Summary of the constants used for the reduction of the turret photometer by (1) for the observing period in September, 1961

Filter	F	W	I	O	T
5300	--	--	8.93	1.053	--
5577	1.83	29.4	4.88	1.038	0.640
5890-96	6.08	15.5	1.47	1.047	0.375-0.607
6300	24.8	25.5	0.36	1.033	0.695

Table 2

The hourly average reduced zenith intensities from the two-color reduction method, the extreme values and the average values for each night and for each standard time of the observing period for [OI] 5577 A

Date	Haleakala Standard Time										Minimum	Maximum	Nightly
	20	21	22	23	00	01	02	03	04	05	Value	Value	Average
1961													
July 18/19						179	144	131	109		109	179	141
19/20						273	203	129	88		88	273	173
20/21						251	290	215			215	290	252
Aug. 2/3		176	157	127							127	176	153
3/4		166	164	146	144						144	166	155
5/6		220	215	224	262	241	228				215	262	232
6/7			137	165	211	212	178				137	212	181
7/8			133	154	167	163	174	144			133	174	156
9/10				260	282	296	253	198			198	296	258
10/11		242	264	212	244	238	197	170	112		112	264	210
11/12			159	195	251	284	288	213	134		134	288	218
12/13		192	163	157	188	237	220	165	98		98	237	178
13/14		138	91	102	105	137	199	216	133		91	216	140
14/15				170	178	222	258				170	258	207
15/16				166		277	231	181	141		141	277	199
16/17					250	250	220	186			186	250	226
Average		189	165	173	207	233	220	177	116				191*

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date	Haleakala Standard Time										Minimum	Maximum	Nightly
	20	21	22	23	00	01	02	03	04	05	Value	Value	Average
1961 31/Sept.1	96	124	203								96	203	141
Sept. 1/2	183	270	340								183	340	264
2/3	136	188	200	187							136	200	178
3/4			331		301						301	331	316
4/5			346	313	290	237					237	346	296
5/6	166	215	284	309	346	346	293				166	346	280
6/7			290	353	322	262	177	140			140	353	257
7/8		160	168	201	189	148	149	151			148	201	167
10/11	135	160	198	295							135	295	197
11/12	108	143	178	140	192	211	145	120			108	211	155
12/13	151	194	223	250	247	230	236	204			151	250	217
13/14		210	268	312	290	244	209	163			163	312	242
14/15			249	276	293	280	250	179			179	293	254
15/16			218		204	204	228	242			204	242	219
16/17				216	230	196	217	247			196	247	221
17/18					197	178	163	129			129	197	167
Average	139	185	250	259	258	231	207	175					220 *
Oct. 1/2	125	136	172	175	123						123	175	146
4/5	385	314	260	309	270	256	293				256	385	298
5/6					306	255	262	272			255	306	274
6/7	297	160	176	181	150	151	182	154			150	297	181
7/8	165	149	140	144	137	139					137	165	146
8/9				172	181	198	229	274	277		172	277	222
10/11		180	170	197	196	232	254				170	254	205
11/12			363	336	265	220	217	237	250		217	363	270
Average	243	188	214	216	203	207	239	234	263				218 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date	20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
	Haleakala Standard Time												
1961 Nov. 3/4	177	208	210	189	175	176	199				175	210	191
4/5		292	273	230	190	186	147	138			138	292	208
5/6				361	276	243	225	191	187		187	361	247
6/7		336	389	392	350	319	302	272	259		259	392	327
7/8	229	252	293	314	318	296	267	296	330		229	330	288
8/9	163	132	138	158	180	149	123				123	180	149
9/10	151	226	269	239	240	246	278	262	311		151	311	247
10/11		130	165	178	202	199	172	168	189		130	202	175
11/12			190	169	163	152	134	118	126		118	190	150
12/13				190	196	217	211	215	218		190	218	208
Average	180	225	241	242	229	218	206	207	231				222 *
28/29	147	172	172	169							147	172	165
29/30	180	179	192	191	186						179	192	186
30/Dec.1	167	179	178	192	215						167	215	186
Dec.9/10		131	160	181	172	160	184	185	181	181	131	185	171
10/11			103	84	85	82	84	102	139	186	82	186	108
14/15									147	80	80	147	114
15/16								70	82		70	82	76
Average	165	165	161	163	164	121	134	119	137	149			151 *
Dec.30/31	269	241	190	149	138	158					138	269	191
1962 31/Jan. 1	80	91	104	104							80	104	95
Jan. 1/2	126	127	122	108	96	95	117	139			95	139	116
2/3	63	59	60	51	50	56	74	112	131		50	131	73
3/4							114	158	177		114	177	150
4/5	74	55	53	48	67	138	117	97			48	138	81
10/11					100	79	84				79	100	88
11/12						163	187	197	203	216	163	216	193
13/14								143	128	98	98	143	123
Average	122	115	106	92	90	115	115	141	160	157			118 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date		Haleakala Standard Time										Minimum	Maximum	Nightly
		20	21	22	23	00	01	02	03	04	05	Value	Value	Average
	1962													
	29/30	59	44	51	40	27	27					27	59	41
	30/31		62	60	58							58	62	60
Feb.	2/3				128	130	128	124	112	107		107	130	122
	3/4		34	52	64	55	52	51	59	67	66	34	67	56
	4/5	114	108	112	118	81	59	61	67	59	68	59	118	85
	5/6	81	82	91	105	82	81	75	63	72	84	63	105	82
	6/7		131	113	116	111	90	57	45	34	48	34	131	83
	7/8				92	92								92
	8/9					110	128	124	128	124		110	128	123
	9/10					78	95	100	89	93	87	78	100	90
	10/11						82	72	86	103	123	72	123	93
	11/12							178	186	180	154	154	186	174
	12/13								134	169	239	134	239	181
Average		85	77	80	90	85	82	94	97	101	109			91 *
Mar.	1/2	74	92	93	106	106	98	116	138			74	138	103
	2/3	60	70	82	93	109	134	152	158	132		60	158	110
	6/7	89	97	117		149	213	230	258	188	189	89	258	170
	10/11					102	118	122				102	122	114
Average		74	86	97	100	116	141	155	185	160	189			127 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
Mar. 30/31		154	130	118	133	151	165	140			118	165	142
31/Apr. 1		163	170	184	207	236	250	230			163	250	206
Apr. 1/2		180	188	190	160	176	167	131	123		123	190	164
2/3		168	172	175	199	204	216	223	314		168	314	209
3/4		192	208	256	230	240	245	261	261		192	261	237
4/5		182	241	268	253	231	300	360	358		182	360	274
5/6			183	217	222	251	309	275	226		183	309	240
6/7					147	188	200	199			147	200	184
7/8				213	246	220	229	218	202		202	246	221
8/9						196	249	269	241		196	269	239
9/10						166	191	235	275		166	275	217
Average		173	185	203	200	205	229	231	250				212 *
26/27			255	224	206						206	255	228
28/29							258						
29/30		277	403	359	287	283	302	223			223	403	305
30/May 1							135	116	120		116	135	124
May 4/5					254	297	255	178			178	297	246
5/6			324	350	276	236	208	172	148		148	350	245
10/11							253	166	105		105	253	175
11/12							233	229			229	233	231
Average		277	327	311	256	272	235	181	124				238 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
May 24/25		252	234	225							225	252	237
25/26		239	218	256	261						218	261	244
26/27		167	144	125	126	118					118	167	136
28/29		136	140	106	103	125	155				103	155	128
29/30		156	159	204	247	268	239	172			156	268	206
31/June 1			313	324							313	324	318
June 1/2		270	187γ	180	203	169	129	141	130		129	270	176
2/3		224	145	140	169	150	154	155	127		127	224	158
3/4			267	262							262	267	264
4/5			180	205	194	214	252	278			180	278	220
5/6				108	115	105	133	170			105	170	126
6/7					351	335	377	310	287		287	377	332
7/8					150	139	115	88	88		88	150	116
8/9						144	106	84	104		84	144	110
10/11							246	242	189		189	246	226
11/12								155	156		155	156	156
12/13								144	124		124	144	134
Average		206	199	194	192	177	191	176	151				186 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 2 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
24/25		79	72	117	144						72	144	103
25/26		270	298	292	314	314					270	314	298
26/27		132	151	186	182	171	164				132	186	164
27/28		100	103	124	155	173	175				100	175	138
28/29		162	196	237	209	186	162	169			162	237	189
29/30		156	175	156	157	138	131	139	133		131	175	148
July 5/6				180	223	205	201	160	164		160	223	189
7/8					164	273	227	174	113		113	273	190
10/11							162	209	172		162	209	181
Average		150	166	185	193	209	175	170	145				177 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3

The hourly average reduced zenith intensities from the two-color reduction method, extreme values and average values for each night and for each standard time of the observing period for NaI 5890-96 A.

Date		Haleakala Standard Time										Minimum	Maximum	Nightly
		20	21	22	23	00	01	02	03	04	05	Value	Value	Average
	1961													
July	18/19						2	10	14	4		2	14	8
	19/20						22	30	26	11		11	30	22
	20/21						10	5	18			5	18	11
Aug.	2/3		18	15								15	18	16
	3/4		9	1		7						1	9	6
	5/6		-2	-4			9	16				-4	16	5
	6/7			18		22	45	60				18	60	36
	7/8			-5		16	18	30	35			-5	35	19
	9/10					10	39	39	34			10	39	30
	10/11		19	19		33	37	39	42	28		19	42	31
	11/12					20	24	27	17	14		14	27	20
	12/13					5	21	32	41	28		5	41	25
	13/14					2	3	-3	8	3		-3	8	3
	14/15					6	22	26		7		6	26	15
	15/16						10	14	13	6		6	14	11
	16/17					10	14	15	10			10	15	12
Average			11	7		13	20	24	23	13				18 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1961													
31/Sept. 1				37									
Sept. 1/2				38									
2/3				41	56						41	56	48
3/4				4									
4/5				70	76	106					70	106	84
5/6				31	42	48	80	112			31	112	63
6/7				46	44	84	93	81	51		44	93	66
7/8			56	37	43	41	32	24	32		24	56	38
10/11		15	16	26	20						15	26	19
11/12		16	33	37	41	41	61	74			16	74	43
12/13		7	14	8	23	35	28	38	34		7	38	23
13/14			45	23	26	34	52	69	71		23	71	46
14/15				63	105	62	86	109	84		62	109	85
15/16				38		63	55	58	55		38	63	54
16/17					8	8	27	27	17		8	27	17
17/18						50	37	43	41		37	50	43
Average		13	33	36	44	52	55	64	48				46 *
Oct. 1/2		48	38	38	54						38	54	44
4/5	136	132	117	130	138	125	123				117	138	129
5/6					78	110	121	122			78	122	108
6/7	67		79	78	67	66	81	86	90		66	90	77
7/8	53	64	62	80	87	69					53	87	69
8/9				108	72	55	59	67	74		55	108	72
10/11		65	50	44	38	44	42				38	65	47
11/12			82	87	85	68	54	64	54		54	87	71
Average	85	77	71	81	77	77	80	85	73				78 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3 (continued)

Date	20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
					Haleakala Standard Time								
1961													
Nov. 3/4	154	221	185	156	140	126	140	139			126	221	158
4/5		133	140	163	176	164	179	165			133	179	160
5/6				123	150	174	247	245	280		123	280	203
6/7		181	204	215	213	212	229	216	257		181	257	216
7/8	214	185	173	160	122	152	158	149	150	148	122	214	161
8/9	183	156	130	126	160	149	121				121	183	146
9/10	148	148	133	116	98	95	81	79	110		79	148	112
10/11		84	82	87	87	83	92	84	97	124	82	124	91
11/12			91	89	94	90	87	91	115	112	87	115	96
12/13				38	49	46	51	47	62	66	38	66	51
Average	175	158	142	127	129	129	138	135	153	112			138 *
28/29	52	42	54	62							42	62	52
29/30	45	58	30	7	39						7	58	36
30/Dec. 1	71	64	52	51	60	57					51	71	59
Dec. 9/10		18	14	24	20	8	25	29	40	46	8	46	25
10/11			66	57	58	40	27	30	34	43	27	66	44
14/15									39	28	28	39	34
15/16								4	20	29	4	29	18
Average	56	46	43	40	44	35	26	21	33	36			39 *
1961													
Dec. 30/31	40	60	68	61	35	36					35	68	50
1962													
31/Jan. 1	22	24	36	33	29						22	36	29
Jan. 1/2	12	17	16	7	-8	-6	0	14			-8	17	6
2/3	29	26	24	3	-7	13	22	36			-7	36	18
3/4							-1	2	0		-1	2	0
4/5	18	8	2	-8	-4	13	30	31			-8	31	11
10/11					-1	4	9				-1	9	4
11/12						-19	9	29	44	58	-19	58	24
13/14								23	27	30	23	30	27
Average	24	27	29	19	7	7	12	22	24	44			19 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
Jan. 29/30	2	4	-5	4	3	9					-5	9	3
30/31	24	10	0	0							0	24	8
Feb. 2/3				14	18	15	20	19	21		14	21	18
3/4	-5	-17	-18	-8	8	9	7	1	1	2	-18	9	-2
4/5	0	0	5	15	21	16	8	0	1	2	0	21	7
5/6	8	-3	7	19	15	5	9	5	4		-3	19	8
6/7		18	24	27	19	22	10	10	3		3	27	17
7/8	no data												
8/9					1	4	1	8	15		1	15	6
9/10					13	12	11	16	12		11	16	13
10/11						24	17	13	22		13	24	19
11/12							43	67	76		43	76	62
12/13								54	50		50	54	52
Averages	7	2	2	10	12	13	14	19	20	2			13 *
Mar. 1/2	3	8	3	16	11	4	4	-2			-2	16	6
2/3	2	8	11	14	6	4	6	7			2	14	7
6/7	22	24	25		24	20	24	32	45	34	20	45	28
10/11					57	53	54				53	57	55
Average	9	13	13	15	24	20	22	12	45	34			18 *
Mar. 30/31		45	42	47	50	45	48	46			42	50	46
31/April 1		43	45	42	40	39	41	40			39	45	41
Apr. 1/2		22	23	26	33	39	64	76	85		22	85	46
2/3		40	49	46	41	51	55	54	51		40	55	48
3/4		39	24	22	25	23	34	40	44		22	44	31
4/5		22	28	39	48	51	48	50	62		22	62	44
5/6			42	44	43	46	111	139			42	139	71
6/7						50	54	65	66		50	66	59
7/8				27	32	42	52	62	66		27	66	47
8/9						26	42	59	75		26	75	50
9/10						42	40	38	34		34	42	38
Average		35	36	37	39	41	54	61	60				47 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3 (continued)

Date		Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
	1962													
Apr.	26/27			71	79	90						71	90	80
	28/29							80						
	29/30		36	37	41	36	40	34	37			34	41	37
30/May 1								45	41	31		31	45	39
May	4/5						62	74	79			62	79	72
	5/6			21	27	47	53	60	63	67		21	67	48
	10/11							58	59	48		48	59	55
	11/12							56	66			56	66	61
Average			36	43	49	58	52	58	58	49				53 *
May	24/25		36	39	51							36	51	42
	25/26		28	28	31	34						28	34	30
	26/27		35	41	33	30	33					30	41	34
	28/29		21	26	29	26	23	14				14	29	23
	29/30		17	19	19	27	35	37	35			17	37	27
31/June 1				31	34							31	34	32
June	1/2		14	24	17	17	19	12				12	24	17
	2/3		20	27	17	15	14	12	14			12	27	17
	3/4			14	14							14	14	14
	4/5			8	9	12	8	4				4	12	8
	5/6				13	8	6	0				0	13	7
	6/7					2	6	8				2	8	5
	7/8					38	31	21				21	38	30
	8/9						22	19		17		17	22	19
	10/11							2		9		2	9	6
	11/12									5				
	12/13									9				
Average			24	26	24	21	20	13	24	10				21 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 3 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
June 24/25		15	14	23	22						14	23	18
25/26		13	9	10	9	14					9	14	11
26/27		16	14	15	9	11					9	16	13
27/28		9	4	3	3						3	9	5
28/29		8	10	14	16	17		17			8	17	14
29/30		12	13	12	8			5	9		5	13	10
July 5/6				6	9			17	15		6	17	12
7/8					4		20	26	27		4	27	19
10/11							8	8	13		8	13	10
Average		12	11	12	10	14	14	15	16				12 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4

The hourly average reduced zenith intensities from the two-color reduction method, the extreme values and the average values for each night and for each standard time of the observing period for [OI] 6300 A

Date	Haleakala Standard Time										Minimum	Maximum	Nightly
	20	21	22	23	00	01	02	03	04	05	Value	Value	Average
1961													
July 18/19						48	67	60	44		44	67	55
19/20						157	162	80	125		80	162	131
20/21						25	32	44			25	44	34
Aug. 2/3		118	78	64							64	118	87
3/4		157	105	42	37						37	157	85
5/6		58	33	73	63	58	82				33	82	61
6/7			67	76	71	64	54				54	76	66
7/8			70	50	79	75	63	102			50	102	73
9/10				56	39	59	60	67			39	67	56
10/11		171	100	35	14	14	28	85	147		14	171	74
11/12			113	113	53	46	46	79	82		46	113	76
12/13		260	127	59	63	104	126	136	107		59	260	123
13/14		215	115	96	52	44	67	104	24		24	215	90
14/15				48	34	169	292				34	292	136
15/16				46		56	93	67	63		46	93	65
16/17					69	49	47	41			41	69	52
Average		163	90	63	52	69	87	79	85				80 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4 (continued)

Date	20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
	Haleakala Standard Time												
1961													
31/Sept. 1		163	80	62							62	163	102
Sept. 1/2		196	168	109							109	196	158
2/3		83	60	60	79						60	83	70
3/4				50	70						50	70	60
4/5				68	71	115	128				68	128	96
5/6		166	96	65	62	65	74	83			62	166	87
6/7				74	58	61	87	121	62		58	121	77
7/8			137	69	98	107	86	80	64		64	137	92
10/11		151	82	78	74						74	151	96
11/12		124	251	242	90	253	283	132	76		76	283	181
12/13		134	87	72	97	124	93	94	65		65	134	96
13/14			79	77	116	58	66	104	82		58	116	83
14/15				59	71	59	76	91	78		59	91	72
15/16				64			90	82	61		61	90	74
16/17					43	52	63	69	47		43	69	55
17/18						153	145	110	76		76	153	121
Average		145	116	82	77	105	108	97	68				97 *
Oct. 1/2	105	134	110	111	162						105	162	124
4/5	528	362	264	288	264	157	102				102	528	281
5/6					61	91	99	85			61	99	84
6/7	439		169	173	106	66	75	97	91		66	439	152
7/8	219	157	111	96	87	125					87	219	132
8/9				92	99	90	70	65	71		65	99	81
10/11		220	102	76	69	62	54				54	220	97
11/12			383	202	110	75	90	115	74		74	383	150
Average	323	218	190	148	120	95	82	90	79				144 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4 (continued)

Date	20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
				Haleakala Standard Time									
1961													
Nov. 3/4	138	128	125	118	104	73	68				68	138	108
4/5		103	69	102	153	97	90	113			69	153	104
5/6				111	86	76	90	108	101		76	111	95
6/7		104	142	144	154	146	135	97	93		93	154	127
7/8	150	145	130	78	91	97	72	67	66		66	150	100
8/9	77	145	138	114	122	106	90				77	145	113
9/10	135	117	135	95	58	51	43	47	53		43	135	82
10/11		109	97	78	66	61	58	58	50		50	109	72
11/12			116	78	105	116	102	99	71		71	116	98
12/13				70	50	39	41	43	57		39	70	50
Average	125	122	119	99	99	86	79	79	70				95 *
28/29	120	68	59	57							57	120	76
29/30	109	80	71	46	44						44	109	70
30/Dec. 1	130	82	99	113	132						82	132	111
Dec. 9/10		47	56	46	33	27	31	33	31	38	27	56	38
10/11			118	82	63	47	40	45	82	70,	40	118	68
14/15									81	40	40	81	60
15/16								29	32		29	32	30
Average	120	69	81	69	68	37	36	36	56	49			65 *
Dec. 30/31	44	105	106	91	63	50					44	106	76
1962													
31/Jan. 1	no data												
Jan. 1/2	87	68	63	44	22	15	18	50			15	87	46
2/3	100	75	60	40	20	22	26	35	39		20	100	46
3/4							31	19	20		19	31	23
4/5	75	40	46	46	34	26	28	33			26	75	41
10/11					25	26	44				25	44	32
11/12						14	29	48	47	35	14	48	35
13/14								49	56	39	39	56	48
Average	76	72	69	55	33	26	29	32	40	37			46 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4 (continued)

Date		Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962														
Jan.	29/30	119	58	67	42	30	30					30	119	58
	30/31		66	65	48							48	66	60
Feb.	2/3				54	33	40	46	42	38		33	54	42
	3/4		49	74	59	49	46	71	40	27	21	21	74	48
	4/5	86	91	59	37	35	40	61	46	25	19	19	91	50
	5/6	86	42	75	80	40	30	31	33	32	24	24	86	47
	6/7		39	52	48	38	38	30	54	23	15	15	54	37
	7/8				41	30						30	41	36
	8/9					14	32	31	33	25		14	33	27
	9/10					34	35	24	33	45		24	45	34
	10/11						24	33	26	22		22	33	26
	11/12							35	42	50	51	35	51	44
	12/13								52	51	62	51	62	55
Average		97	58	65	51	34	35	40	40	34	32			44 *
Mar.	1/2		70	58	33	28	36	42	37			28	70	43
	2/3		81	55	56	42	45	36γ	31	29		29	81	47
	6/7		59	50		42	44	39	43	45	36	36	59	45
	10/11					54	44	33				33	54	44
Average			70	54	44	42	42	38	37	37	36			45 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4 (continued)

Date	Haleakala Standard Time										Minimum	Maximum	Nightly
	20	21	22	23	00	01	02	03	04	05	Value	Value	Average
1962													
Mar. 30/31		184	91	37	54	75	69	54			37	184	81
31/Apr. 1		73	51	50	69	77	51	34			34	77	58
Apr. 1/2		97	35	18	32	30	48	51	43		18	97	44
2/3		70	49	28	39	72	58	47			28	72	52
3/4			40	24	40	26	23	43	37		23	43	33
4/5		80	38	25	32	36	40	42	30		30	80	40
5/6			41	37	47	38	40	36	71		36	71	44
6/7						35	35	58	43		35	58	43
7/8				19	24	33	43	59	41		19	59	36
8/9						27	44	52	32		27	52	39
9/10						42	29	26	37		26	42	34
Average		101	49	30	42	45	44	46	42				47 *
26/27			59	55	140						55	140	85
28/29							80						
29/30		69	52	36	24	34	47	40			24	69	43
30/May 1							79	67	71		67	79	72
May 4/5					65	44	58	66			44	66	58
5/6			43	42	46	55	92	69	50		42	92	57
10/11							80	57	38		38	80	58
11/12							83	68			68	83	76
Average		69	51	44	69	44	74	61	53				60 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 4 (continued)

Date	Haleakala Standard Time 20	21	22	23	00	01	02	03	04	05	Minimum Value	Maximum Value	Nightly Average
1962													
May 24/25		168	65	56							56	168	96
25/26		108	70	34	55						34	108	67
26/27		127	56	48	46	75					46	127	70
28/29			31	20							20	31	26
29/30		79	71	90	83	87	80	60			60	90	79
31/June 1			30	49							30	49	40
June 1/2		60	27	43	52	34	31	24	34		24	60	38
2/3			75	23	15	16	21	32	31		15	75	30
3/4			39	20							20	39	30
4/5				38	20	10	44	57			10	57	34
5/6	No data												
6/7	No data												
7/8					78	49	55	72	89		49	89	69
8/9						19	21		52		19	52	31
10/11							88	112	70		70	112	90
11/12								31	30		30	31	30
12/13								54	22		22	54	38
Average		108	52	42	50	41	49	55	47				53 *
24/25		156	111	63	53						53	156	96
25/26		232	171	122	54	46					46	232	125
26/27			48	42	33	32	32				32	48	37
27/28		117	96	24	50	109	80				24	117	79
28/29		60	53	44	56	38	80	118			38	118	64
29/30		40	28	41	47	40	28	55	59		28	59	42
July 5/6				61	52	63	67	77	119		52	119	73
7/8					48	114	72	54	44		44	114	66
10/11							71	81	43		43	81	65
Average		121	84	57	49	63	61	77	66				70 *

* This is the average value for the observing period and not the mean of the nightly averages.

Table 5

The least-squares solutions based on averages
for each observing period for the
covariance of the three
emissions in Figure 2

5890-96	=	0.66	x	[rayleighs 5577]	-	74.6,	R	=	0.57	(all data)
5890-96	=	1.39	x	[rayleighs 6300]	-	53.4,	R	=	0.59	(all data)
5577	=	1.98	x	[rayleighs 6300]	+	42.7,	R	=	0.62	(all data)

Table 6

STATION	GEOGRAPHIC LAT	GEOGRAPHIC LON	GEOMAGNETIC LATITUDE
Haute Provence	44°N	6°E	46°N
Cactus Peak	36°N	118°W	43°N
Tamanrasset	23°N	5°E	25°N
Haleakala	21°N	156°W	21°N

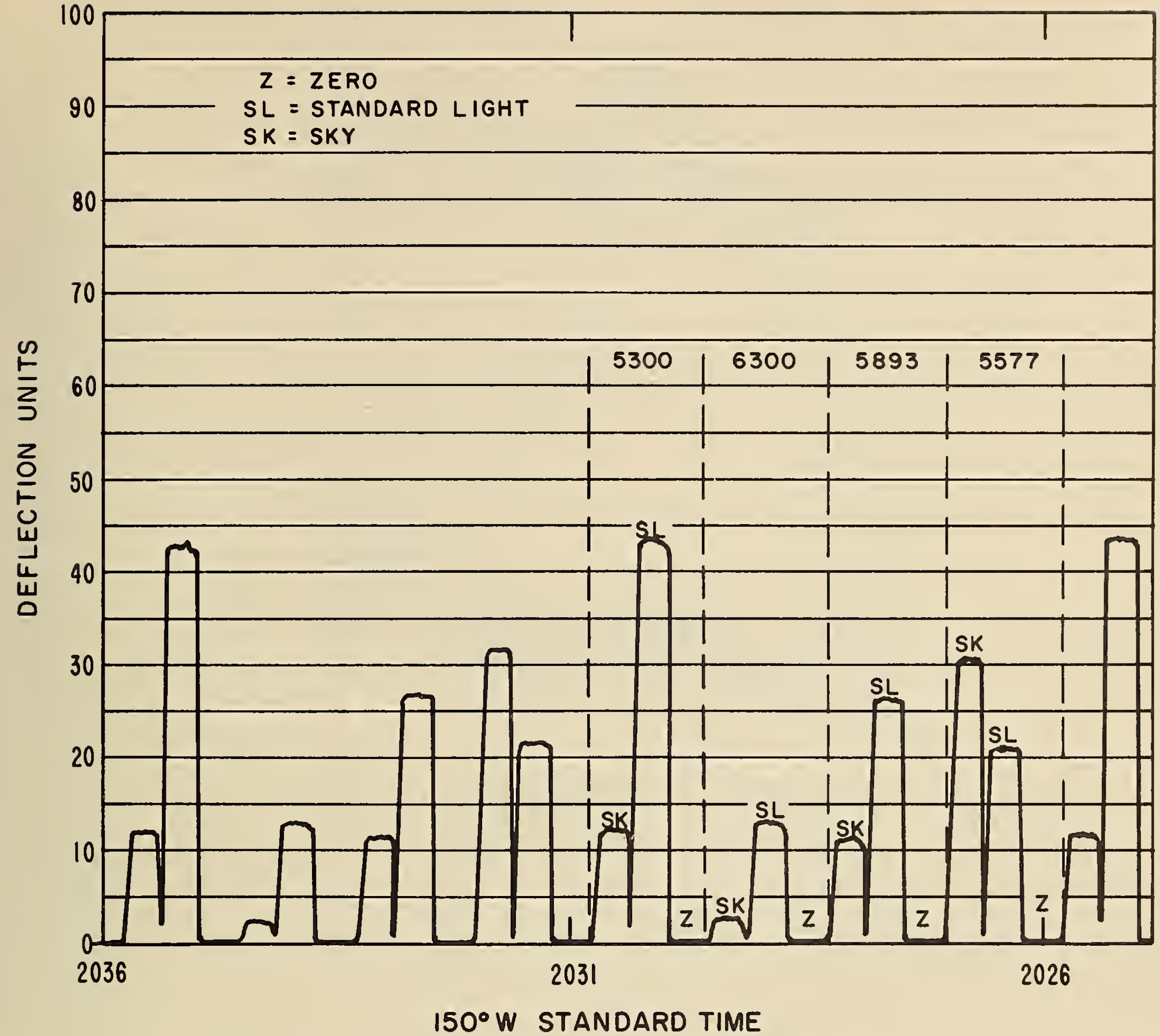

Fig. 1 - Illustration of a strip chart recording from the zenith photometer.

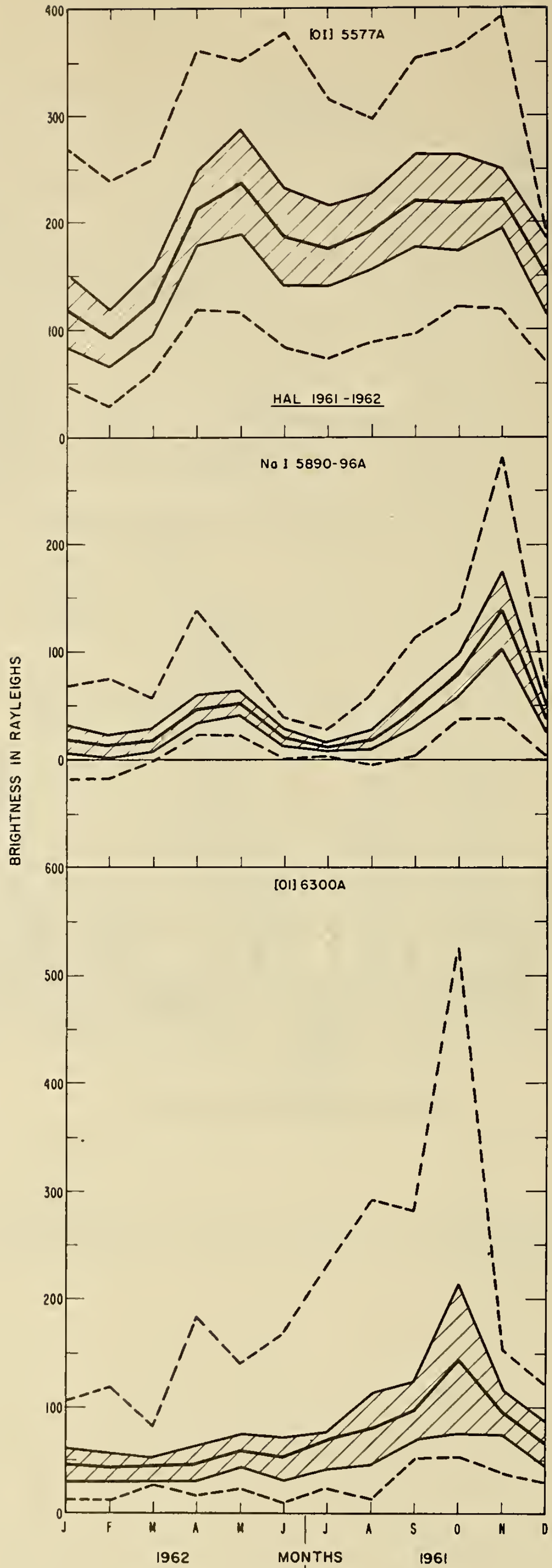

Fig. 2 - The average zenith intensities, the extreme values, and the probable errors for each observing period for [OI] 5577 A, [OI] 6300 A, and NaI 5890-96 A.

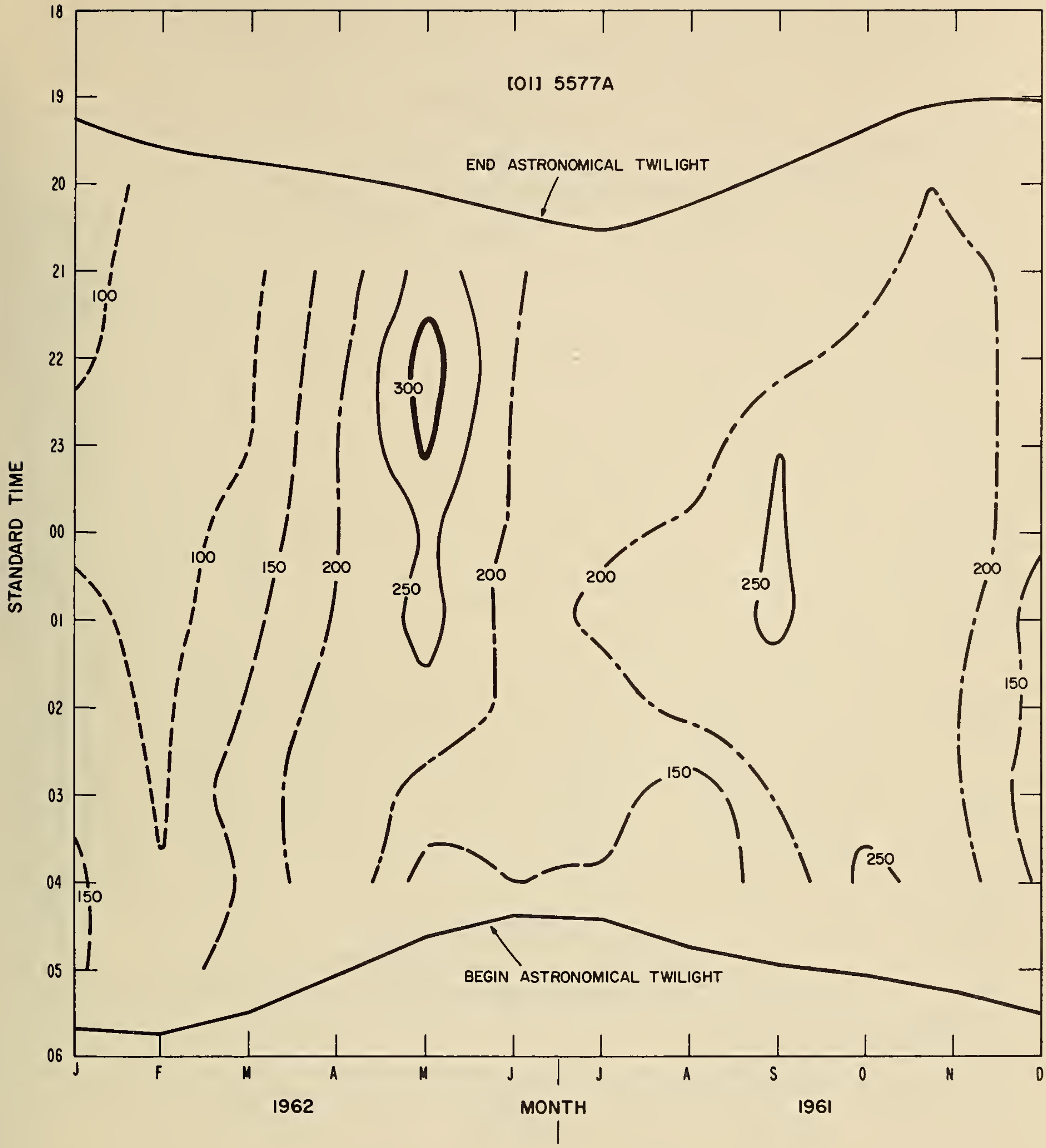

Fig. 3 - The 5577 A intensities plotted as a function of local time and month. Isophotes are in rayleighs.

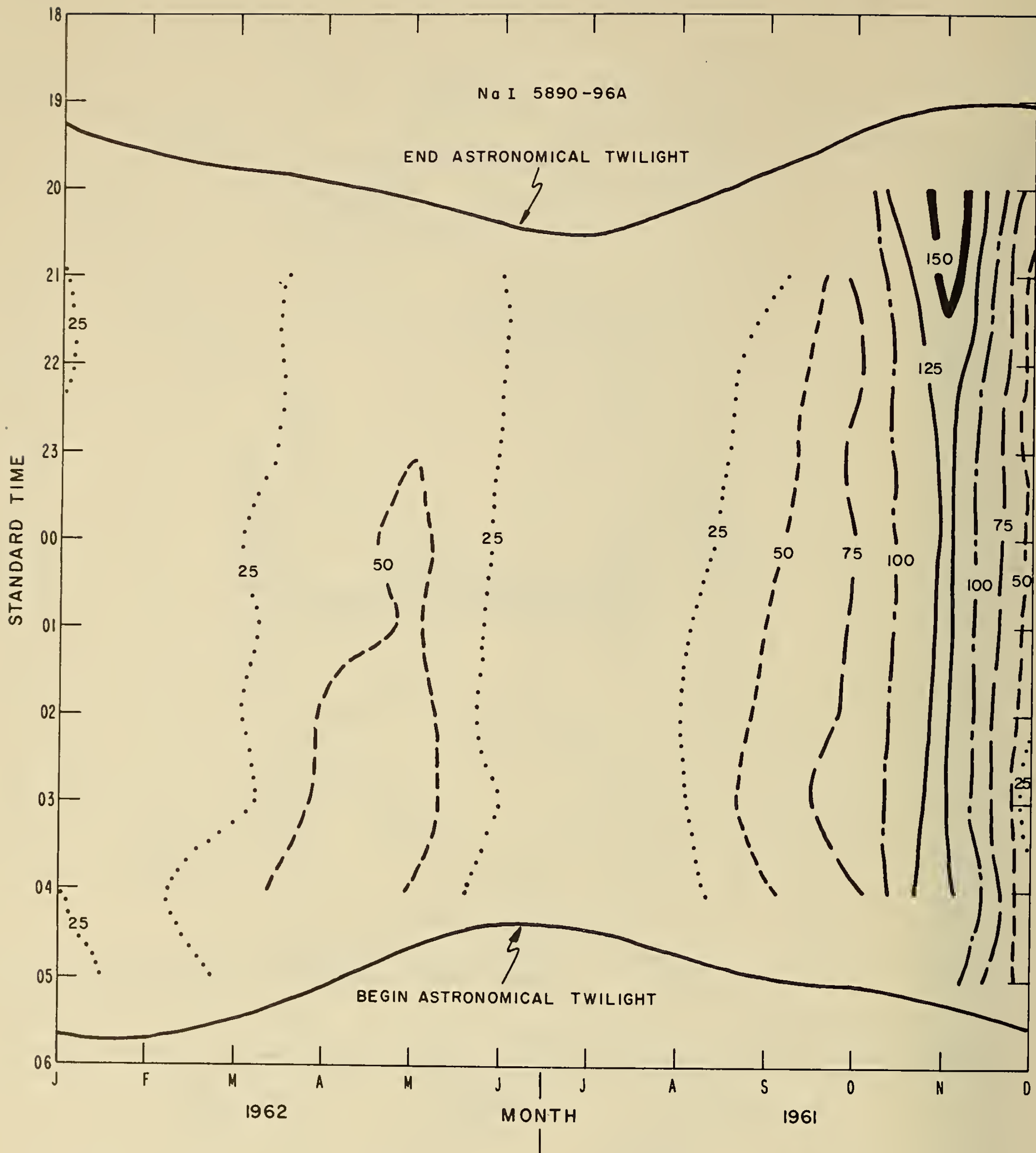

Fig. 4 - The 5890-96 A intensities plotted as a function of local time and month. Isophotes are in rayleighs.

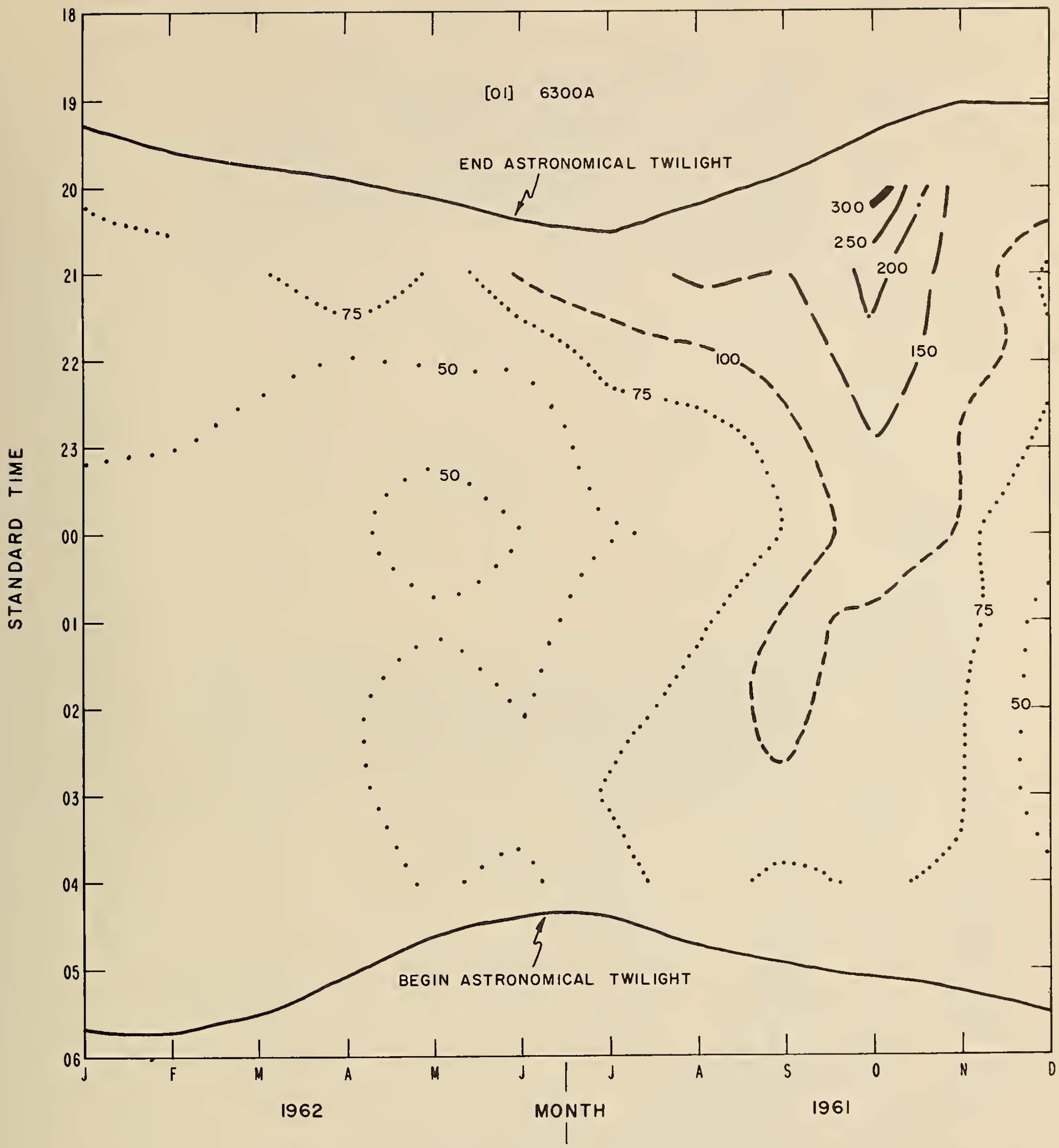

Fig. 5 - The 6300 A intensities plotted as a function of local time and month. Isophotes are in rayleighs.

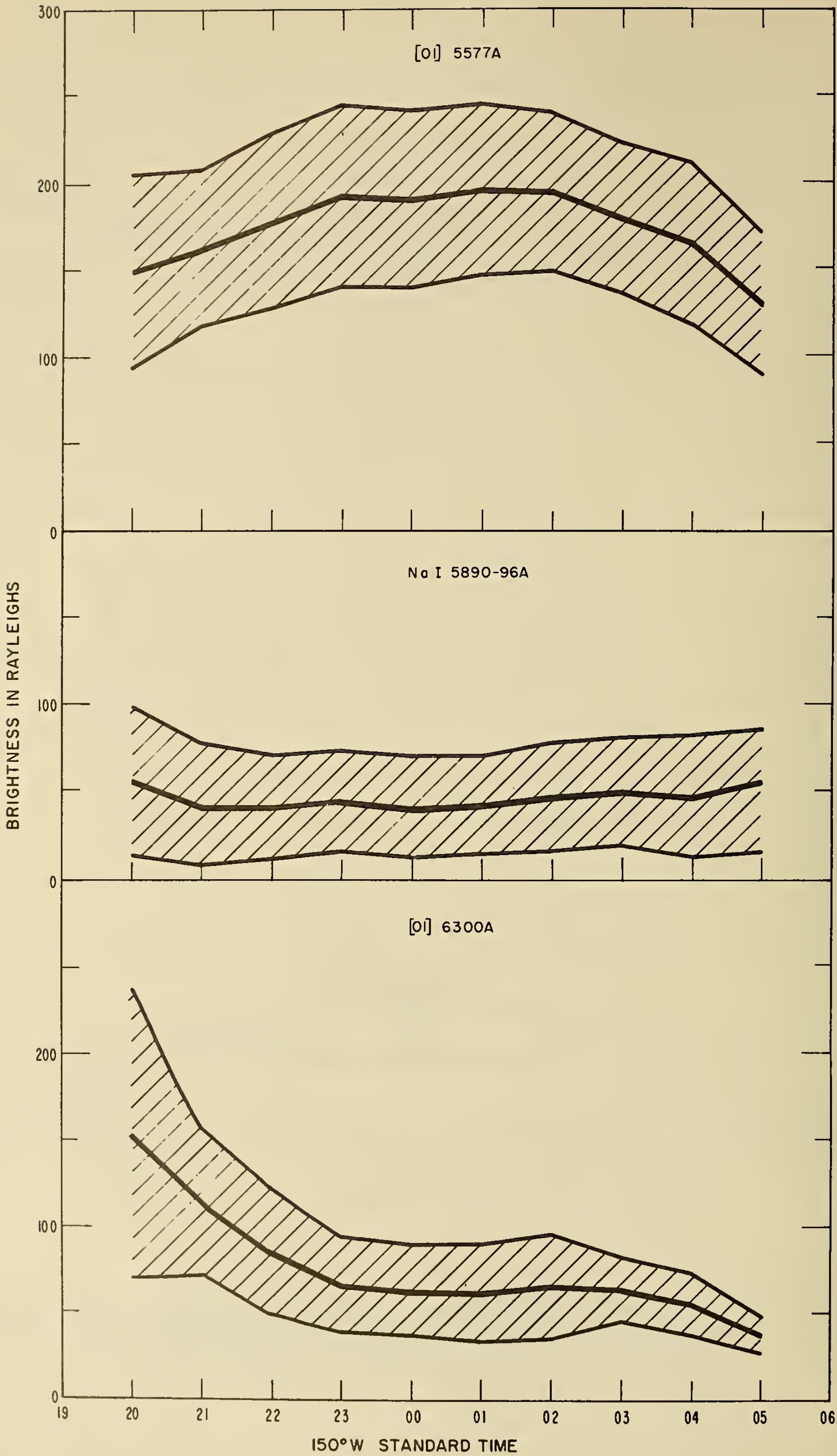

Fig. 6 - The average diurnal variations and the probable errors for [OI] 5577, [OI] 6300, and NaI 5890-96 A.

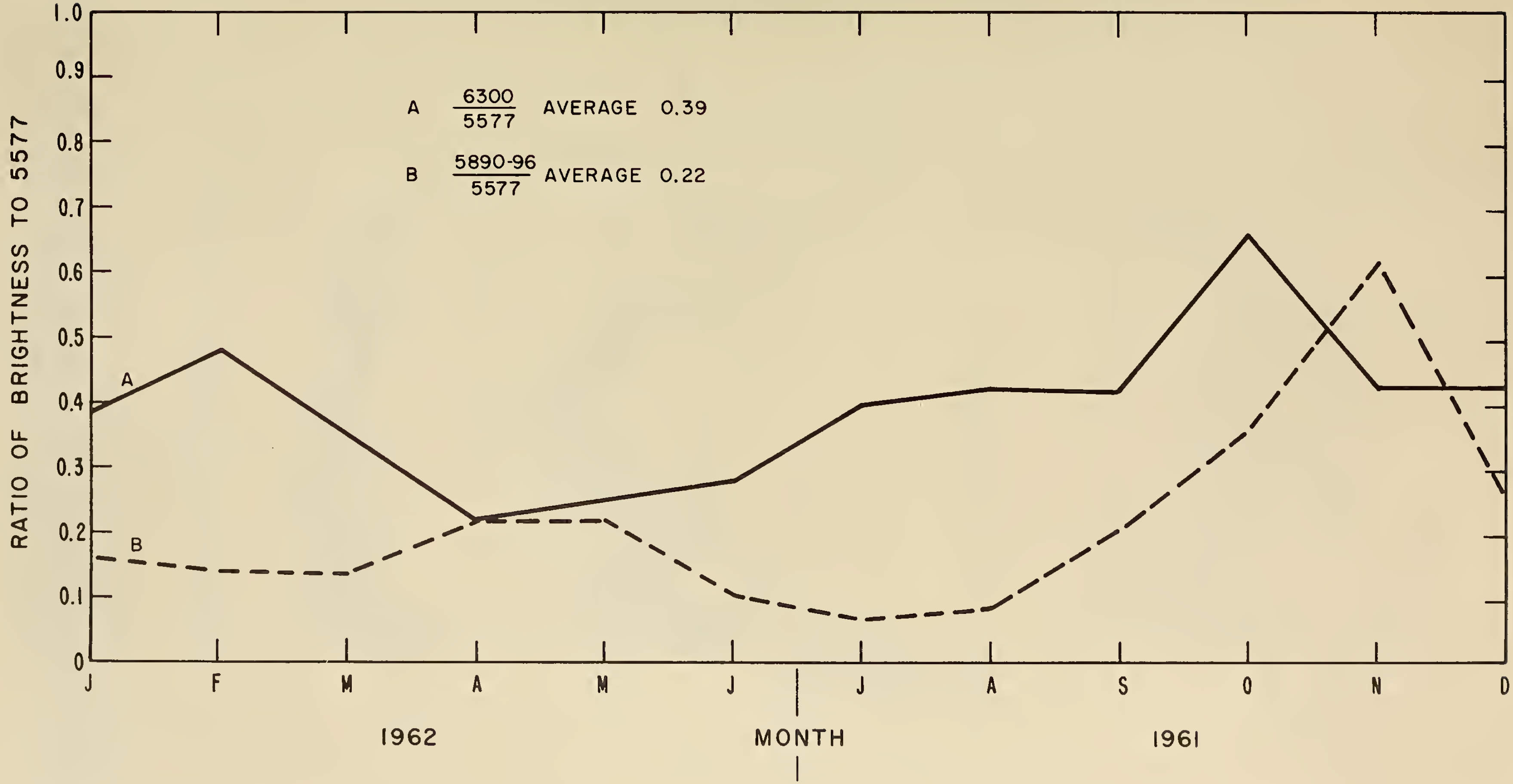

Fig. 7 - The average monthly intensity of NaI 5890-96 A and [OI] 6300 A relative to [OI] 5577 A.

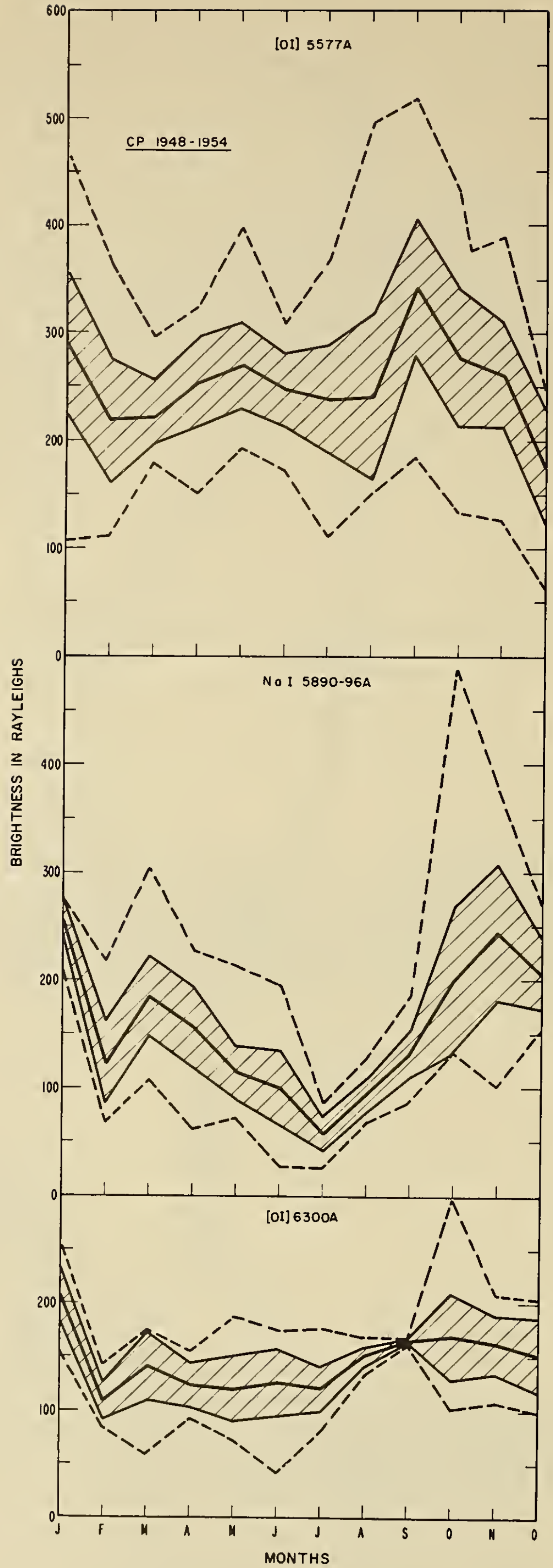

Fig. 8 - Seasonal variations of [OI] 5577, [OI] 6300, and NaI 5890-96 A at Cactus Peak for the period November, 1948 to March, 1954. The inner curve represents the averages, the center curves represent the probable errors, and outer curves represent the extreme values. After Pettit, et al. [1954].

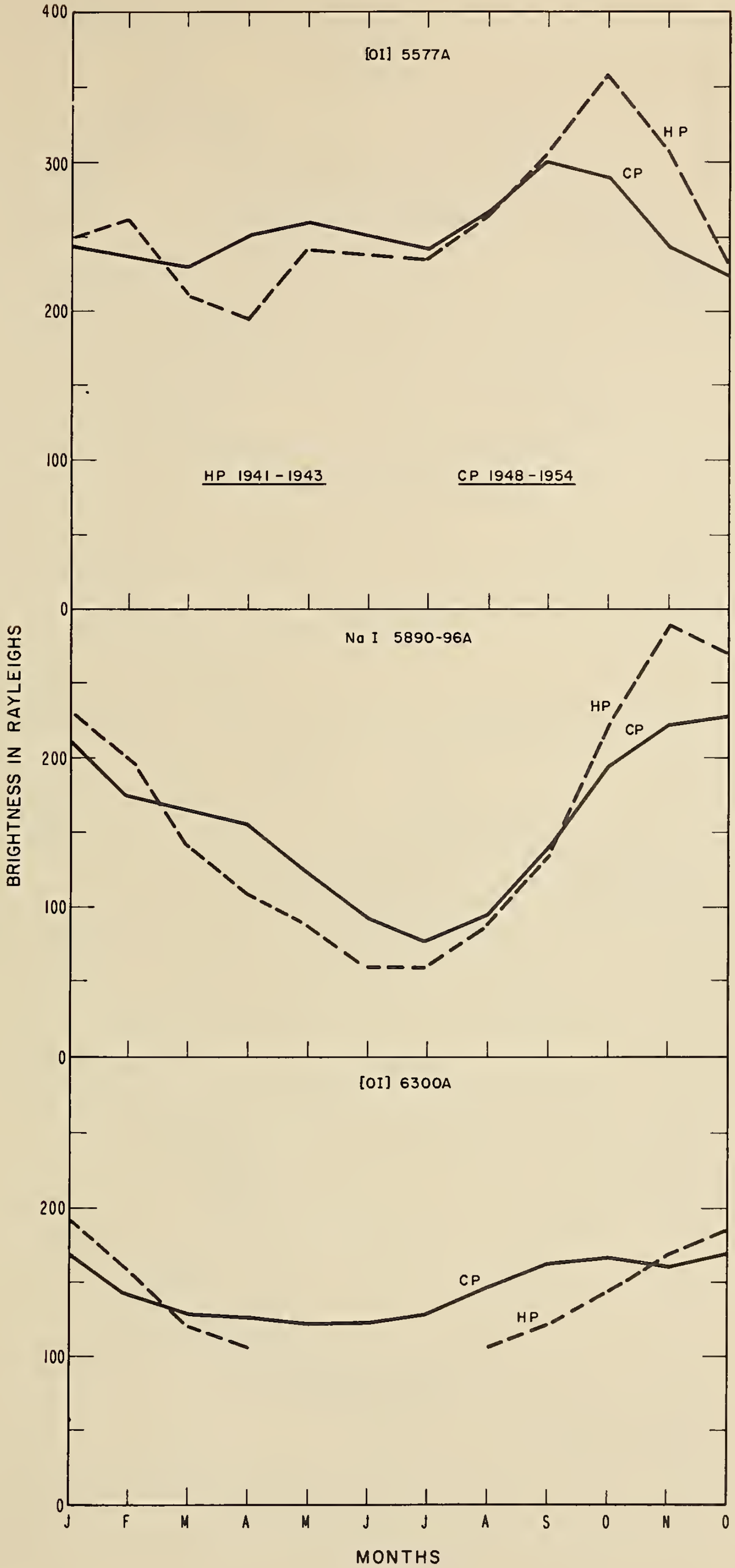

Fig. 9 - The comparison by Roach [1955] of the seasonal smoothed results of Cactus Peak (CP) with the results from Haute Provence (HP) normalized to the Cactus Peak results for [OI] 5577, [OI] 6300, and NaI 5890-96 A.

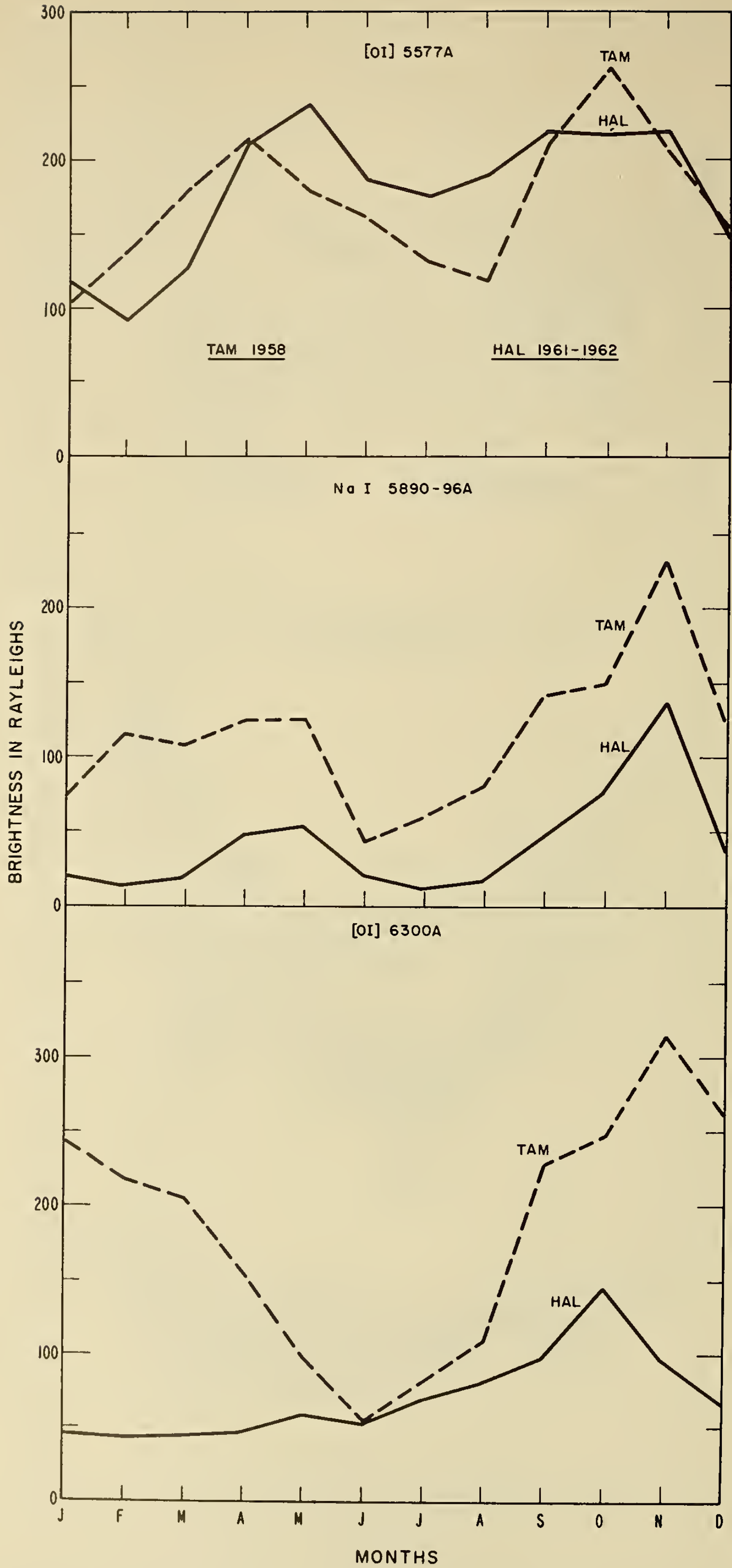

Fig. 10 - Seasonal variations of [OI] 5577, [OI] 6300, and NaI 5890-96 A at Tamanrasset for the calendar year 1958 and at Haleakala for 1961-1962.

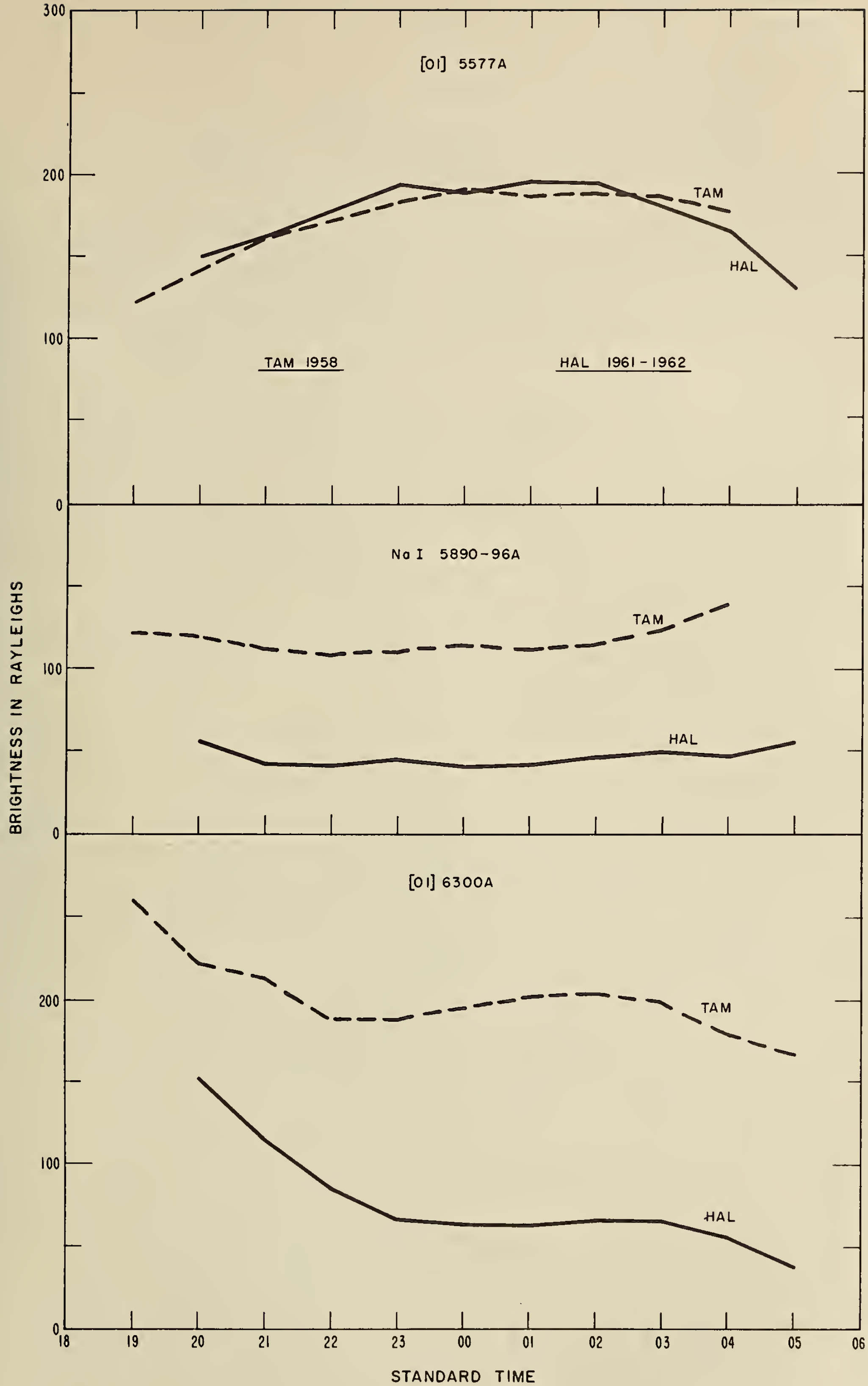

Fig. 11 - The average diurnal variations for [OI] 5577, [OI] 6300, and NaI 5890-96 A from Tamanrasset and Haleakala.

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