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Observing conditions for optical astronomy at Leh

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Abstract. The sky and atmospheric conditions at Leh have been monitored since 1984 with a view to determining its suitability as a site for a high altitude observatory. During 1987 May–November we monitored relative humidity and other parameters giving qualitative indices viz. photometric and spectroscopic hours, and seeing conditions throughout the non-winter months. Extinction coefficients in UBV bands have been measured on 30 nights in 1987. The average values of extinction coefficients are $k_V = 0.18 \pm 0.05$(s. d.), $k_b = 0.28 \pm 0.04$, and $k_u = 0.53 \pm 0.04$. These values agree well with those reported earlier for 1985–86, and appear to represent consistent conditions.

Key words: astronomical seeing—relative humidity—photometric and spectroscopic sky—extinction coefficients—site survey

1. Introduction

The site survey at Leh was started in 1984 using the 50-cm Bhavnagar telescope of the Indian Institute of Astrophysics. The extinction measurements obtained with this telescope during 1985 and 1986 have been reported in an earlier paper (Singh *et al.* 1988 ≡ Paper I). During the year 1987, more concerted efforts were made to obtain continuous observations of temperature, humidity, and seeing conditions at Leh. An organized scheduling of the observing teams from Indian Institute of Astrophysics made it possible to monitor the various sky and atmospheric conditions for a period of seven months from 1987 May 1 to November 30, without any gap. In addition, the measurements of the extinction

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due to earth's atmosphere were obtained for a total of 30 nights spread over these seven months. In this paper, we present the results of these observations.

2. Instrumentation and observations

The temperature and humidity have been monitored with a standard calibrated thermometer and a hygrometer. The readings were noted four times during the night : midway between dusk and 21 : 00 hours; at about 22 : 30 hours; at about 01 : 30 hours; and finally at a time midway between 03 : 00 hours and dawn. These readings were entered in the observatory's log book.

The seeing conditions were estimated by visually judging the quality of the stellar images at the focal plane of the Bhavnagar 50 cm telescope and the estimated mean values of seeing over each of the three-hourly intervals have been recorded. Following the standard procedure, the extinction measurements were obtained by observing the standard stars at various airmass levels on all possible clear nights (see Paper I).

Continuous visual estimates of the sky conditions were made to ascertain the number of photometric and spectroscopic hours per night. A photometric hour is defined as an hour without any passing clouds in the sky and having good transparent sky. An hour with poor transparency and passing clouds but without dark clouds at least in half of the sky has been taken as a spectroscopic hour.

3. Results

3.1. *Clear nights*

As usual, every night with at least six uninterrupted hours of photometric sky conditions is labelled as a clear night. The count of such nights is obtained from the photometric hours data available in the log book. There were of course several other nights with smaller number of photometric hours and all these hours are listed in table 1 as aggregates for each month. The corresponding numbers for Vainu Bappu Observatory, Kavalur, are included for comparison. It is obvious that the number of clear nights at Leh is either comparable to or more than that in Kavalur for the seven months under consideration.

To see the seasonal variation in the number of photometric hours, the entire period is divided into two subperiods : May–July, and August-November. In each subperiod, the number of nights are binned according to the number of photometric hours. This information is presented in figure 1 as percentages for these two subperiods. These histograms clearly indicate that about 50% of each subperiod had nights with less than one photometric hour, while the clear nights totalled 31% in May–July and 37% in August–November. Table 1 shows that the months of October and November have the maximum number of clear nights.

A similar analysis has been made for the spectroscopic hours data recorded in the log book. These hours also are shown in table 1 as aggregates for each month along with those of Kavalur observatory. The frequency of nights as a function of spectroscopic hours per night is shown in figure 2 for the two periods

Table 1. Number of photometric and spectroscopic hours per month at Leh and Kavalur.

Month 1987	Photometric hours Leh	Photometric hours Kavalur	Spectroscopic hours Leh	Spectroscopic hours Kavalur	No. of clear nights Leh	No. of clear nights Kevalur
May	52	47	94	136	7	6
Jun	88	1	118	58	11	0
Jul	71	3	115	70	7	0
Aug	23	3	45	46	1	0
Sep	43	1	101	65	0	0
Oct	120	5	161	50	14	0
Nov	227	38	279	87	25	4

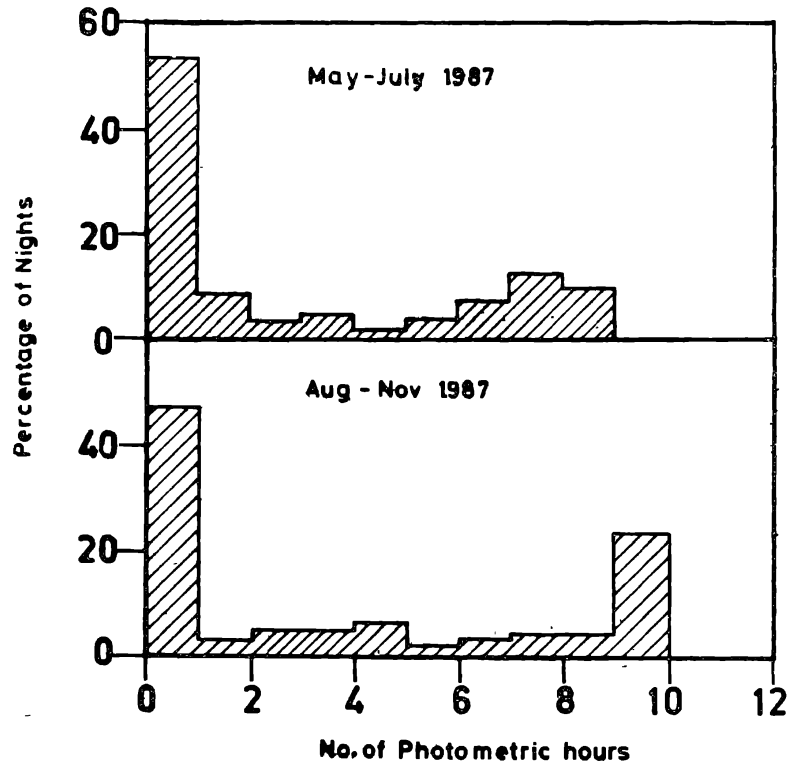

Figure 1. Frequency distribution of number of nights as a function of number of photometric hours per night for 1987 May–July, and August–November.

May-July and August–November. In this case, the figure shows that about 40% of the nights in each part were not suitable for spectroscopy. It may also be noticed that the spectroscopic work could have been done for 6 hours or more on 37% and 43% of the nights in the first and the second part of the period respectively.

Due to logistics difficulties, we have been able to collect the data only during the 7 month period of May to November and the sky conditions could be completely different for the remaining 5 months. Therefore, a direct comparison of

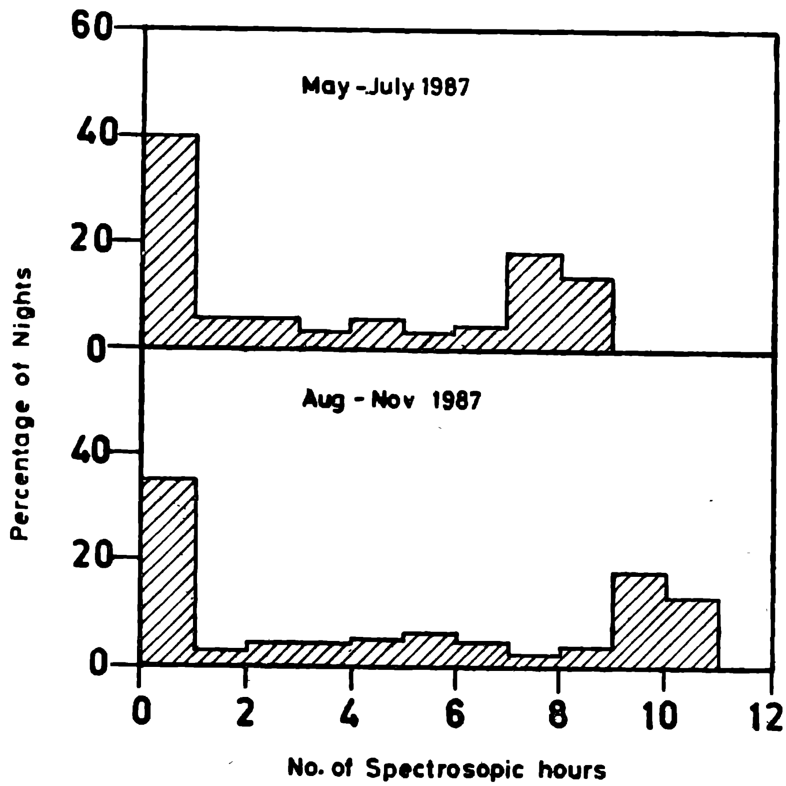

Figure 2. Frequency distribution of number of nights as a function of number of spectroscopic hours per night for 1987 May–July, and August–November.

available number of nights at Leh with those at other sites may not be of much use. However, here we give the statistics of some of the best observing sites in the world. The Las Campanas observatory located at an elevation of 2,280 meters at the southern tip of the Chilean Atacama desert had about 55% of the

Table 2. Percentages of photometric and spectroscopic nights at different astronomical sites

Location	Altitude (m)	Period of observations	% Nights	
			Photo-metric	Spectro-scopic
Leh	3500	1987	31	40
Kavalur	700	1972–76	32*	43*
		77–82	21*	44*
		83–85	12*	41*
		86–87	9	36
Cerro-Tololo	2399	1973–83	62	77
La Palma	2300	1982–83	59	78
Las Campanas	2280	1978–83	55	70

*These are the percentages of total number of photometric/spectroscopic hours assuming maximum number of spectroscopic hours 10 per night and 8 photometric hours per night.

nights available for photometric observations during the period 1978–83. In addition about 15% of the nights were available for spectroscopic observations and about 18% nights were partially clear (Duhalde & Krzeminski 1984). At Cerro Tololo the observing records over the ten year period 1973 to 1982 show that an average of 62% of the nights were photometric and in all 77% of the nights were useful for observations (Osmer & Wood 1984). And at La Palma, Canary islands, 59% of the nights were found to be photometric and a total of 78% were useful during 1982–83 (Ardeberg 1984). A summary of the photometric and spectroscopic nights at various observatories is given in table 2.

3.2. Temperature

The temperatures near the telescope at the four earlier mentioned times of each night were also recorded and are shown in figure 3. It may be seen that the night temperatures during the months of July, August and September were generally in the range of 15 C to 25 C followed with a gradual decrease in the subsequent months, reaching as low as —8 C by the end of November. Nevertheless, the overall picture gives a fair indication of the seasonal variations which can be expected during these months.

Figure 3 shows that the decrease in temperature during the night is fairly gradual. The recording of the temperatures at both ends of the night may be utilized for determing the variation of temperature during a given night. In order to see this variation, the difference of the above mentioned two readings is plotted against their respective dates in figure 4.

The value of the dusk-to-dawn variation generally is between 4 to 10 C but on a few days the amplitude is less than 3 C. The average variation is abont 7 C between dusk and dawn.

3.3. Humidity

A calibrated hair hygrometer was used to determine the relative percentage humidity in the air near the telescope. The percentage humidity was noted, at the same four times, along with temperature and other readings. A plot of these values is shown in figure 5. The percentage humidity gradually increases during the night and becomes maximum in the morning hours. Figure 5 indicates that the relative humidity varies between 20 and 70% in the early part of the nights and between 40 and 90% in the later part and the day-to-day fluctuations in the relative humidity are much less in the months of June–July as compared to the other months under consideration. The difference between the last and the first value of each night has been plotted against each day in figure 6. This figure shows that change in relative humidity is about 10–40% during the night in most of this period except for the months of June–July during which the change is only about 5%.

3.4. Seeing conditions

Astronomical seeing or optical atmospheric turbulence plays a crucial role in determining the detection limit and the operating efficiency of a given telescope.

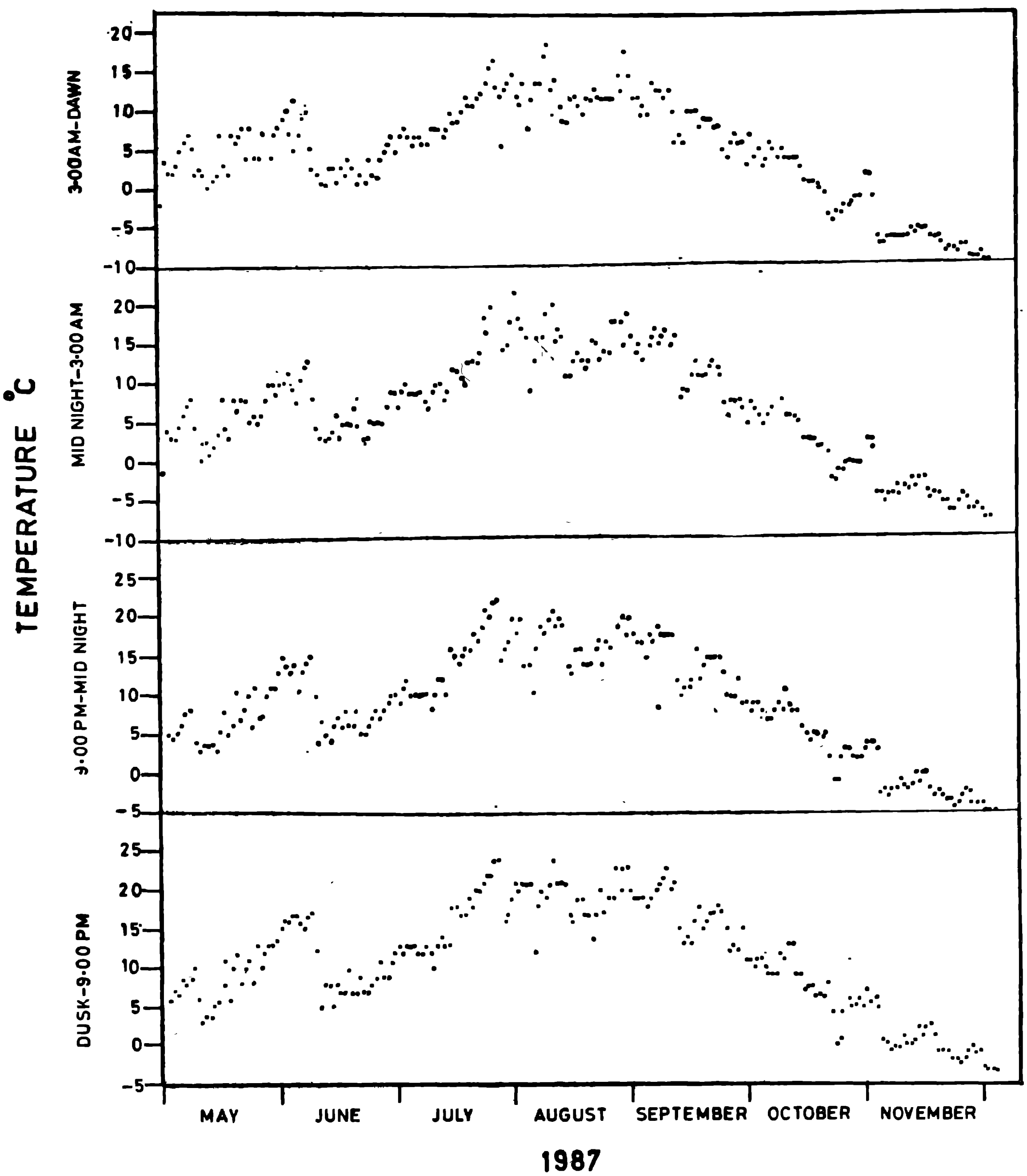

Figure 3. Values of temperature in the course of each night taken at an interval of 3 hours during 1987 May–November.

However, the precise measurement of the astronomical seeing has been rather difficult problem. The technique used in most cases is subjective and yields results that depend upon the method used. At the site in Leh, the method used was to see the image of a star in the eyepiece of the 50 cm telescope and then qualitatively judge the size of the image and the extent of its 'dancing' in arcsec against a small aperture of 9 arcsec. These estimates were made by

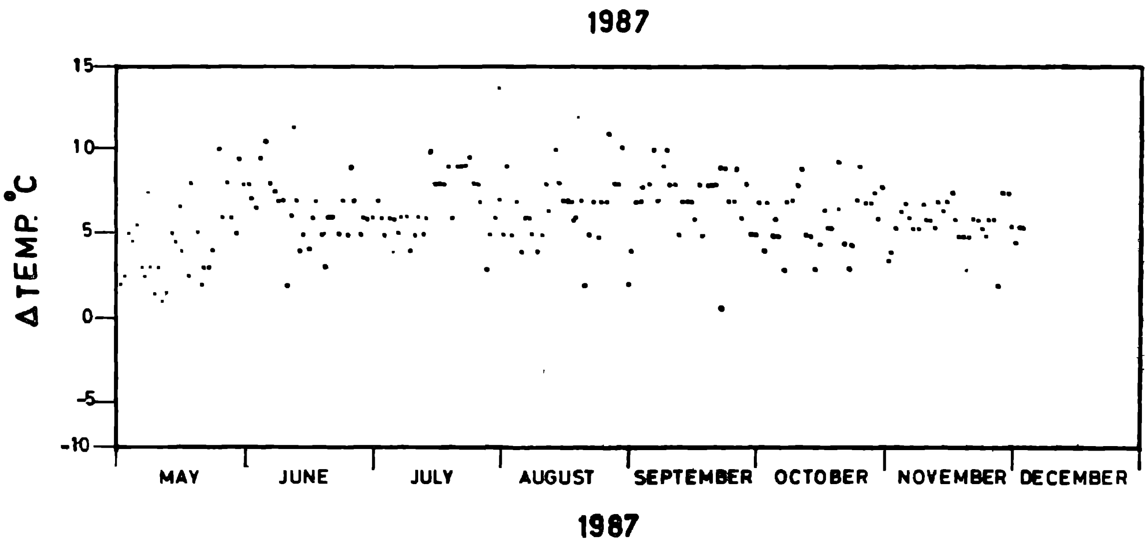

Figure 4. Variation of temperature between dusk and dawn during 1987 May–November.

three well experienced observers and may therefore, be assumed to be fairly reliable.

The seeing has been divided into four categories of < 1, 1–2, 2–3 and > 3 arcsec. These are given in table 3 as the number of hours during each month. August and September appear to be poorer with no nights having better than 2 arcsec seeing, whereas June and November appear better, with many nights with seeing of 1 arcsec or less. In general, a fairly large number of hours with the seeing better than 2 arcsec were available during the months of May, June, July, October and November with the month of November having the highest number, viz., 264 hours out of the 279 observable hours. These seeing conditions have been derived from the stars near the zenith; stars at lower altitudes display broader seeing distorted images.

Table 3. Seeing conditions in number of hours per month.

Month 1987	No. of hours with seeing (in arcsec) < 1	1–2	2–3	> 3
May	0	71	12	11
Jun	28	68	18	4
Jul	6	30	59	20
Aug	0	0	25	20
Sep	0	0	71	30
Oct	0	128	26	7
Nov	80	184	15	0

3.5. Transparency of the sky

As mentioned in paper I, the extinction coefficient k which is an indicator of the transparency of the sky was determined in the U, B, and V filter bands using the standard procedure. The values thus obtained are listed in table 4 as $k(v)$,

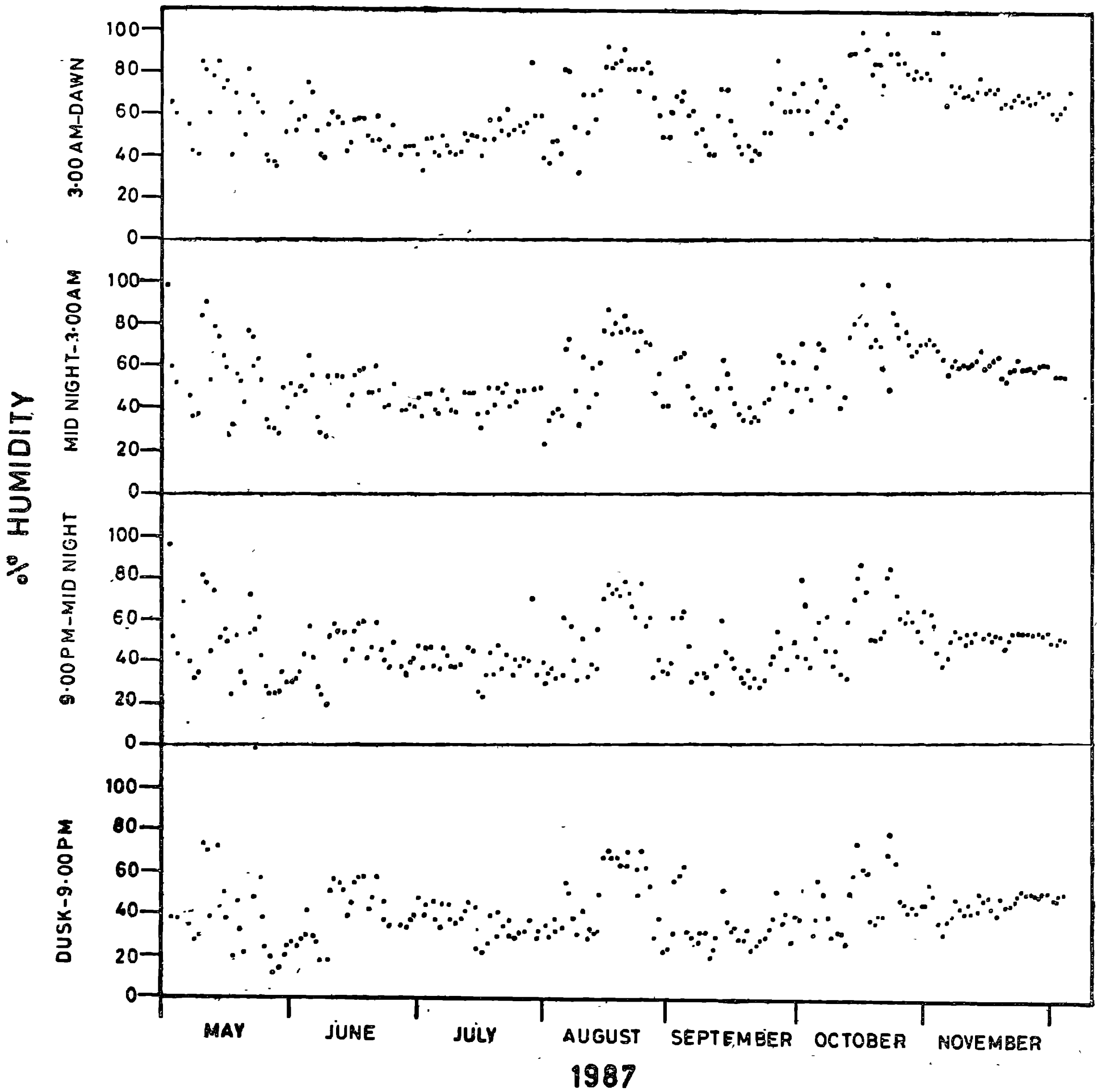

Figure 5. Values of percentage relative humidity during the nights taken at an interval of 3 hours during 1987 May–November.

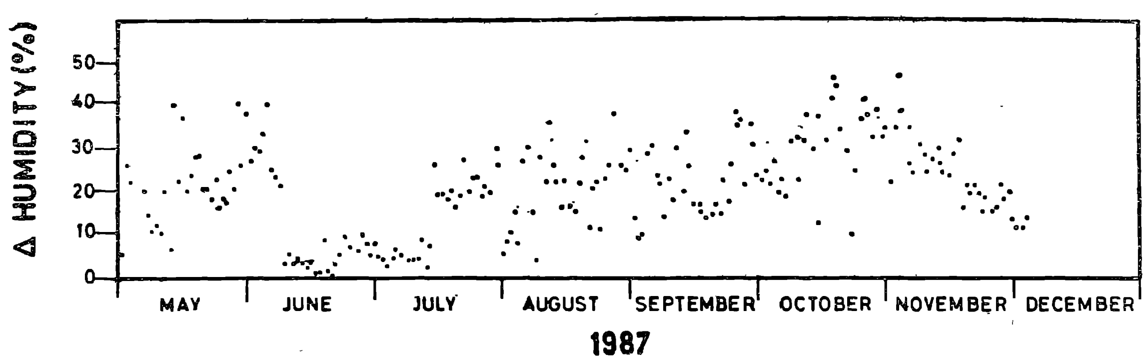

Figure 6. Variation of percentage relative humidity between dusk and dawn during the period 1987 May–November.

Table 4. Extinction coefficients

S. No.	Date	Star name	Sp. type	Mag. (V)	$k(v)$	$k(b-v)$	$k(u-b)$
1	1987 May 24	16 Com	A4 V	5.00	0.19 ± 0.01	0.09 ± 0.01	0.27 ± 0.02
2	,,	14 Com	FO p	4.95	0.20 ± 0.01	0.09 ± 0.01	0.22 ± 0.01
3	May 25	13 Com	A3 V	5.18	0.18 ± 0.01	0.10 ± 0.01	0.21 ± 0.02
4	,,	16 Com	A4 V	5.00	0.19 ± 0.01	0.07 ± 0.01	0.21 ± 0.01
5	,,	14 Com	FO p	4.95	0.19 ± 0.01	0.10 ± 0.01	0.18 ± 0.01
6	May 26	22 Com	A 4 V	6.29	0.16 ± 0.01	0.08 ± 0.01	0.23 ± 0.02
7	,,	23 Com	AO IV	4.76 R	0.16 ± 0.01	0.10 ± 0.01	0.24 ± 0.01
8	,,	β Com	GO V	4.28	0.15 ± 0.01	0.08 ± 0.01	0.23 ± 0.01
9	May 29	ι Lyr	B7 IV	5.17 R	0.15 ± 0.01	0.12 ± 0 01	0.22 ± 0.01
10	May 30	,,	,,	,,	0.19 ± 0.02	0.07 ± 0.01	0.22 ± 0.01
11	May 31	σ Boo	F2 V	4.45	0.15 ± 0.01	0.13 ± 0.01	0.27 ± 0.01
12	June 1	,,	,,	,,	0.17 ± 0.01	0.12 ± 0.01	0.26 ± 0.01
13	June 24	γ Ser	F6 V	3.85	0.16 ± 0.01	0.13 ± 0.01	0.27 ± 0.01
14	July 3	γ CrB	B9 IV + A3V	3.84	0.29 ± 0.01	0.08 ± 0.01	—
15	July 4	,,	,,	,,	0.16 ± 0.01	0.11 ± 0.01	0.23 ± 0.01
16	July 8	θ CrB	B6 V	4.14	0.23 ± 0.01	0.12 ± 0.01	0.28 ± 0.01
17	July 8	γ CrB	B9 IV + A3V	3.84	0.24 ± 0 01	0.12 ± 0.01	0.27 ± 0.01
18	July 19	θ CrB	B6 V	4.14	0.21 ± 0.01	0.08 ± 0.01	0.27 ± 0.01
19	July 21	,,	,,	,,	0.22 ± 0.02	0.12 ± 0.02	0.32 ± 0.02
20	July 28	δ CrB	G3.5 III-IV	4.63	0.19 ± 0.02	0.09 ± 0.02	0.33 ± 0.02
21	July 29	,,	,,	,,	0.25 ± 0 02	0.11 ± 0.02	0.32 ± 0.02
22	July 31	Kappa Aql	BO. 5 III	4.95	0.25 ± 0.02	0.11 ± 0.02	0.29 ± 0.02
23	Aug 6	α Del	B9 IV	3.77	0.23 ± 0.02	0.08 ± 0.02	0.31 ± 0.02
24	Aug 9	δ Aql	F3 IV	3.36	0.28 ± 0.02	0.12 ± 0.02	0.32 ± 0.02
25	Aug 25	λ And	G8 III–IV	3.82	0.11 ± 0 01	0.11 ± 0.01	0.15 ± 0.01
26	Aug 26	,,	,,	,,	0.13 ± 0.01	0.10 ± 0.01	0.21 ± 0 01
27	Sep 7	,,	,,	,,	0.11 ± 0.01	0.13 ± 0.01	0.19 ± 0.01
28	Nov 10	58 Aql	AO III	5.53 R	0.15 ± 0.01	0.09 ± 0.01	0.25 ± 0.02
29	Nov 12	,,	,,	,,	0.17 ± 0.01	0.11 ± 0.01	0.20 ± 0 02
30	Nov 13	ι Del	A2 V	4.42 R	0.14 ± 0 01	0.10 ± 0.00	0.24 ± 0.02
31	Nov 14	58 Aql	AO III	5.53 R	0.17 ± 0.01	0.09 ± 0.01	0.21 ± 0.01
32	Nov 16	ι Del	A2 V	4.42 R	0.12 ± 0.01	0.12 ± 0.01	0.23 ± 0.01
33	Nov 19	18 Tau	B8 V	5.64	0.12 ± 0.01	0.12 ± 0.01	0.28 ± 0.01
34	Nov 20	,,	,,	,,	0.14 ± 0.01	0.12 ± 0.01	0.28 ± 0.01
35	Nov 21	ι Del	A2 V	4.42 R	0,19 ± 0 01	0.07 ± 0 01	0.22 ± 0.01
36	Nov 23	θ_2 Tau	A2 III	3.41	0.12 ± 0.01	0.10 ± 0.01	0.32 ± 0.01
	Average				0.18 ± 0.05 (s.d.)	0.10 ± 0.02 (s.d.)	0.25 ± 0.04 (s.d.)

$k(b-v)$ and $k(u-b)$ along with the names of the standard stars observed. A plot of these quantities (figure 7) shows that $k(v)$ ranged between 0.11 mag and 0.29 mag, with the value being more than 0.2 mag only during the months of July and August. The plot of $k(b-v)$ shows a fairly steady value around 0.1 mag, indicating that $k(b)$ also behaved almost in the same manner as $k(v)$, but showing a greater extinction of 0.1 mag per air mass. On the other hand, $k(u-b)$ showed a variation which matches that of $k(v)$. The extinction in U band was much higher during the months of July and August.

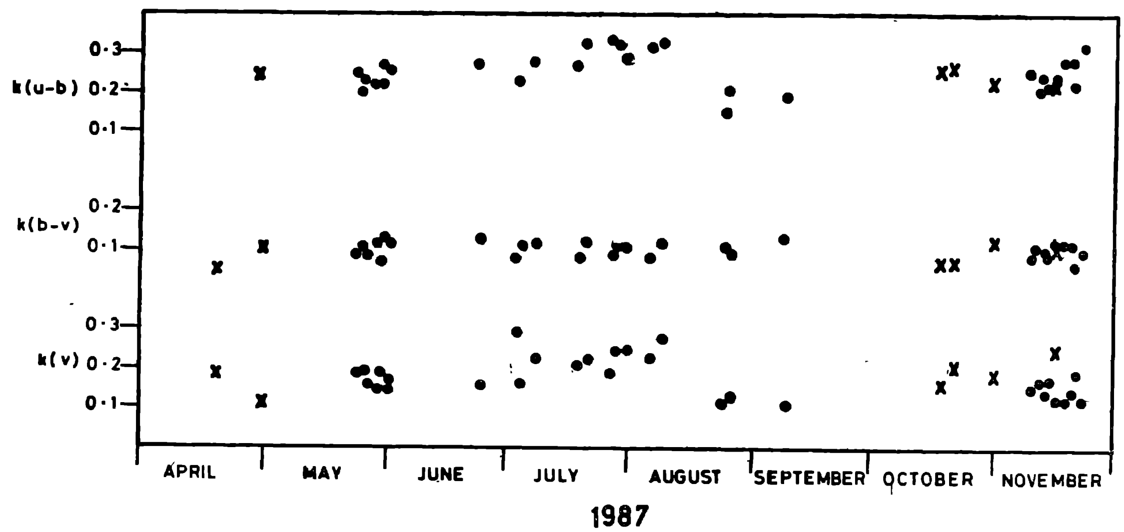

Figure 7. Extinction coefficients during 1985–87. × and ● represent the values of k in 1985–86 and 1987 respectively.

According to Walker (1986) the value of measured extinction coefficient in the broad band (~ 1000Å) blue and ultraviolet regions of the spectrum varies with the colour of the star, whereas at red and infrared wavelengths it is small and somewhat insensitive to changes in the transparency of the atmosphere. Thus, the best representation of k can be obtained from the observations through the V filter where the extinction coefficient is still relatively larger but independent of star's colour. Walker also mentioned that the effects of Rayleigh and aerosol scattering decrease with the altitude of the observing site, while Ozone absorption remains constant. The absorption by water vapour diminishes with the altitude of the site, and is negligible in the V band. The water vapour content in the atmosphere also depends on the geographical characteristics of the site.

In figure 8, we have reproduced two graphs from Walker (1986) showing the visual extinction coefficient $k(v)$ with altitude in a photometrically clear sky, both with and without aerosol contamination. In this plot we have also shown the mean value of $k(v)$ obtained at various observatories along with that at Leh (3500 m). Walker pointed out that as a general rule, a site will not be suitable for precise photometric observations if $k(v)$ is variable or more than twice as large as the value given by the gas plus aerosol curve. It may be seen that the mean value of 0.18 mag at Leh is less than double the value of about 0.11 mag at this

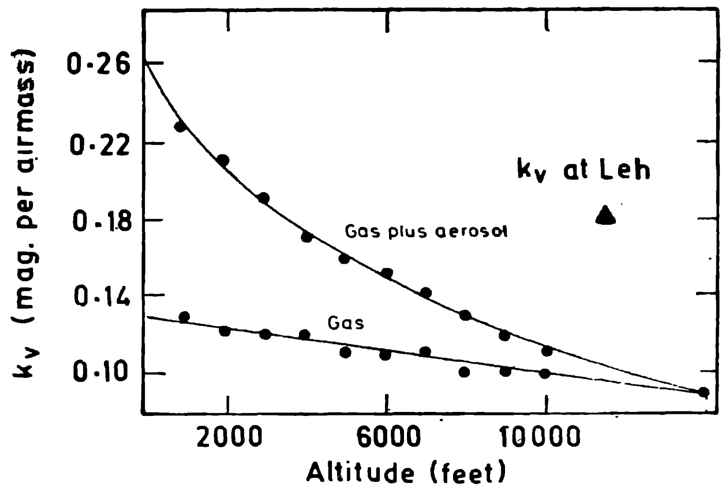

Figure 8. Variation in the visual extinction coefficient with altitude of the observing site above the sea level (adapted from Walker 1986). The lower curve is extinction due to molecules scattering and absorption by ozone. The upper curve includes the additional contribution from the atmospheric particles. The value at Leh, Kavalur, Kodaikanal, Naini Tal, and Canary islands are shown.

height for gas plus aerosol curve. The value at Leh becomes much better (~ 0.15 mag), if the months of July and August are excluded.

In figure 7, we have also plotted the k values obtained during the earlier years of 1985 and 1986. The average values of the extinction coefficients during the period of 1987 were $k_v = 0.18 \pm 0.05$ (s. d.), $k_b = 0.28 \pm 0.04$ and $k_u = 0.53 \pm 0.04$. These agree well with those of 1985–86.

4. Conclusions

During the 1987 observations at Leh 31% of the nights were found to be photometric and 40% spectroscopic. The average variation in temperature during the night was about 7 C. The relative percentage humidity varied between 20 to 90 and the change in relative humidity was about 5–40% during the nights. The months of October–November had more number of photometric hours and better seeing in comparison with other months. The atmospheric extinction coefficients during the period of 1987 agree well with those of 1985–86 and indicate consistent sky conditions.

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