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THE ASTRONOMICAL SEEING AT KAVALUR

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ABSTRACT

A summary of observing conditions at Kavalur Observatory is presented These relate to spectroscopic and photometric observations and to seeing as evaluated at the 102-cm telescope. Nearly fifty percent of nights on which observations can be made have seeing better than 1.5 arc seconds Best observing conditions are in the months December to April when a high percentage of the nights are also photometric There is some correlation of seeing with humidity, very good seeing is usually followed by a very low ground fog that fills in the valleys and ravines around Kavalur and seldom reaches the telescope that is located 20 metres above ground Three component layers apparently contribute to seeing effects in the tropics These are (1) thermal effects in the immediate vicinity of the telescope, (2) a layer, two to three hundred metres high which is the principal contributor and is orography dependent, (3) a high level contribution which is part of the large scale global circulation

Key words astronomical seeing — site testing

1 Introduction

The principal requirements of a site for optical observations in astronomy are clear, dark and transparent skies, with good seeing Other factors that undoubtedly influence the final choice are ease of access, availability of power and water, and the important aspect that the location pose no physiological problems to the observer, either by virtue of altitude or climatic rigour A compromise on these criteria, and of location, is guided by the purpose for which the telescope is to be used This main theme narrows down the choice in a relatively rare situation, when sites of comparable quality exist In 1882 N R Pogson, then Government Astronomer at the Madras Observatory had proposed the location of a 20-inch telescope in the Palni Hills, for making observations of an astrophysical nature Soon thereafter, Michie Smith carried out seeing tests at both Kodaikanal and Kotagiri in 1883 (Smith 1885) and in 1892 (Smith 1892) The decision to have an observatory at Kodaikanal devoted to solar physics was taken soon after and the new observatory started functioning in 1898. An account of atmospheric conditions at Kodaikanal, especially for observations at night, is summarised by Evershed (1915).

Experience at Kodaikanal in the late fifties and early sixties indicated that the total number of hours available in a year for stellar research ranged from 600 to a maximum of 900 The weather at Kodaikanal is quite unpredictable, but there are sufficient spells of good weather interspersed with longer spells of poor weather, when possibly some kind of work can be done However, it is obvious that a telescope of moderate to large aperture at Kodaikanal would work at considerably lower efficiency, than it would at a better site With this in mind, a search was made for an improved location that would be south of 13 N latitude, without giving away the advantages of the location of Kodaikanal from the standpoint of southern hemisphere astronomical research Several places were explored with this possibility in mind and after extended seeing tests of over a year, Kavalur, at latitute 12° 34 4' N, longitude 78° 49 4' E, altitude 725m, was chosen as a site for operation of a field station for stellar research, and where the now 102-cm telescope could be located

2 Climatology and Possible Astronomical Sites

The general pattern of cloudiness over India can be determined from the climatological data published by the India Meterological Department These indicate that the maximum cloud free areas are in the Rajasthan desert and that the skies become more cloudy as one moves towards the ocean or the Himalayas. The number of clear mornings and

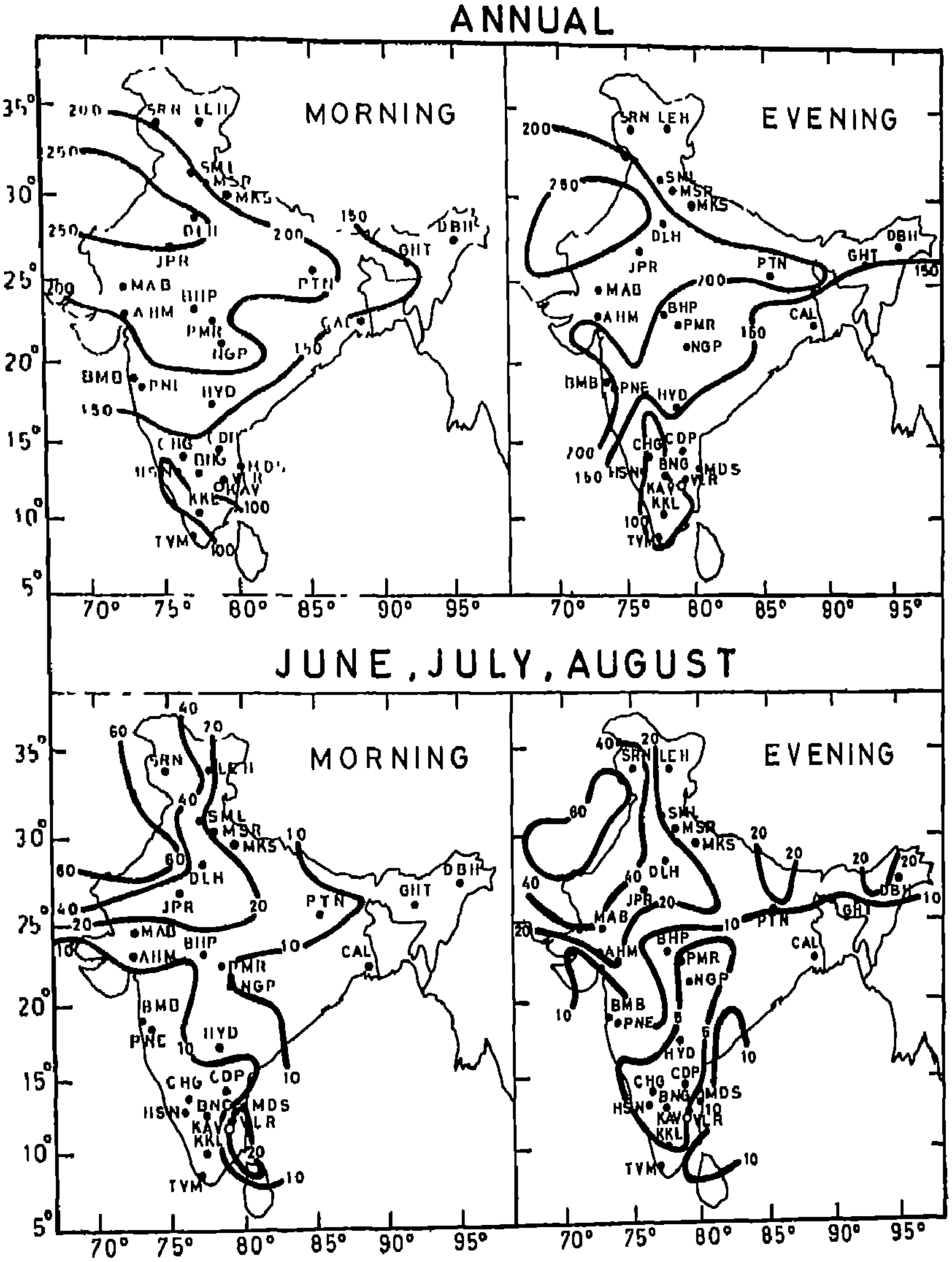

Fig. 1. Number of days with cloud amount less than three octas

evenings over the clearest regions exceed 250 in a year, while over the extreme southern tip of the peninsula, these average less than 100 days The patterns of variation are illustrated in Figure 1 We see that contours of equal frequencies of clear occasions generally follow the coastline and the Himalayan belt There are zones of unusual cloudiness, partly in the mountain regions, but other than these, the pattern is quite regular

Taking the year as a whole, a location with a maximum of skies is obviously desirable The extreme north-western location has several drawbacks Besides, the latitude of the zone is too high, as a result of which the region of interest in the southern hemisphere will be beyond the reach of the telescope The horizontal visibility is poor and the skies are dusty, thus severely affecting transparency

To be effective in exploring the southern Milky Way, an observing station needs to be south of atleast latitude 20°N Such a location falls in the peninsular part of the country and the effects of dust blown in from the deserts of the west are non-existent Regions of relatively cloud-free skies lie along the eastern slopes of the Western Ghats. They also prevail in the semi-arid areas of north-western Tamil Nadu The cloudiness is more in the extreme southern tip of the peninsula, particularly in the hilly areas. A suitable compromise will then be a station in the 10° to 15°N belt that is also far away from the coastal influence

Most of India, excepting the north western region, is heavily under the influence of the South-West Monsoon, when it is difficult to get any observable skies during the months of June to September In the low latitudes, the neighbourhood of the east coast provides some opportunity for astronomical observation In Figure 1, we note the prevalence of clear skies during these monsoon months and find that a relatively clear patch lies along the east coast, south of Madras The station Vellore, for example, shows a rather unusually large number of clear mornings during this period This factor had influenced us in the choice of Kavalur (60 km south of Vellore) over a decade ago, when we selected the site for the 102-cm telescope The clear nights in July and August provide an opportunity to work on the galactic centre as well as, much of Centaurus These nights are by no means as numerous as clear nights are in winter time, but they atleast provide some opportunity for examining a very important area of the galaxy and which certainly cannot be done by virtue of cloudy weather from the northern latitudes in this country These arguments influenced our search for a site for the proposed 234-cm reflector, to be confined to the eastern slopes of the Western Ghats or in the range of hills from Madanapalle to Salem In particular, extended seeing tests were made at two locations, Sakanagere (lat 13°30′ long 74°50′, alt 1221m) and Horsley Hills (lat 13°30′, long 74°50′, alt 1252m), before it was decided that Kavalur would be the site of the 234-cm telescope

Our first survey of possible sites for the 234-cm telescope covered most of the country from Cape Comorin upto Pachmarhi (lat 22°28′, long 78°26′, alt 1075m) which lies on a plateau of the Satpura range of hills in the midst of good jungle growth As a basis of comparison of general characteristics of the Himalayan foothills we have used the published information (Bappu 1960) pertaining to observing conditions at Naini Tal (lat 29°22′, long 79°37′ alt 1927m)

It is common experience that clear skies after the South-West Monsoon prevail over central India by September, thus providing October to be one of the best months for astronomical work in northern India Almost simultaneously this area of clear skies progresses to the south along a narrow corridor that covers Poona, Panchgani, Dharwar and the vicinity of Shimoga We were interested in determining whether the effects of the corridor of clear weather would be felt at Sakenagere Simultaneous weather observations near this location and Kavalur showed that the two stations, during the test period, had similar characteristics

However, when skies are clear in the regions we explored for possible astronomical sites upto Pachmarhi, we ran into the common difficulty seen all over the Gangetic Plains, of a strong ground haze under perfectly cloudless skies The haze is a serious handicap to good transparency This was so in the Aurangabad plateau and in the Panchgani area (alt 1270m)

A site of much promise in central India is Pachmarhi This location, like the foothill of the Himalayas, has heavy rains during the South West

Table 1. Observing conditions at Kavalur

	1973			1974			1975			1976			1977		
	Hrs of spec sky	Hrs of phot sky	Clear nights 100%	Hrs of spec sky	Hrs of phot sky	Clear nights 100%	Hrs of spec. sky	Hrs of phot. sky	Clear nights 100%	Hrs of spec sky	Hrs of phot sky	Clear nights 100%	Hrs of spec sky	Hrs of phot sky	Clear nights 100%
Jan	232	162	23	298	255	30	207	108	18	138	76	10	288	138	26
Feb	228	167	22	220	168	22	208	121	17	231	178	23	185	88	12
Mar	270	234	26	223	173	26	275	210	24	270	244	26	214	126	19
Apr	136	52	12	240	77	22	270	188	24	171	84	14	164	42	12
May	122	70	12	123	41	10	103	30	7	137	61	6	98	22	4
Jun	37	10	1	76	6	5	41	8	3	82	26	3	43	6	2
Jul	43	4	0	23	8	1	19	4	1	11	0	0	57	0	2
Aug	59	27	3	66	13	6	23	0	3	24	0	0	29	5	1
Sep	46	16	4	46	10	3	48	0	1	81	18	2	67	6	1
Oct	64	14	4	97	61	7	39		1	104	59	7	95	45	8
Nov	162	89	12	170	107	16	109	23	10	56	16	1	65	5	2
Dec	133	62	11	207	125	20	138	62	10	141	65	9	206	28	15
Annual Total	1485	886	130	1787	1034	167	1479	754	119	1446	836	100	1516	521	104

Mean Values
Spectroscopic hours = 1542
Photometric hours = 806
Clear nights of nine hour observation = 124

Monsoon, but has mostly clear skies the rest of the year. It is also on the periphery of the dust belt of northern India. Its location far away from industrial activity and large cities makes it a potential site for astronomical activity of the future. Seeing measures made at this location for a short duration indicate the possibility of a good performance on this aspect.

3 Observing Conditions at Kavalur

In Table 1, we present data on observing conditions at Kavalur as extracted from the log books of the 102-cm reflector. Each year of observation has 3 columns, the first giving the number of hours when the spectrograph was used or could have been used. The second column indicates the number of hours when photometry could have been done. This is based on estimates by the observer, of transparency during the night. The last of the three columns gives the number of 100 per cent clear nights. Such a night is defined as one of nine hours duration when work was possible and the clouds much less than 3 octes. The average number of spectroscopic hours is about 1642 with 52 per cent permitting photometry. The average number of 100 per cent clear nights is 124. It is of interest that during the period January-April when skies are very clear, the percentage of photometric nights is even larger than the value given above.

Seeing observations have been made at the 102-cm reflector either with the spectrograph slit width as a reference index or at the 20 cm guide telescope with its facility of angular measurement. With few lapses, these are available since 1973 at Kavalur. The data from the observer's log book are plotted for each night. Figure 2 is a sample page of seeing plots from which the average seeing for the night is derived. These data are plotted as histograms for each month. Figures 3-6 show histograms covering a five year period of observation at Kavalur.

Walker (1971) has similar histograms derived at some very well known astronomical sites like Cerro Tololo, Kitt Peak and Flagstaff. Some salient features of a comparison of Figures 3-6 with the Walker diagrams are (1) that seeing diameters of 6 to 7″ seen at other sites have not been seen at Kavalur even during the South-West Monsoon period, (2) that Kavalur has a very high percentage of its nights yield average seeing of a second of arc or better. This is best seen in Table 2 where the number of nights in any seeing range is expressed as a percentage of the total number of nights observed. The number of nights on which observations have been made are comparable in the case of Tololo, Junipero Serra, Kitt Peak and Kavalur. At Tololo, Junipero Serra and Kavalur the seeing is better than 2 arc seconds for nearly 78 per cent of the time. One can contrast this with a very active site like Kitt Peak which has seeing better than 2 arc seconds for only 39 per cent of time. Flagstaff which is well known for its long effort in planetary studies has seeing inferior to 2 arc seconds for 65 per cent of the time. This comparison shows that the seeing at Kavalur is as good as that prevalent at some of the top class sites in the world.

An interesting aspect of Kavalur's seeing is that it maintains its quality over most of the year. In Table 3 we compare the yearly values with those over the six month interval December to May when minimum cloudiness prevails. Such a situation ensures that when the weather is continuously good the seeing is also good and this contributes to efficient observing.

Table 2 Percentage of observed nights with different values of seeing

Location	Best seeing observed	Percentage of observed nights with average seeing as indicated				Total No. of nights observed
		< 1.0″	1.1″ to 1.5″	1.6″ to 2.0″	> 2.0″	
Tololo	0.70″	24	32	22	22	509
Junipero Serra	0.5″	26	38	13	23	559
Kitt Peak	0.75″	15	30	16	39	253
Canary Islands		50	29	10	11	38
San Pedro Martir	0.75″	15	25	17	42	52
Flagstaff	1.0″	1	5	29	65	80
Kavalur	0.5″	24.7	30.4	23.4	21.6	796

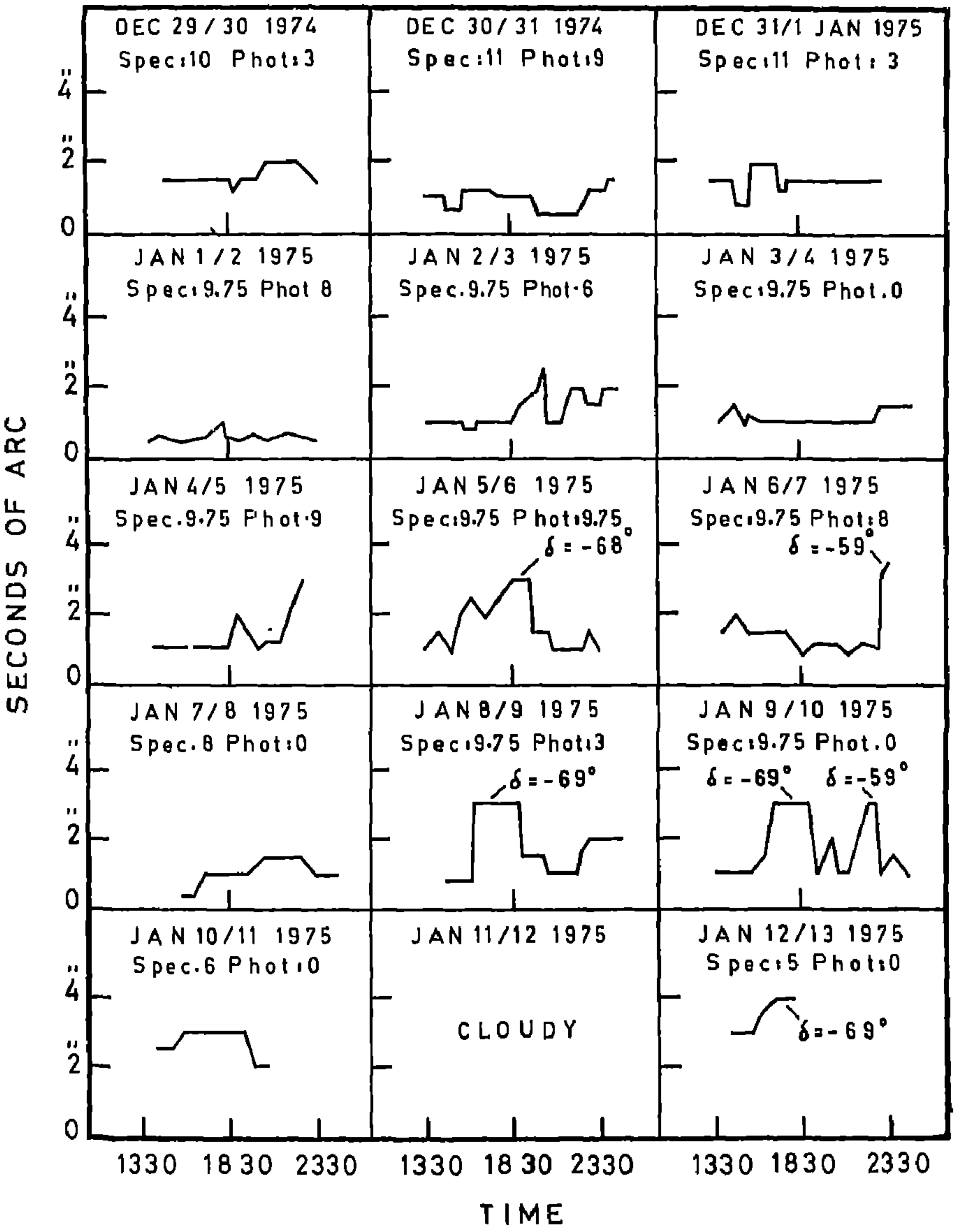

Fig 2. A sample plot of seeing evaluation during each night

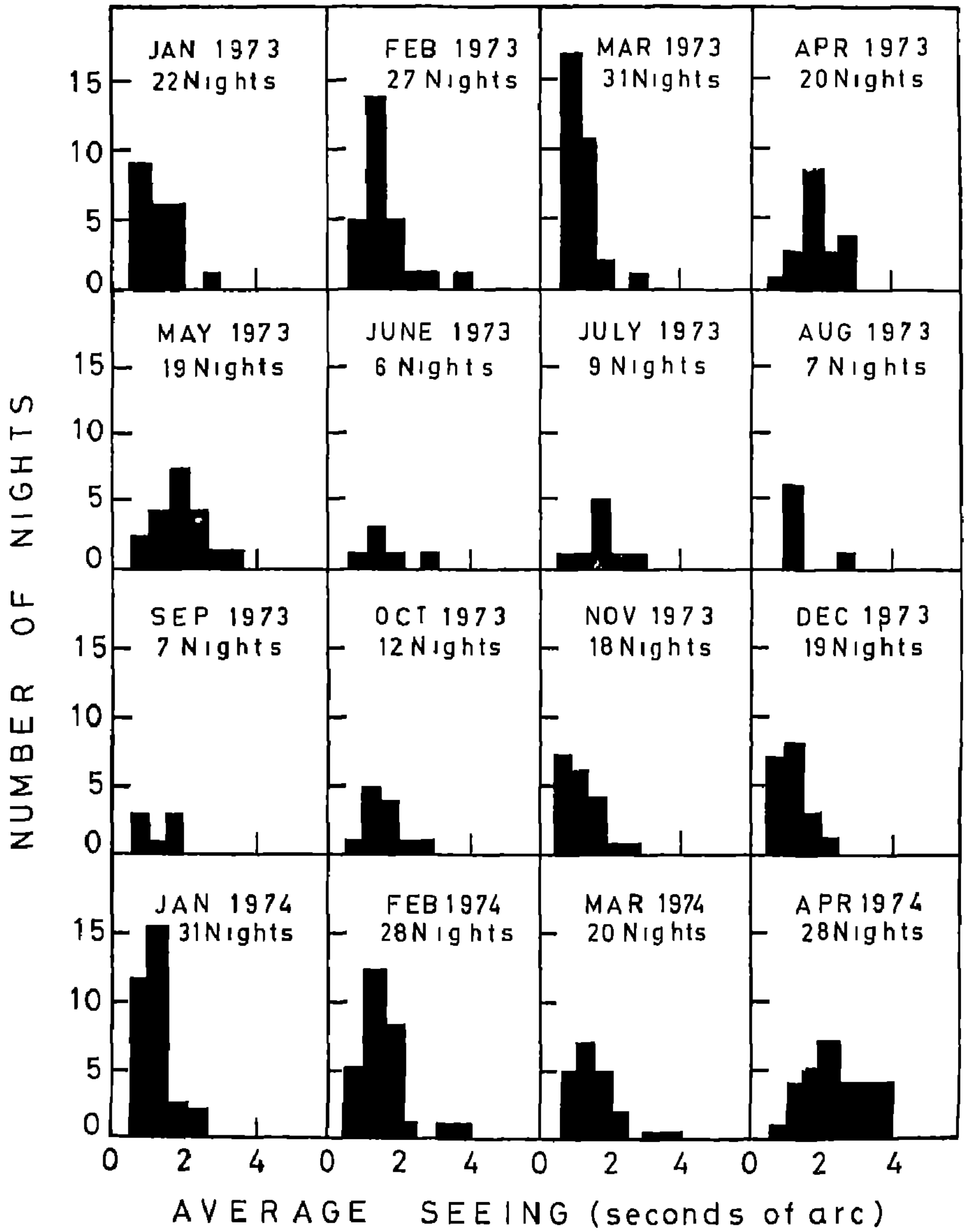

Fig 3 Histograms of Kavalur seeing

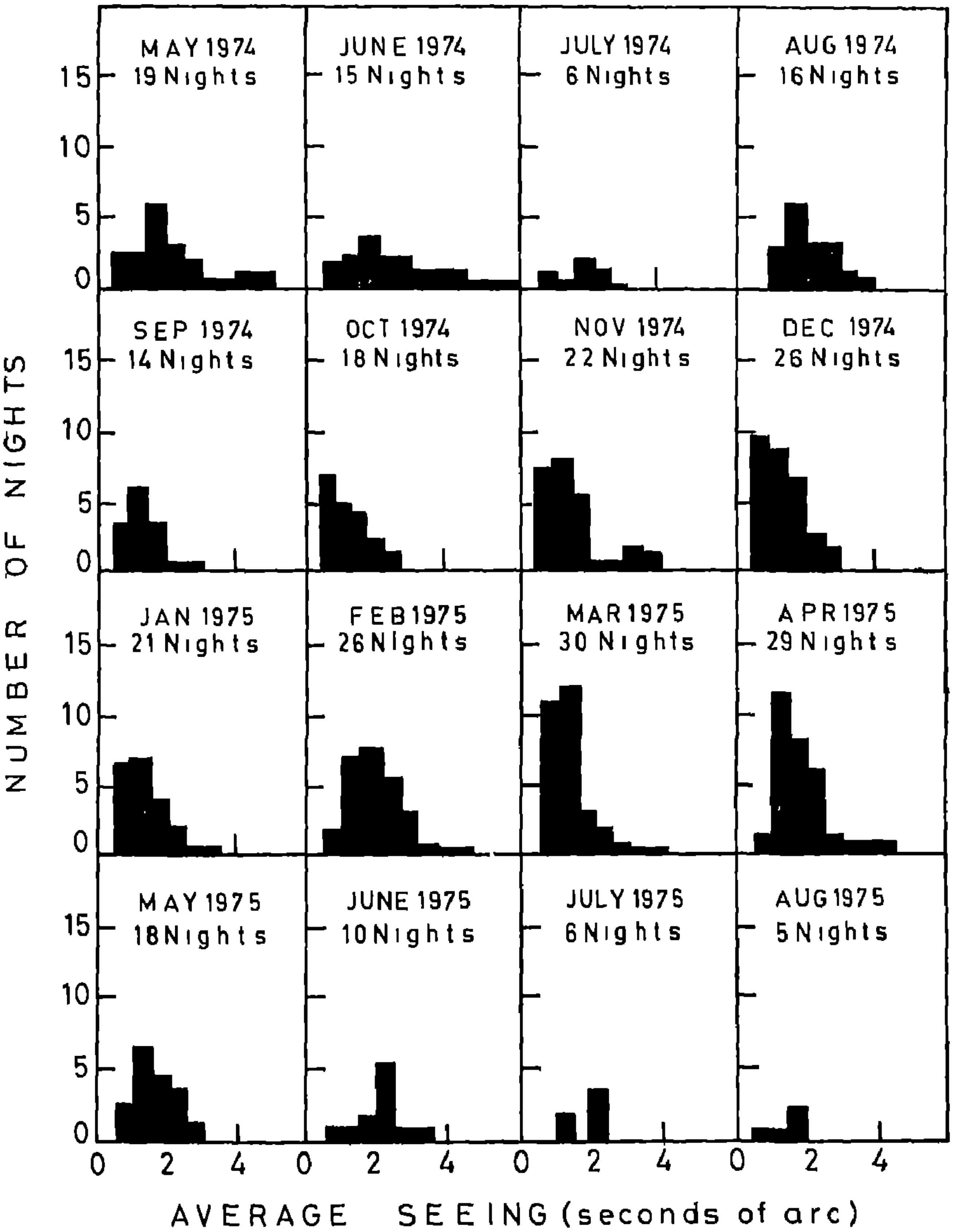

Fig 4 Histograms of Kavalur seeing

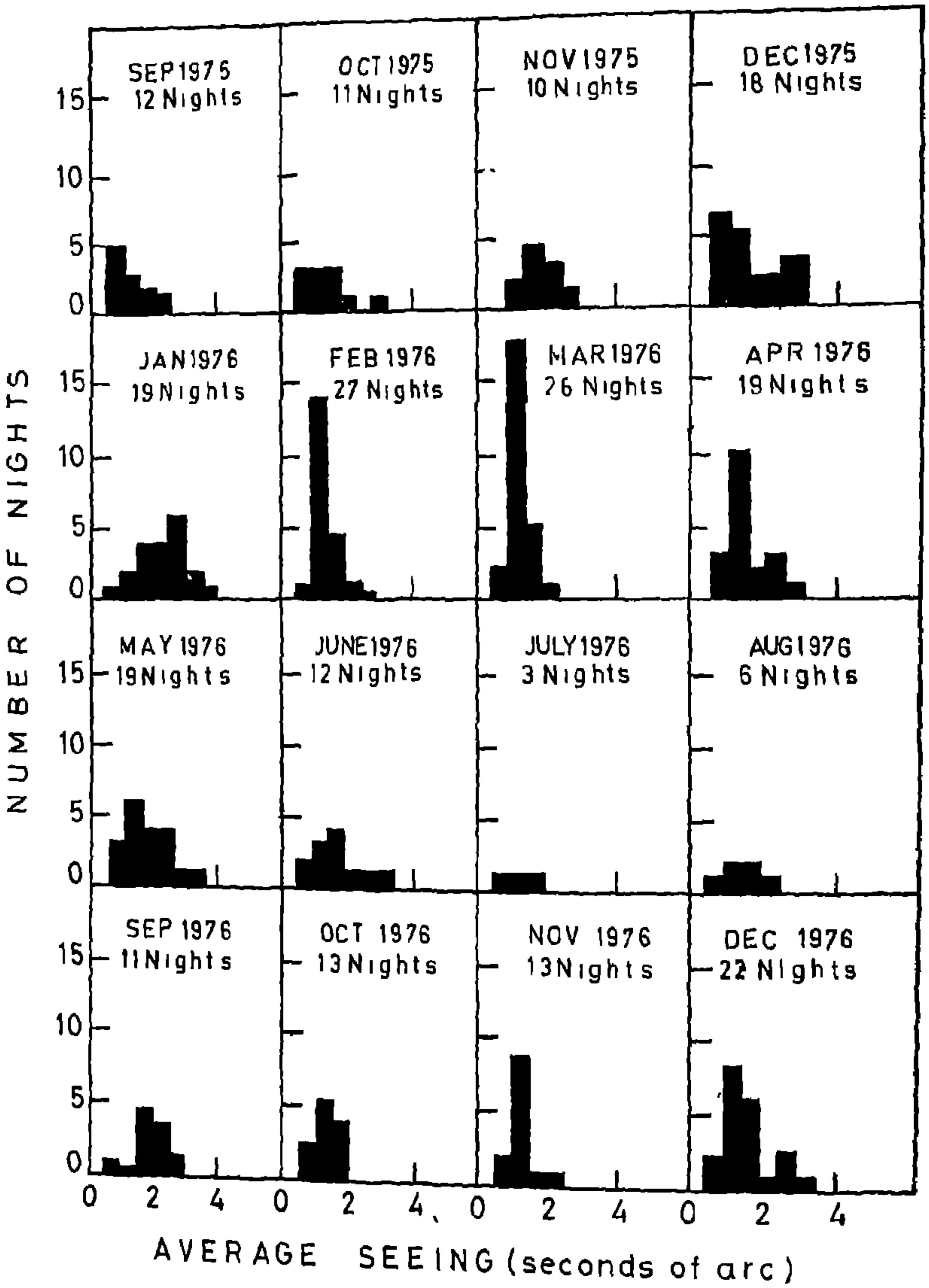

Fig 6. Histograms of Kavalur seeing

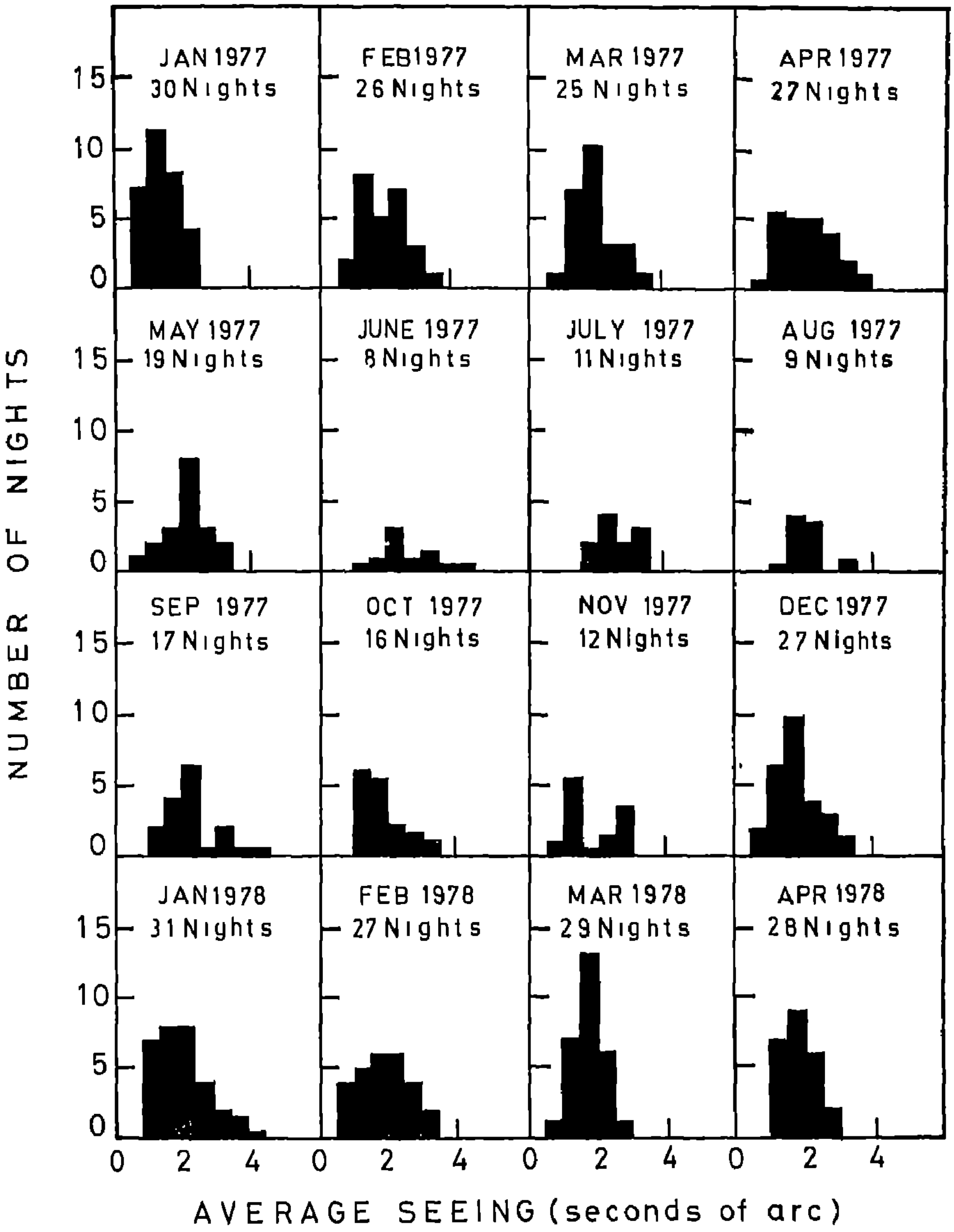

Fig 6 Histograms of Kavalur seeing

Table 3 Comparison of annual average seeing with values obtained in the period December to May

	Total number of nights	Per cent observed < 1.0"	1.1 to 1.5"	1.6 to 2.0"	> 2.0"
Average for 12 months	795	24.7	30.4	23.4	21.6
6 month period Dec to May	569	24.7	31.6	22.8	20.7

4 Transparency

The low latitude of Kavalur minimizes all possibility of largescale dust being brought in by air circulation from deserts at great distances. In fact on several occasions in September and January, coronal skies in the day time have been seen at Kavalur. This is surprising, since the altitude is only 725 m. But it is proof of the absence of dust that is typical at the higher latitudes in this country. A contribution to extinction from aerosols is unavoidable principally because of Kavalur's location in scrub jungle that is far away from the sea. Extinction values obtained with a spectrum scanner follow the pattern $K = 0.014\,\mu^{-4}$

Kavalur is also located far away from sizeable towns that in the years to come could offer the increasing hazard of city lights. Sky brightness measurements measured photoelectrically with a pulse counting photometer on the 102-cm telescope indicate a brightness value of 20.93 mag (arcsec)$^{-2}$ through a V filter at the zenith.

5 A discussion on seeing

We have made a comparative study of seeing at Kavalur and other sites from the data of Table 2. The data for sites other than Kavalur are those provided by Walker (1971), McInnes and Walker (1974), and have been obtained by Walker's seeing monitor of 15-cm aperture. The Kavalur observations are principally extracted from the records of the 102-cm telescope. About eighty per cent of these values originate from the observers estimate of image diameter with the width of spectrograph slit of known dimensions and comparable size. Since seeing monitors of portable sizes are utilized to estimate seeing qualities of sites for locating moderate to large aperture telescopes, one can hardly deny the greater reliability of a value when the seeing estimate is made with the large telescope itself. Under these circumstances, a comparison of the Kavalur performance with that of some of the established good sites is indeed very favourable. The last column of the table indicates the large time interval covered and hence the fact that it is a sustained performance with good repeatability from year to year.

The 102-cm telescope is located in a titanium oxide painted dome and tower at a height 20 metres above the surroundings. The improvement in seeing by virtue of the height is quite marked, we reach this conclusion on the basis of simultaneous seeing observations made at the 102-cm telescope and a 60-cm telescope at ground level.

Walker (1971) concludes from his studies along the West Coast of the North and South American continents that sites located on isolated mountain peaks near coasts that have cold currents off shore, or isolated locations in cold oceans, provide the best seeing. While this is true for the limited sites he has examined, we note that comparable seeing exists at many sites that have no cold oceans in their vicinity. The west coast of the Indian peninsula hardly has this qualification and Kavalur is very much inland with a ring of hills around it that are about a thousand feet higher. Also of considerable interest is the report by Pickering (1919) of seeing conditions in Jamaica. Good seeing prevails at many places in the tropics at sites near the ocean or far from it, and which are mostly governed by the general orography of the location. The spells of high quality seeing at Kavalur are usually followed by a rise in relative humidity and the appearance of a low level ground fog. This would seem to indicate a principal role of minimum disturbances in a layer not higher than two or three hundred metres above the telescope. Three component layers may then be said to contribute to seeing effects in the tropics, (a) the immediate vicinity of the telescope where the bad effects are reduced by locating the telescope at a height above the ground and by proper thermal characteristics of the dome and observing area, (b) a layer three hundred metres high which is the principal performer (c) the high level atmosphere that is part of the large-scale global circulation. The first contributor is controllable, the second can be searched for, while the third has to be accepted for what it is. We, therefore, know so little on what characterizes good seeing, that the best approach to choice of a good site still continues to be one of tedious search, preferably with a telescope 50 to 100-cms aperture.

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