Bull. Astr. Soc. India (1996) **24**, 859–869

Recent astronomical site survey at Hanle, Ladakh

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Abstract. The aspirations of Indian astronomers for a high altitude observatory have led to the exploration of Hanle, southeastern Ladakh as a possible site. After a discussion of the historical background, we present results of the first year of continuous site survey carried out by the Indian Institute of Astrophysics. This high altitude (4500 m) cold desert merits serious consideration due to low atmospheric water vapor, good seeing, low extinction, low sky background, a good number of spectroscopic and photometric nights, and approachability.

1. Introduction

1.1 A good observatory site

The essential requirements for a good observatory site are : (1) availability of a large number of hours of clear could-free skies in a year; (2) very good seeing; (3) low atmospheric extinction; (4) low sky background emission; (5) absence of radio and microwave radiation; (6) unlikelihood of future deterioration; (7) low precipitable water vapour content; (8) accessibility through all weather roads; (9) availability of basic amenities such as water. Given the stringent criteria for excellent astronomical sites, it is understandable that there are only a few first-class sites on the earth. The already identified ones fall into two categories: (1) certain island sites, such as Hawaii and La Palma (Canary Islands), and (2) coastal sites such as the Chilean coast and the southwest African coast. Good sites are generally located in the sub-tropical zone (25° - 35° positive or negative latitudes) and are mostly located at high altitudes, typically 2000 m or more above the mean sea level. Though the coastal and island sites are understood in terms of meteorological models, it has become apparent during recent years that excellent inland, high altitude sites exist in Antarctica and to the north of Himalayas (Tadjikistan, Uzbekistan, Tibetan plateau and near its northern boundary) which are not yet understood in the framework of these models (Murdin 1996). However, one expects that a high-altitude cold desert will have most of the advantages listed above, because of reduced amount of atmosphere above the site.

The occurrence of monsoons and severe summer storms and winter cyclones render very large tracts of India unfavourable for astronomical observations. Among the existing astronomical observatories in India (Kavalur, Rangapur, Gurshikhar, Naini Tal), Gurushikhar stands out above others, though it does not have all the advantages of a high-altitude site and is affected by dust and light pollution. The Indian astronomical community has hence been looking for a site which has the advantages of both the high altitude and clear skies.

1.2 *Early survey in Ladakh*

The first systematic site survey in the country that has been fully documented is the Leh site survey done during 1984-1989 under the sponsorship of DST. A mountain top, at about 25 km from Leh and 3 km from Leh-Srinagar metalled highway, was chosen as a prospective site. It was an inter-institutional project and the Indian Insitute of Astrophysics formed the single largest unit participating in it (Singh *et al.* 1988, 1989, 1990; Bhattacharyya *et al.* 1990). Almost all the aspects of an astronomical site survey were addressed. The study "concluded that Mt. Nimmu site is acceptable as regards the following parameters : (i) zenith precipitable water vapour (ZPWV), (ii) temperature variation (ΔT) during night time, (iii) wind speed and direction, (iv) relative humidity, (v) astronomical 'seeing', (vi) day sky brightness (marginally acceptable), (vii) night dark sky brightness (marginally acceptable), (viii) extinction coefficients in UBVIJH bands, and (ix) microthermal temperature fluctuations. Due to low percentage of the available clear weather, this site may not be acceptable for optical observational astronomy... It has been found that on an average only 52% useful nights per year are available at Mt. Nimmu. Therefore this site may not be as good as the best sites elsewhere in the world for large optical astronomical observations. Even within India, other comparable observatories seem to be marginally better than Mt. Nimmu" (Bhatnager & Gandhi 1991).

The primary reason for poor weather around Leh region in its location in the Indus Valley, in a crevice in Ladakh mountains, overlooking the Zanskar range which does not fully deter the clouds from sliding over them. It was hence imperative that one moves away from this region and closer to the Tibetan plateau.

1.3 *Fresh effort : Reconnaisance trips*

While the Leh site survey was in progress, it was suggested "If Mt. Nimmu is unacceptable, extend the survey project by another two year period to find out the suitability of other sites eg. Khardung-La (18000 ft), Taklang-la (17000 ft) etc. and take up the feasibility study of a remote-operated infrared telescope in collaboration with Department of Space" (Bhattacharyya 1987). Unfortunately, this step could not be taken immediately.

In the 1990s, as the consensus on the need for a National Large Optical Telescope (NLOT) began to grow, the NLOT Working Group focussed its attention on the choice of an appropriate site for the large optical telescope. Based on available meteorological data, the regions around Dalhousie in Himachal Pradesh and Devasthal in Kumaoun Hills appeared promising. There was very little meteorological information available on the upper and trans-

Himalayan regions. Hence INSAT 1B and LANDSAT images of these regions were examined and simultaneous reconnaisance trips were undertaken to six sites in 1993 September. The sites were (i) Vasuki Tal region near Kedarnath, U.P., (ii) Lamdal area in H.P., (iii) Kalpa area, Kinnaur, H.P., (iv) Kaza, Spiti, H.P., (v) Hanle region in south-east Ladakh and (vi) Tso Moriri in south-east Ladakh. All these sites were at an altitude of 4000 m or higher.

Six teams, each consisting of 5 or more members, visited these locations in 1993 September for about a week. The accessibility of the sites, general weather conditions, wind pattern and a variety of related aspects were studied. Hanle region was chosen for further in-depth study based on the criteria such as relatively less cloudiness, approachability, low precipitation and local topography conducive to good seeing. Further trips were made to Hanle by the teams consisting of astronomers and engineers in 1994 January, partly as endurance tests during winter, and in 1994 August to study the feasibility of observations from the peak.

The Hanle region includes mainly a large, more-or-less flat, high altitude plain in south-east Ladakh. The plain, bearing the name 'Nilamkhul Plain', is roughly elliptically shaped, with a major axis of 13 to 14 km running in the direction ENE to WSW, and a minor axis of 5 to 6 km in the direction of NNW to SSE. Somewhat off centre, towards the ENE end of the plain, is a hill with a fairly flat top affording an area of about half a square kilometer. The altitude of the top is 4517 meters above msl; the average altitude of the plain immediately surrounding the hill is 4240 metres above msl. The coordinates of the peak are, approximately, latitude : 32° 47' north, and longitude : 78° 57.5' east. The plain is bounded to the east by the southern Karakoram mountain range, and to the north, west and south by the Ladakh, Zanskar and Rupshu mountain ranges. It appears to have been formed by the glacial activity during the last ice age and subsequent meanderings of the Hanle river and smaller streams criss-crossing the plain on their way to the river. While the mountain ranges obstruct the passage of clouds to the Hanle region, the horizon obstruction is minimal and the local topography helps stabilizing the atmosphere.

Hanle can be accessed the year round by road from Leh. There is a metalled road running south-east, connecting Leh to the sub-divisional town of Nyoma about 180 km away; this is normally five-hour drive. The metalled road continues upto the Loma bridge near the confluence of Hanle river with Indus (201 km). There is an unmettaled road (49 km) beyond, connecting the Hanle Monastery, which forms an entrance to the Nilamkhul plain. There are tracks in the Nilamkhul plain, right up to the foot of the hill, which can be negotiated by jeeps, trucks and the minibuses that connect nearby villages to Leh.

As is the case for most of the Ladakh region, Hanle is a very dry area and is—in essence—a high altitude, cold desert. The main sources of information — prior to the current site survey — on the incidence of cloudiness were the units of the defence and paramilitary forces stationed in the area, the civil authorities in Nyoma and the personnel of the GSI who have been surveying the region. From these sources, estimates of the number of clear days / nights per year range from 250 to 300. It has been observed that sometimes there is a local formation of patches of clouds, starting around mid morning, which however tends to dissipate by early evening. The information from paramilitary forces indicated that in the winter months there may be two or three spells of snowfall, each lasting a few days, during which the sky is fully cloudy. The total annual precipitation is of the order of 1 cm. This statistics of cloudiness was corroborated by the analysis of satellite maps. Some meteorological data available from the paramilitary forces situated in a hollow between the surrounding hills shows that the wind speed is generally very low.

2. Observations

There is a continuous presence of astronomers of IIA at Hanle since 1994 December 23. The astronomers participating in the site survey have anywhere from 5 to 20 years of observing experience in the night-time astronomy. Many of them have experience in previous site surveys at Leh and / or Devasthal. In addition, fairly senior astronomers have participated in the site survey, spending altogether 7 months in Ladakh during the first one year. A satellite communication link between Bangalore and Hanle was established in September 1995 and has helped in monitoring the progress on a daily basis.

The main task undertaken during the first year was to monitor the cloud cover, temperature and humidity on an hourly basis. This data is complete to 90% level. The observations are made from a site near the edge of the plains due north of the hill, where logistic support was easily available. The cloud cover is not likely to be substantially different at the peak compared to the current location. However, ground fog will certainly be higher at the current location which is situated in a crevice in the surrounding hills. The humidity and temperature profiles during the night will also be more favourable at the peak due to laminar flow and reduced convection in air current.

In addition to the meteorolocial parameters, the atmospheric extinction and sky brightness, precipitable water vapour, and astronomical seeing were estimated on a few occasions. In these cases also, the measurements will give a lower limit on what can best be achieved from the peak.

The results of the first year of site survey are presented in the following sections.

2.1 Statistics of observing nights

Definitions :

1. The length of the observing night : The interval between the evening astronomical twilight and the morning astronomical twilight is taken to be the length of the observing night. At Hanle, it varies from about 6 hours (in June) to about 11 hours (in January) with a mean value of 8.5 hours. This criterion is strictly applicable to optical photometry only. Infrared observations and optical spectroscopy can be carried out beyond this interval as well.

2. Photometric night : An observing night is considered to be photometric if the sky is cloudfree (cloud cover = 0 octas) for 4 or more hours continuously. Such night hours are counted as photometric hours.

3. Spectroscopic night : An observing night is considered to be spectroscopic if the cloud cover is less than or equal to 3 octas for 4 or more hours in not more than two stretches. All photometric nights are therefore also spectroscopic by definition.

An analysis of cloud cover for Hanle following the above definitions is given in Table 1 for the period 27 December 1994 – 26 December 1995. Figure 1 shows the same results as histograms.

Table 1. Monthly distribution of observing nights / Hours at Hanle (1994 December – 27 December 26)

Month	Total No. of		Photometric				Spectroscopic			
			Nights		Hours		Nights		Hours	
	Nights	Hours	No.	%	No.	%	No.	%	No.	%
Jan.	31	310	20	64.5	176	56.8	23	74.2	209	67.4
Feb.	28	270	7	25.0	57	21.1	13	46.4	95	35.2
Mar.	31	250	8	25.8	56	22.4	18	58.1	115	46.0
Apr.	30	216	7	23.3	44	20.4	15	50.0	97	44.9
May	31	186	14	45.2	90	48.4	18	58.1	114	61.3
June	30	150	23	76.7	130	86.7	25	83.3	148	98.7
July	31	175	12	38.7	69	39.4	16	51.6	97	55.4
Aug.	31	204	2	6.5	16	7.8	5	16.1	34	16.7
Sep.	30	233	16	53.3	129	55.4	22	73.3	174	74.7
Oct.	31	279	26	83.9	221	79.2	29	93.6	258	92.5
Nov.	30	270	23	76.7	200	74.1	24	80.0	227	84.1
Dec.	31	305	10	32.3	85	27.9	13	41.9	108	35.4
Total	365	2848	168	46.0	1273	44.7	221	60.6	1676	58.9

The astronomical twilight was excluded from the definition of an observing night mainly from the point of view of observing faint objects in the optical region. Spectroscopy can be carried out during the twilight hours as well. Observation in the infrared bands can be carried out during and beyond the twilight hours. If one excludes only half an hour after sunset and before sunrise, the total number of useful hours increase by over 200. Some useful data can be obtained even on nights which are partially clear for 3 hours. If we define these nights as usable nights, we obtain

Total number of usable nights : 250
Total number of usable hours : 2000

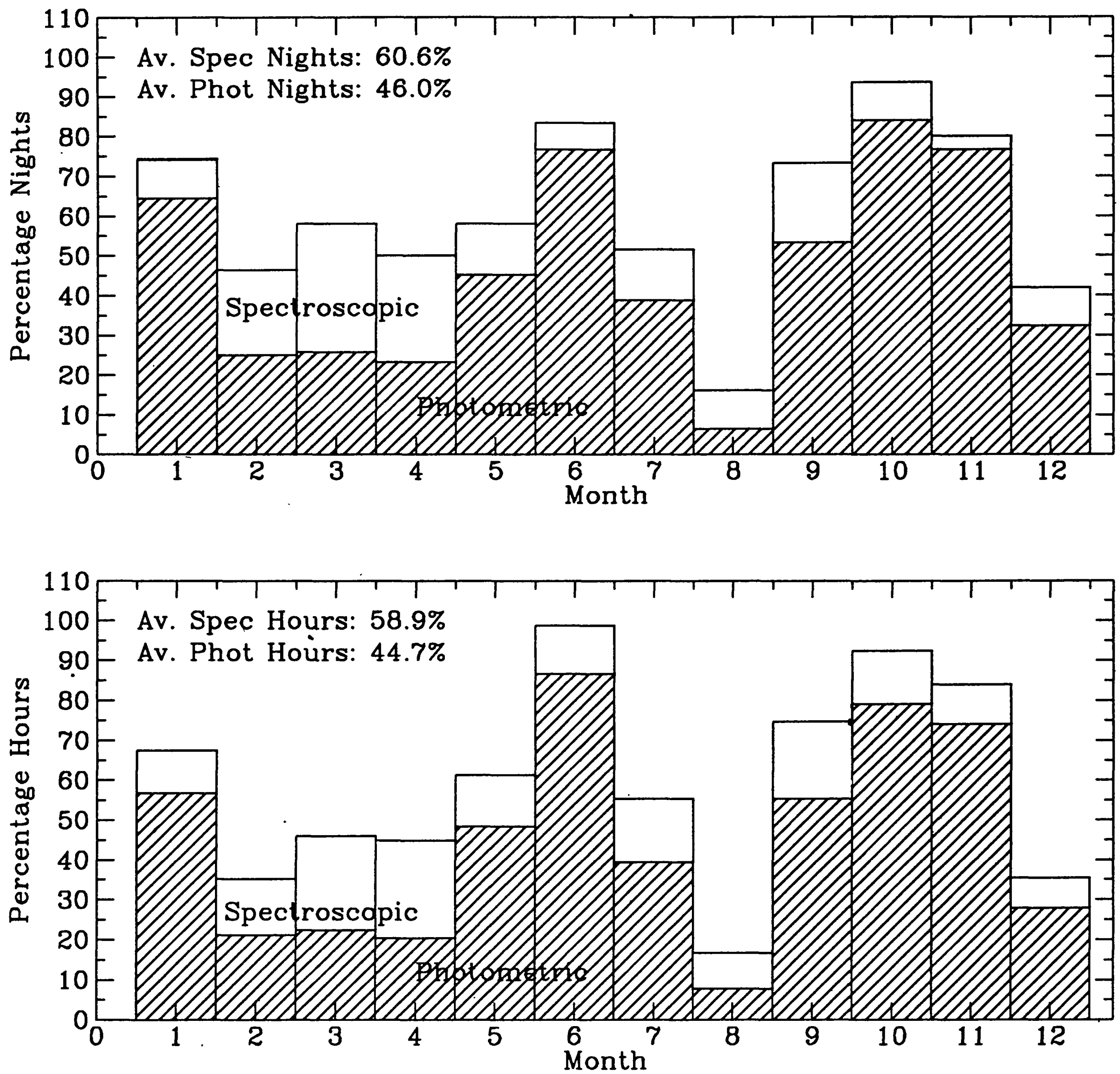
Av. Spec Nights: 60.6%
Av. Phot Nights: 46.0%
Percentage Nights
Spectroscopic
Photometric
Month
Av. Spec Hours: 58.9%
Av. Phot Hours: 44.7%
Percentage Hours
Spectroscopic
Photometric
Month

Figure 1.

On the other hand, if we require a night to have at least 6 hours of cloud-free sky, the percentage of photometric nights reduces by about 9% and hours by less than 5%. The exceptionally good nights, that are clear from dusk to dawn, were 104 during the period. All these statistical measures are better than at Lowell Observatory, Arizona (B. Skiff 1996 on vsnet usegroup), for the same period and will be discussed again later.

Table 1 and Figure 1 bring out the main advantage of Hanle that the effect of monsoons is negligible. The useful nights are almost equally distributed over the year with a significant dip only in the month of August. This helps observations of objects spread over the entire range of right ascensions which have significant bearing on international compaigns involving longitudinal coverage, simultaneous observations in different bands, coordinated ground and satellite-based observations, etc. No other site in India whether in the foothills of Himalayas, or to the south of it has such an advantage.

The lengths of continuous stretches of clear nights and of useless nights are also parameters useful in judging the probability of getting useful data from a given site. The cloud data shows that there were 7 stretches of clear spells when photometry was possible for over a week at a stretch. These spells occurred in the months of January, May, June, September, October and November. The longest of these stretched for over two weeks during May / June. About half the photometric nights are in stretches longer than one week and 75% of the photometric nights are in stretches longer than two days. The stretches of spectroscopic nights are longer, the longest stretching for over three weeks in September. Again, about half the spectroscopic nights are in stretches longer than a week and about three-fourth are in stretches longer than two days. Many good stretches are separated by only one or two useless nights as seen from the statistics of bad stretches which peak around one or two nights. The average lengths of photo metrically useful and useless spells are 2.9 and 3.8 nights respectively. Thus, if an observing period stretches for a week, there is a fair chance that one finds more than half the time useful.

2.2 Precipitation

Information on the annual pattern of snowfall and rainfall is useful in planning time allocation as well as for taking necessary precautions for the maintenance of equipment. Though meterologically accurate estimate of this parameter was not made, qualitative description was noted down whenever snowfall or rain occurred. It was found that, as expected, Hanle is an extremely dry site making it substantially easy to maintain optical and other components, in addition to providing useful nights in all the months of the year and thus helping to observe objects at all right ascensions.

A small amount of snowfall occurs at Hanle during the winter months. During the first one year, it was noticed that there was light snowfall (of the order of a few mm) roughly once a month during December - March. There was snowfall of the order of a few cm in the month of April. The total snowfall was about 4 cm at stick which corresponds to about 3 mm of precipitation.

The rainfall occurred only during July / August. The onset of monsoon was heralded by fine drizzle lasting for about 10 to 20 minutes on 3 occasions between July 20 and 22. There was intermittent drizzle between August 1 and 13. This could be marked as the peak of monsoon. Following this, there was a clear spell of a few days. Thereafter, it drizzled again during August 18-28, albeit less often. The estimated amount of total rainfall is about 2 cm during the entire monsoon period. It should be mentioned that the rainfall in Ladakh was considered to be more than usual during 1995 by the local population.

2.3 Temperature and relative humidity

Information on temperature and relative humidity are vital in planning human endurance and equipment specifications. The data for 1995 show a minimum temperature of –26.7° C in January and a maximum of +34.3° C in June. The night-time maximum was +21.2° C in July. The average night temperature was –17.5°C in January, increased to +12.0° C in July and dropped to –12.4° C in December. The average night-time humidity over the year was 65 ± 9%. The values include both usable and useless nights. The photometric nights were colder and drier. The driest month was May when the relative humidity reached a value of 10% during the day and 18% during the night. One expects the peak to be colder and drier compared to the current camp location. Even so, the observing time loss due to humidity above 85% was about 3% of photometric and spectroscopic hours.

The low ambient temperature during a better part of the year implies reduced atmospheric emission in the infrared and ease of operating the astronomical detectors which usually need to be cooled to reduce thermal emission. In fact, it was possible to operate a Peltier-cooled CCD at –50°C in winter!

2.4 Precipitable water vapour in the atmosphere

Precipitable water vapour at Hanle was measured with the water vapour meter belonging to the Physical Research Laboratory (PRL), Ahmedabad. Measurements were made on 15 days during the period between 26 March and 27 April, 1995 with the Sun as the radiation source. The measured values were converted first to precipitable water vapour in millimeters using a calibration curve and then reduced to the zenith (ZPWV). The cumulative histograms of daily mean values are listed in Table 2.

Table 2. Cumulative percentage histograms of daily mean values of precipitable water vapour reduced to zenith (ZPWV).

ZPWV (mm)	All measurements %	Upto 3 octa clouds %	clear sky %
< 1.5	40	44	50
< 2.0	47	55	86
< 2.5	87	89	100
< 3.0	93	100	
< 3.5	100		
Median (mm)	2.1	1.8	1.5

The measurements were made in the beginning of summer and mostly during the first half of the day. On the days when it was monitored for longer durations of the day, it is apparent that the ZPWV reaches a peak at about noon and declines continuously thereafter. Hence we expect the night-time values to be still smaller. Since the saturation vapour pressure drops steeply with decreasing temperature, the values are expected to be lower at night and in winter. Thus one may consider these values as upper limits to what one can obtain from the peak at least for the period September – April.

2.5 Extinction and sky brightness

Extinction and sky brightness were measured on a few occasions using the images of open cluster M 67 which contains a large number of photometric standards. The images were obtained with a Peltier-cooled CCD (ST 6 from Santa Barbara Instrumentations Group) and an 18-inch Newtonian telescope (NGT 18 from Jim's Mobile Inc.). The telescope is equipped with standard *UBVRI* filters. The average extinction measured on two days (1996 March 11 and June 29) in *V* band is 0.10 ± 0.04 mag. This value agrees with what is expected from a purely Rayleigh-scattering atmosphere at the altitude of Hanle (Bessell 1990) and proves that there are essentially no aerosols in the atmosphere.

The values of the sky brightness in units of mag arcsec^{-2} and listed in Table 3. Typical measurement errors are 0.15 mag in *BVRI* bands and 0.3 mag in *U* band.

Table 3. The measurements of night sky brightness

Band	1995 March 3 z = 20°	1995 June 29 z = 50°
U	24.2	23.2
B	23.2	23.1
V	21.5	21.4
R	19.8	19.6
I	18.5	18.0

2.6 Astronomical seeing

Only preliminary estimates of seeing were obtained using the equatorial star trail method. The NGT 18 telescope was employed together with Kodak SO 2415 film. The resolution of the film is 5 μm which translates to 0.5 arcsec at the f/4.5 focus. The centroid and halfwidth measurements can be made to an accuracy of about 0.1 arcsec. The full-width at half maximum of the trails should give an estimate of short exposure image size. However, this estimate is confounded by the problems of intensity calibration in addition to the problem of achieving the best focus. It is more conventional to use the star trails to measure the image motion (see Stobie *et al.* 1993). The rms image motion measured on one of the trails recorded in 1996 April in six strips of 18 second duration each gave a mean value of $\sigma_\alpha = 0.44 \pm 0.03$ arcsec. Using the equation (Coulman 1985; eq. 5.10)

$$\sigma_\alpha^2 - 0.358\ (\lambda/r_1)^{1/3}\ (\lambda/r_0)^{5/3},$$

one finds the value of Fried parameter $r_0 = 0.127$ m. Using the equation (Coulman 1985: eq. 5.11) $s = 0.98\lambda/r_0$, one obtains the estimate of image size 1.15 arcsec for a large telescope. This is an upper estimate since the telescope vibrations are not filtered out. Also, the topography of the current location is not best-suited for obtaining the best seeing. The winds are generally low in the Nilamkhul plain with a fairly constant direction of flow, and the topography of the peak is conducive to very good seeing. More detailed measurements from the peak have been planned on a routine basis.

3. Summary

The prime advantage of Hanle is that it is a high altitude desert removed from primary sources of water. It was already shown by Chandrasekhar et al. (1983) that the water vapour measurements in the Ladakh region agree with what one expects purely from the altitude dependence. Their measured values of 1.4 – 2.0 mm at altitudes above 4400 m compare well with our measurement of 1.5 – 2.1 mm in April. The spread is correlated with weather, clearer days giving smaller values. The water vapour would be lower at night, slightly higher in summer, but significantly lower in winter. These values compare well with the annual average of Mt. Palomar (6.0), Kitt Peak (7.1) and Tenerife (3.8) (Lena 1986). The mean value for Naini Tal is also higher : 4.7 mm excluding the wettest months (Bhatt & Mara 1991). Hanle is at a slightly higher altitude compared Mauna Kea, currently the world's highest major observatory. The precipitation at Hanle is also much lower compared to Mauna Kea which is an island site in the tropical zone.

The atmospheric extinction is also lower at Hanle compared to most of the sites in the world and compares well with Mauna Kea and the theoretical expectations for the altitude. The preliminary estimates of seeing agree with the median values for the best sites and topographically best location needs to be identified at the central peak using further measurements.

The fraction of clear skies at Hanle during 1995 compares well with several existing inland sites in the world, though it is slightly lower than the best coastal and island sites such as Chile, Hawaii, Canary Island and South Africa. During the same period (1995), Lowell Observatory, Flagstaff turned out to be poorer in comparison, especially with regard to the spells of usable nights (Skiff 1996 on vsnet usegroup). The average stretch of a photometric spell at Hanle was 2.9 days against 1.8 days in Arizona. The maximum stretch of photometric spell in Arizona was 8 days, whereas it was 16 days at Hanle with 7 spells of 8 days of longer duration.

It is thus apparent that the overall prospects for astronomy from Hanle are highly promising. Since Indian coastal island mountains are not high and are severely affected by monsoons, we may not find any other site in the country for establishing an astronomical observatory that has both the altitude advantage and clear weather.

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