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Site-survey inputs for the Himalayan Infra-red/Optical Telescope (HIROT) using INSAT cloud imagery data

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Abstract. A systematic examination of the INSAT satellite cloud imagery databases, for the period 1989-94, suggests that the average annual percentage of clear (spectroscopic) nights is ~55% for the sub-Himalayan locations of Devasthal and Dalhousie and ~ 47% for the Himalayan sites of Hanle and Leh, to be compared with the national best of ~ 70% for Gurushikar, Mt. Abu, a non-Himalayan site. On the other hand, the average percentage of clear nights during the monsoon period is the highest for Hanle and Leh (~56%) as against ~18% for Gurushikar. The results are discussed with reference to the recently-reported results of a 1-year long ground-based site survey programme conducted by the Indian Institute of Astrophysics at Hanle.

1. Introduction

The Himalayan Infra-red/Optical Telescope (HIROT) project, currently in its first phase of implementation, aims at establishing in the country a national facility for faint-source observations in the infra-red and optical regions of the electromagnetic spectrum. In pursuance of this important long-term objective, it has been accordingly decided to install and operate, in the first phase of this project, a 2-meter class infra-red/optical telescope at Hanle, Ladakh (32°.47'N, 78°57.5'E, 4517m asl) by the end of this century. The following two pre-requisites are needed to be satisfied by this site for successfully realizing the long-term HIROT scientific aims and objectives : It must have an excellent 'seeing' (≤1 arc second), adequately low atmospheric water-vapour column density (<3mm) and small background light-and thermal-noise contents. Moreover, it must have cloud-free skies for a substantial part of the year. Studies, carried out in the past (Bhattacharya, 1989), indicate that the stipulations may be best satisfied in India by a high-altitude site, located in or near the Himalayan region, at heights > 2500m above sea level. This possibility needs to be investigated critically and the actual site for locating the telescope identified. A convenient strategy to adopt for checking the quality of the sky conditions at Hanle from the point of view of average degree of cloudiness in comparison with that at another candidate-location is to make a quick statistical study of the INSAT satellite cloud imagery data-bases, and then follow it up at some of the more promising locations with detailed in-situ measurements of various site-qualification parameters, including seeing, atmospheric extinction, etc., for upto a few years. The Indian Meteorological Department (IMD), New Delhi, has a repository of the INSAT cloud imagery data-bases, collected over the last one decade or so. In view of the experience already acquired by us (Kaul et al., (1994) in utilizing these data-bases for the site-survey programme of the γ-ray astronomy project GRACE of the Bhabha Atomic Research Centre (Bhat et al., 1994), we have recently completed a similar site-survey study for the HIROT project also. Here we report the important results of this repeat investigation.

A total of 5 sites were considered during these studies. They are (Table 1) : Hanle, Leh, Dalhousie, Devasthal (Naini Tal), and Gurushikhar (Mt. Abu). Out of these 5 sites, Gurushikhar is the farthest from the Himalayas and is meant to be used primarily as a reference station (see Section 2 for this preference).

Table 1. List of potential sites investigated.

Sl. No.	Location	Longitude E	Latitude N	Altitude m asl
1	Leh	77°34′	34°09′	4100
2	Hanle	79°00′	32°48′	4500
3	Dalhousie	76°01′	32°21′	1800
4	Devasthal	79°43′	29°24′	2330
5	Gurushikhar	72°43′	24°36′	1700

2. Guidance from previous INSAT database studies

In our earlier work (Kaul et al. 1994), we reported the results of a detailed analysis of the INSAT satellite IR-band cloud imagery data for eight locations, namely, Gulmarg, Jammu, Solan, Naini Tal, Pachmarhi, Rangapur, Gurushikhar and Kavalur and identified Gurushikhar as potentially the best site with ~ 68% clear nights on an average per year. It is pertinent to note that a 'clear night', in the present context, includes a spectroscopic night, for, in view of the limited spatial resolution of the INSAT 'weather' photographs (~50km), only extended cloud formations above a candidate site are readily identifiable by the satellite imagery technique. Another important finding of this study is that, for a non-Himalayan site like Gurushikhar, both V-band and IR-band imagery data give comparable results about the sky condition. However, while for a Himalayan station like Leh, analysis of the IR-band cloud imagery leads to a clear identification of cloudy days, it may not be always possible to distinguish a partially cloudy (locally clear) day from a cloudy day through an examination of the IR-band photographs. This is so because, in the black and white IR cloud imageries, the Himalayan region invariably appears engulfed inside a foggy patch (thin cloud-like), which makes it difficult to unequivocally distinguish between a clear and a partly cloudy day. The exact cause of this foggy background in the IR-band photographs is not certain. Although it has not been possible for us to determine the exact nature of the foggy background appearing in the IR-band photographs, yet it can be said with a high degree of confidence that it is not a manifestation of thinly dispersed water vapour in the atmosphere over the Himalayan region — in-situ measurements of the water column over Hanle and the Leh by the HIROT team, for example, yield too low a value of ~ 2 mm for this water vapour column (Singh, 1998). As this 'foggy' patch does not show up in the V-band photographs of the Himalayan region, we are mainly relying here on the available V-band imagery data for the candidate sites in this region (Leh and Hanle); on the other hand, the results from the V- and IR-bands, both, are utilised for sites which lie outside this 'foggy' patch, viz., Dalhousie, Devasthal and Gurushikhar.

3. Methodology adopted

The cloud imagery database employed here is some of the latest available in the form of black and white photographs at the IMD, New Delhi, and covers the five-year period 1989-90 and 1992-94. These photographs have been generated from the cloud imagery data transmitted to a satellite ground-station by the Very High Resolution Radiometers (VHRR) on-board the INSAT series of satellites launched by the Department of Space during the last decade or so. The INSAT visual-band imageries (λ ~ 550-750nm) are available at 3-hourly intervals between ~0830-1730h IST every day and in the IR-band (λ ~ 10500-12500nm) between 0530-0230h IST daily. For the present analysis, we have used the V-band imagery data taken at 0830h and 1130h and the IR-band data, at 4 different epochs between 2330-0830h. It has been shown in Kaul et al. (1994), that, for a non-Himalayan site, the average cloud cover picture obtained from the analysis of V-band data at the two morning epochs (0830h and 1130h) is generally representative of the night-time conditions there and leads to results which are in a reasonable agreement with those reported by other workers using in-situ observations and climatological tables. On the other hand, this representative picture may not be quite valid for a Himalayan site where it is found sometimes that local cloud formations seen in the morning settle down on the neighbouring mountain peaks by evening time (Bull. Astron. Soc. India, 1996, 24, 859). As this type of local weather pattern is known to last for a few months only (mainly January-April), this can lead to small underestimation of clear nights for the Himalayan site by the present technique.

To illustrate the analysis procedure deployed here, we show in Fig. 1a and 1b the typical 'weather photographs' recorded in the V- and IR-bands, superimposed on a map of India showing the parallels of longitude and latitude. Each individual cell in the grid pattern has dimensions of 5°(long.) × 5°(lat.), corresponding to a linear size of 500km × 500 km for a representative latitude of ~20°N. As the actual position of a desired location can be fixed on the image plane with an uncertainty of ~ 50km, we have associated a 'circle of influence' of ~ 100km diameter around the candidate site. Next, for a given epoch, each location has been graded as either cloudy (0) or clear (2) depending upon whether its 'circle of influence' is

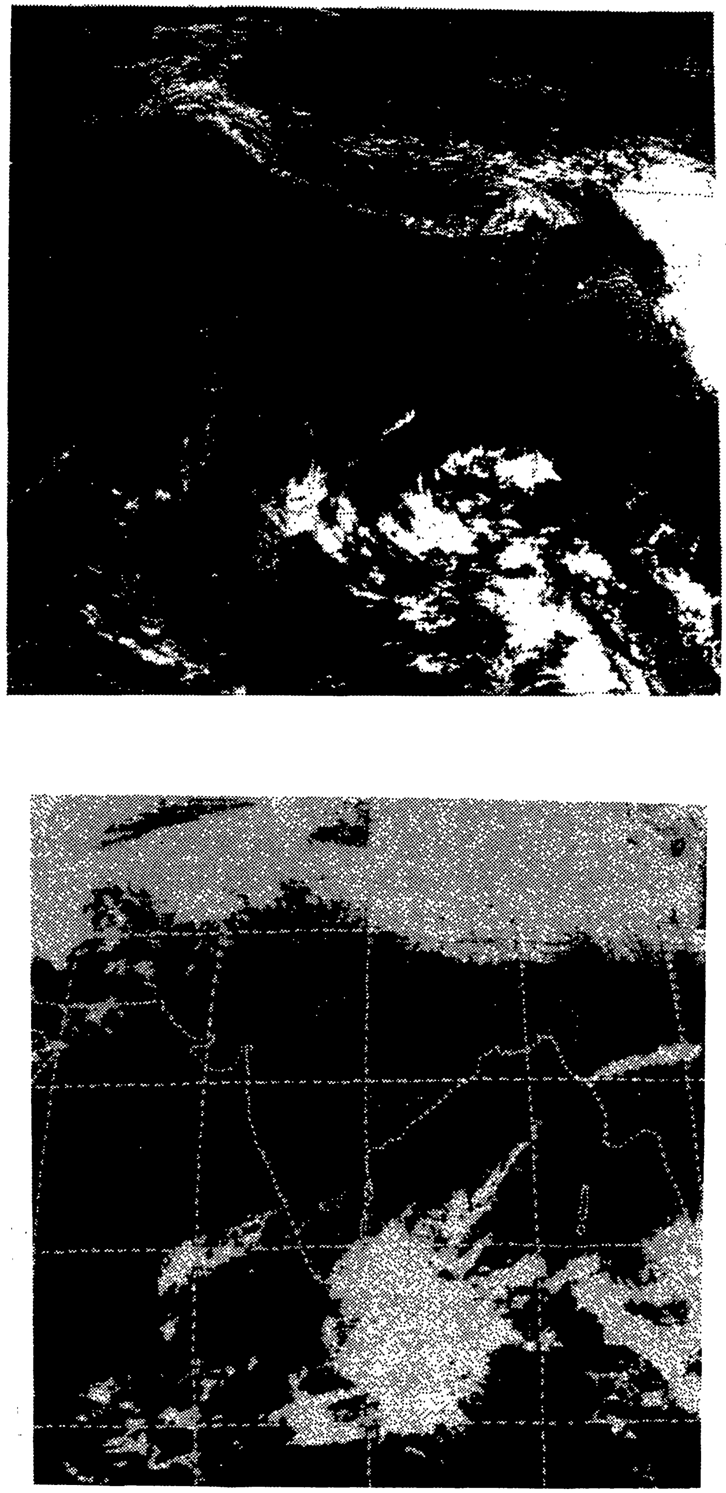

Figure 1. Typical INSAT cloud-imaging photographs in the V-band (a) and IR-band (b).

completely free of clouds in the V-band cloud imagery data (uniform black background) or is under a cloud-mass (a white patch in lieu of the black background). For the IR-band cloud imagery data at four epochs, we have adopted the same prescription as followed in our earlier analysis (Kaul et al. 1994) to determine the total spectroscopic hours of observation at each location. Here, each location is graded on a scale of 1-4 on a daily basis at the above-referred 4 epochs, depending upon whether its 'circle of influence' is completely cloud free or is under a thick cloud cover (grade 4). Depending upon the grading obtained at each epoch, a particular night is classified as 'excellent' (~10h of clear sky) if all the 4 epochs register a grading 1, while, if only three consecutive epochs are graded as 1, the night is classified as 'good' (8h of clear sky). Similarly, for only two consecutive epochs of grade 1, the night is classified as 'fair' (4.5h of clear sky), while isolated gradings of 1 at the 4 epochs denote a 'poor' night (0h of clear sky). As discussed in Kaul et al. (1994), the results from the IR-band analysis are more likely to refer to 'spectroscopic' sky conditions. Based on the grading secured at a given epoch, the corresponding night is classified as clear or cloudy from the V-band data-analysis, while the IR-band data are employed to derive the available spectroscopic hours of observation on a night-to-night basis. The resulting information is compiled to calculate the average population of clear and cloudy nights (as well as spectroscopic hours) on a monthly/annual basis.

It may be noted that in addition to the few bright-white cloud-complexes sometimes seen overlying central Kashmir and North-West Pakistan, the IR-band photographs invariably show most of the remaining Himalayan region under a structureless foggy patch, which makes it difficult to unambiguously classify the underlying places, around the boundaries of this patch, including Leh and Hanle, as either cloudy or clear (Fig. 1b). This is a typical limitation of the IR-band imageries so far as the overall Himalayan region is concerned. On the contrary, the typical V-band picture, represented by the photograph shown in Fig. 1a, presents no such confusion problem as the entire Jammu and Kashmir state can be unequivocally classified as cloud-free (in the present case) because of the well-demarcated and readily identifiable ground-terrain features, e.g., water courses, snow cover on the mountain ranges, etc.

4. Results and Discussion

Fig. 2 summarizes the main results in the form of average percentages of clear days per year for the five stations listed in Table I. These results are given here separately for two V-band and one IR-band data-sets for purposes of a direct intercomparison. The V-band results for the 0830h epoch refer to the 3-year period 1989, 1990 and 1992 (total no. of days : 777) while those at 1130h refer to the 5-year period 1989, 1990 and 1992-1994 (total no. of days : 1331). The IR-band results, on the other hand, are derived from the daily cloud-imagery data at 4 epochs (0230h, 0530h, 0830h and 1430h IST; total number of days : 1331) for the same 5-year period. A closer look at Fig. 2 reveals a reasonably good agreement among the values of the percentage of clear days derived for each station from the three different data-sets (two V-band and one IR-band), except in the case of Leh and Hanle (and to some extent for

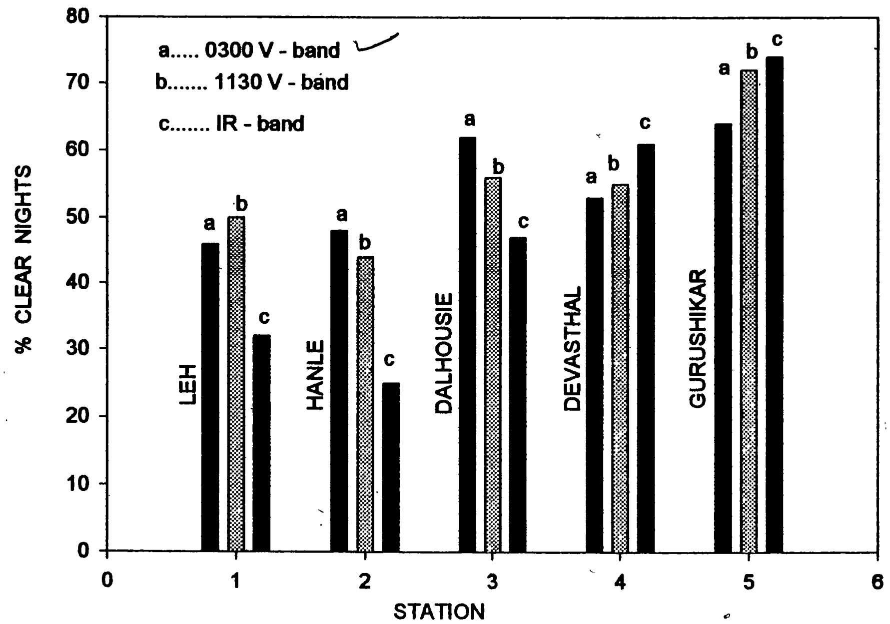

Figure 2. Average percentage of clear nights per year for the five candidate sites. The (a), (b) and (c) bars represent the averages derived from the 0830 V-band data, 1130 V-band data and the IR-band data respectively. For other details, refer to text.

Dalhousie), where the average annual percentage of clear days is significantly underestimated from the IR-band data-set analysis, due to reasons referred to in Section 2.

In Fig. 3 we present the composite picture about the average number of clear days per year for these five stations, derived by combining the results shown in Fig. 2 for each location separately. Two values of the average annual number of clear days are plotted against each

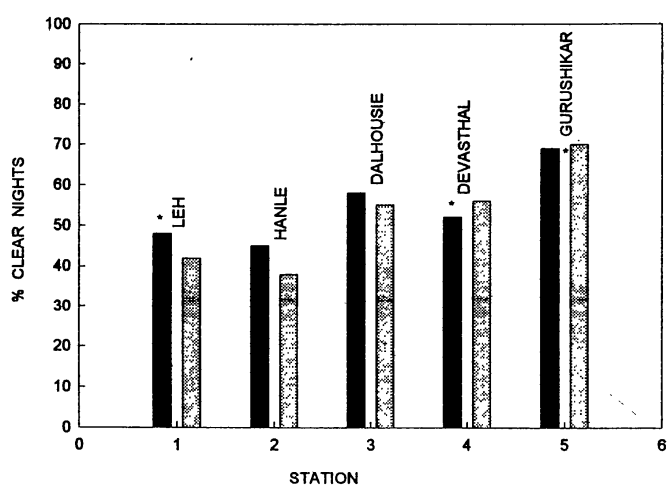

Figure 3. Average percentage of clear nights per year for the five candidate sites. The left hand bar represents the average value derived from the two V-band data sets (a & b of Fig. 2) while the right hand bar represents the averaged frm the conbined V- and IR-band data (a, b and c of Fig. 2). The stars represent the values of the annual percentage of clear nights reported in literature for some of these sites.

station, the one on the left derived form V-band data only (a + b) and the one on the right derived from the combined V– and IR-band data (a + b + c). The stars in Fig. 3 represent the values for the average annual percentage of clear days reported for some of these stations from other independent observations, based on both in-situ measurements and climatological models (e.g., Singh et al. 1989, Bhattacharya, 1989, Singh et al. 1990, Bhatnagar and Gandhi, 1991). It is evident from Fig. 3 that, except for Leh and Hanle, the results from IR- and V-band data-sets for the other three sub-Himalayan stations are in reasonable agreement with each other and with the values reported in literature (wherever available). This broad agreement between results derived from different data-sets at these stations indicates the general correctness of the methodology followed in the present study. In view of this optimistic outlook it can be safely inferred that, so far as cloud-free skies are concerned, Gurushikhar continues to be in the lead with ~70% days clear on an average per year, followed by the two sub-Himalayan stations, Dalhousie and Devasthal (~55%) and finally by the high-altitude Himalayan stations, Leh (48%) and Hanle (46%). It is pertinent to point out here that our estimate for cloud-free skies at Leh (~48%) is in close agreement with the average value of ~ 52% from in-situ observations at Mt. Nimmu, Ladakh, for the period 1984 - 1988 (Singh et al. 1989; 1990) and justifies our preference for using the V-band data only for the two Himalayan stations (Leh and Hanle) for drawing the above inference.

We now turn to finding how these clear-sky days are distributed on a monthly basis at each station. This has an important bearing on the actual observation time possible for a cosmic source in the optical/IR bands from each location. For deriving the desired profiles, we have determined the average percentage of clear days on a monthly basis using the 0830h and 1130h V-band data-set for the 3-year period 1989-90 and 1992. Fig. 4 (a-e) shows the resulting monthly distributions for each individual station. The following inferences can be drawn from a close examination of the figures :

i. For the two Himalayan stations, Leh and Hanle (Fig. 4a, 4b), the monthly-average percentage of clear days is ≥ 40% for 9 months of the year, with September-November claiming the highest percentage (~56%) of clear days and January-March representing a significant low, with ≤ 30% clear days. It is interesting to note that, at both these stations, there is no marked deterioration of the average sky condition during the monsoon period, unlike what is true for lower-latitude stations in the country.

ii. At the two sub-Himalayan stations, Dalhousie and Devasthal (Fig. 4c, 4d), the monthly mean percentage of clear days is ≥ 60% for seven months of the year. This percentage falls below 30% during the monsoon months of July-August.

iii. For the reference station of Gurushikhar, the monthly mean percentage of clear nights is ≥ 80% for seven months of the year, while it dips to ≤ 30% during the monsoon period (July and August). This is in excellent agreement with the corresponding distribution profile presented by Kaul et al. (1994), based on an extensive analysis of the IR-band imageries only.

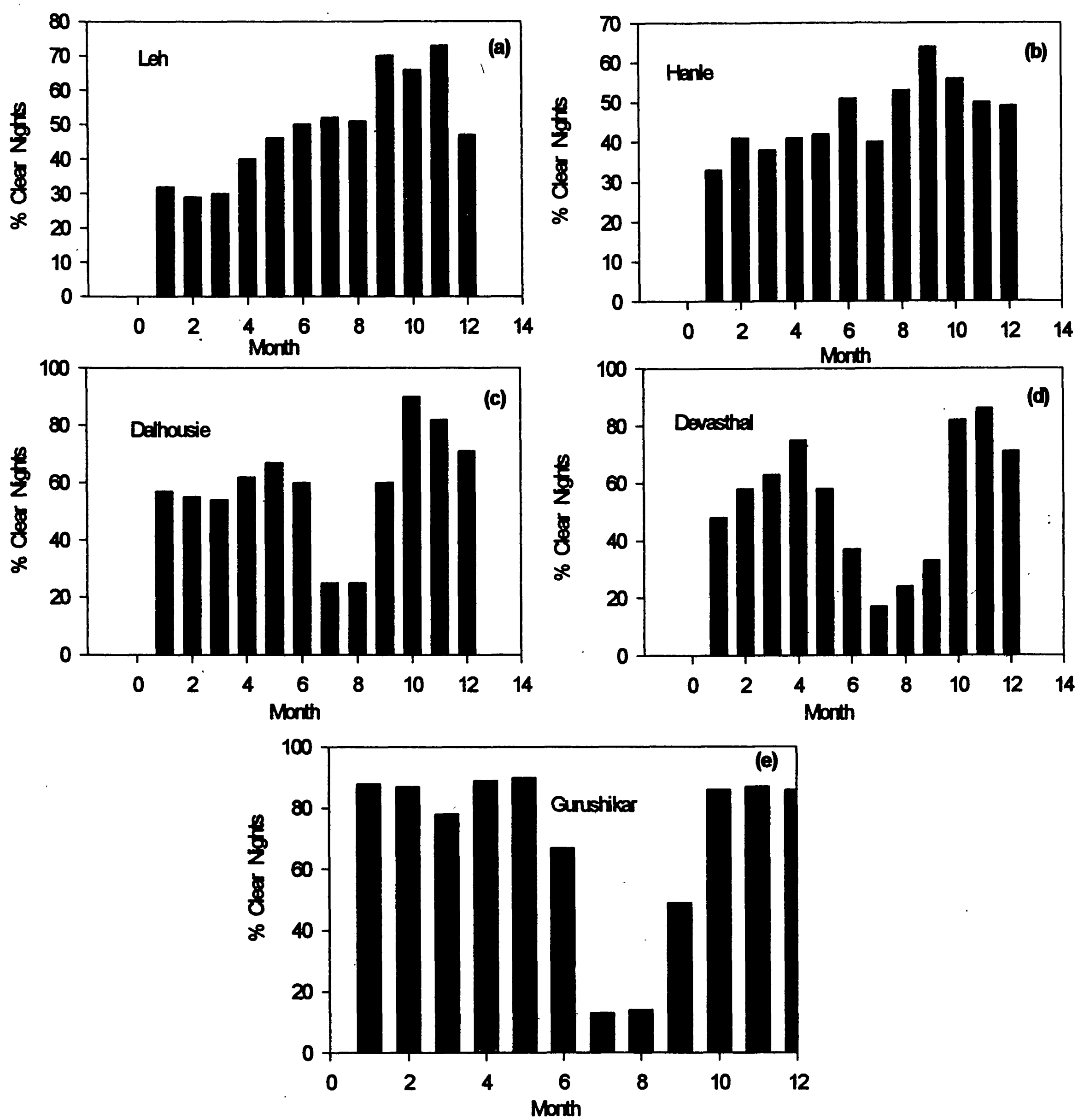

Figure 4. Distribution of the percentage of clear nights on a monthly basis for the five candidate sites, using the 0830 and 1130 V-band data sets. The two Hinalayan sites, Leh and Hanle, exhibit almost a uniform percentage of clear nights over the entire year.

iv. The deterioration in the sky condition during the monsoon period shows a significant enhancement as one progresses from a Himalayan location to a station at lower latitudes, being the severest at Gurushikhar. This is in general agreement with the behaviour of monsoons over peninsular India.

5. Comparison with ground-based observations at Hanle

The HIROT team of the Indian Institute of Astrophysics, Bangalore, have recently reported (Bull. Astron. Soc. India, 1996, 24, 859) the results of the first year of their site-survey programme, presently in progress at Hanle. They find that ~ 46% of the nights (~ 1273 h) are suitable for photometric studies at Hanle, while ~60.6% nights (~ 1676 h) may be useful for spectroscopic studies. The HIROT team define a photometric night as one during which the sky is cloud free (cloud cover = 0 octas) for 4h or more continuously, while a spectroscopic night is referred to as one during which the cloud cover is less than or equal to 3 octas for ≥ 4h in not more than two stretches. A plausible reason for the ~10% difference in the estimate of spectroscopic nights from the satellite and the ground observations may be the year-to-year variation in the local weather (the satellite-based average being for a 3-year period as compared to only 1 year for the ground observations). It could also arise from a possible systematic underestimation of spectroscopic nights from the analysis of satellite database due to the limited temporal and spatial resolution of satellite-based cloud imagery data analysis, where the percentage of spectroscopic nights is estimated from the sky condition at only 2 three-hourly epochs (at 0830h and 1130h) in the morning instead of the hourly data-sets available from ground observations. As already pointed out in section 3 above, it may be noted that the HIROT team have reported frequent local cloud-informations at Hanle during January-April period which usually start around mid-morning and tend to dissipate by early evening. As a result, some of the nights which are classified as cloudy from the analysis of 0830h and 1130h INSAT V-band imagery, may actually be clear and, thus, add up to the total percentage of spectroscopic nights. It is desirable to have a direct comparison between the results of ground observations and the inferences drawn from the analysis of INSAT database on a day-to-day basis to find an explanation for the different estimates of spectroscopic nights made on the basis of ground observations and those based on the cloud imagery data analysis. At the time the present analysis was done, we have had overlapping ground-based data for a two-month period only, viz., January and February, 1995. We have compared the results of satellite and ground-based data analysis for these two months on a day-to-day basis and present the results below.

The daily cloud-imagery data recorded at 0830h (V-band) during this 2-month period have been examined and Hanle graded as either cloudy (grade 0) or clear (grade 2), following the same prescription as adopted before. The results have been compared with the average of the gradings derived from the ground data logged at 0800h and 0900h. Fig. 5 summarizes the results from this analysis : Out of a total of 49 days constituting the data-sample, ground observations establish 28 days as clear and 21 days as cloudy, to be compared with 31 clear days and 18 cloudy days, as suggested by the satellite data. More specifically, using the in-situ Hanle data for reference, the satellite observations indicate 24 days as clear (out of 28 days actually) and 14 days as cloudy (out of 21 days logged at Hanle). The latter leads to a value of (1.7 ± 0.33) and (1.5 ± 0.52) for the ratio for the observed (Hanle) and the 'predicted' (satellite) values of overlapping clear and cloudy days in the two data-samples. (The errors indicated are only statistical). Keeping in view the limited size of the overall samples (49 days), it can be reassuringly concluded that the satellite-predicted numbers of clear and cloudy days at Hanle are in reasonable agreement with the corresponding in-situ measurements. This, in turn, strengthens faith in the results obtained here on the percentage of clear days likely to be logged at Hanle (and other similar Himalayan sites, based on analysis of the INSAT cloud-imagery data done over the period 1989-90 and 1992).

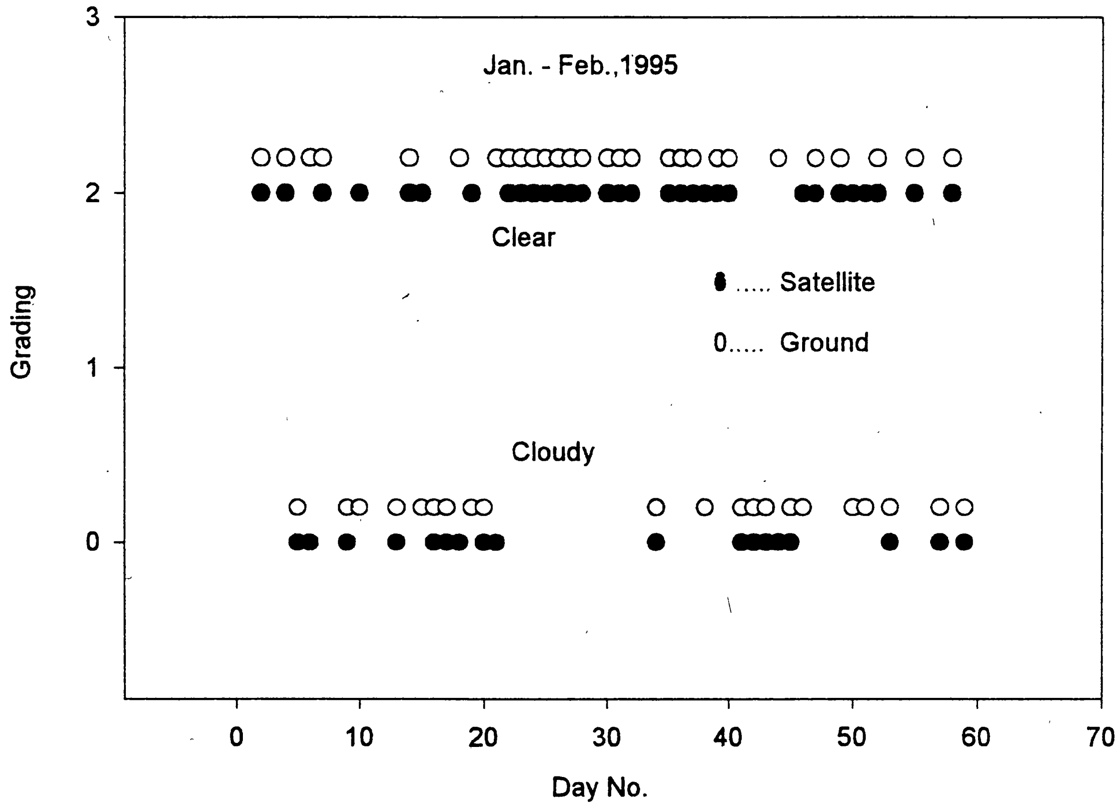

Figure 5. Comparison between satellite and ground-based measurements of the sky condition at Hanle during January - February, 1995.

6. Conclusions

A systematic examination of the recent INSAT satellite imagery data-bases lead to the following main conclusions :

i. The V-band INSAT photographs yield reasonably reliable results with regard to the average monthly/yearly population of clear days for a given location in the country in as much as the average values for a given station belonging to different epochs match with one another reasonably well as also with independent in-situ measurements, wherever available (including Leh in the Himalayan region).

ii. The IR-band photographs give results which, while exhibiting an excellent agreement with the corresponding V-band results for a sub-Himalayan location, are ambiguous about mean percentage of clear days for a Himalayan site, like Leh and Hanle, and, in all likelihood, can underestimate it by a factor of upto 2. This is seen clearly in Fig. 2, where the percentage of clear nights derived from IR-band data analysis is almost a factor of two lower than the value derived from the V-band data for, both, Leh and Hanle.

iii. Of the four candidate sites considered in this study, Devasthal and Dalhousie have, on average, ~ 55% (spectroscopic) clear days per year, while it is 46-48% for Hanle and Leh (based on V-band data only for the latter two sites). This may be compared with the corresponding figure of ~ 70% for the reference site at Gurushikhar.

iv. The average monthly fraction of clear days is the highest for Hanle and Leh (~56%) during the monsoon period, to be compared with ≤ 30% for Gurushikhar for the same period.

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References

Bhat C.L. et al. 1994, "Towards a Major Atmospheric Cerenkov Detector-III", Universal Academy Press, pp 347-358.

Bhattacharya J.C., 1989, Indian Institute of Astrophysics Newsletter, 4, 18.

Bhatnagar A., Gandhi S.L., 1991, Tech. Report on the DST project "Astronomical and atmospheric observations in Ladakh region with long-term view of setting up a National High Altitude Astronomical Observatory for Infra-red and Optical studies".

Kaul R.K. et al., 1994, J. Astron. & Astrophys., 15, 95

Singh J. et al., 1989, BASI, 17, 83

Singh J. et al., 1990, BASI, 18, 7

Singh J. et al., 1998, Pvt. Communication