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Application of INSAT Satellite Cloud-Imagery Data for Site Evaluation Work of Proposed GRACE Observatory

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Abstract. The weather-imageries from the INSAT group of satellites provide reliable and concurrent multistation cloud-cover data – an important input for a proper selection of an observatory site for optical, infra-red and γ-ray astronomy work. Using these data, it is shown that Gurushikar, Mt. Abu, promises to be an excellent site for setting up the proposed GRACE facility for high-sensitivity Gamma-Ray Astrophysics Cerenkov Experiments.

Key words: INSAT-satellites—cloud-imageries—observatory site-selection—groundbased gray astronomy.

1. Introduction

Our group has been actively involved, for over 2 decades now, in a variety of investigations related to the field of gamma-ray astronomy. These studies, based mainly on the use of ground-based atmospheric fluorescence and Cerenkov techniques (Bhat 1982), have covered a wide range of photon energies from ~ 100 keV to a few PeV, and time-scales from a few nanoseconds to around a second. In the initial phase, a series of exploratory experiments were carried out at Gulmarg and Srinagar for detecting short time-scale cosmic gamma-ray bursts expected to accompany Supernova outbursts and the explosive evaporation phase of primordial black-holes (Bhat *et al.* 1980). Successful searches were made for PeV γ-ray signals from cosmic sources like Cyg X-3 and AM-Her binary systems (Bhat *et al.* 1986; Bhat *et al.* 1991a). More recently, a TeV γ-ray telescope (Koul *et al.* 1989) was developed and operated at Gulmarg between 1985 and 1989 to detect cosmic gamma-ray sources and study their emission characteristics on a variety of time-scales (see Razdan 1989; Bhat 1993 and references therein). We have plans to consolidate these activities further in the next decade. Accordingly, under a new project GRACE (Gamma Ray Astrophysics Cerenkov Experiments), two high-sensitivity telescopes, TACTIC and MYSTIQUE, both based on the atmospheric Cerenkov technique, are being developed to undertake comprehensive temporal and spectral studies of cosmic gamma-ray sources over the energy range 0·2 TeV – 10 PeV. While we refer the reader to Bhat *et al.* (1991b, 1993) for a discussion on the design philosophies and other technical details of the experiments, we limit ourselves here to pointing put that an essential pre-requisite for their successful execution is a proper observatory site. The main qualifications for such a site are:

1. Cloud-Free nights, as far as possible, during a calendar year.
2. Dark site, with a negligible contribution to the background light level from artificial sources.
3. Atmosphere free from haze, dust and anthropogenic pollution.
4. Operational ease, good logistics and mild climate.
5. Reasonably flat terrain of upto 0.25 km^2 in area – a requirement for MYSTIQUE mainly.

Unlike in optical astronomy, a high order of atmospheric 'seeing' (< a few areseconds) is not particularly required in the context of atmospheric Cerenkov work. On the other hand, it is of paramount significance here that the night-sky is as cloud-free as possible for the sake of maximizing possible observation time (T_0) per source per calendar (or sidereal) year (Bhat *et al.* 1993). This need is perhaps far more acute here than for optical and infra-red astronomies because the typical source flux that one is dealing with in the very high energy (VHE) and ultra high energy (UHE) gamma-ray regions is extremely small, both in absolute terms as also in relation to the cosmic-ray-generated background events (Weekes 1988; Bhat 1993). This renders the experimental scene in gamma-ray astronomy analogous to searching for the proverbial 'needle-in-a-haystack' situation. Several techniques have been developed, in the last few years for retrieving the extremely weak γ-ray signals from the far-excessive cosmic-ray background in these energy domains and thereby helping to boost the sensitivities of telescopes like TACTIC and MYSTIQUE (Weekes 1992). Nevertheless, the importance of maximizing T_0 continues to remain valid, in order that the full potential of these systems is exploited for making a real dent in this still-fledgling, *albeit* promising, field (Lamb 1989).

In view of this importance, we have embarked on a search for a proper observatory site in India, which, in addition to satisfying pre-requisites (2) to (5) listed above, can also offer the maximum number of cloud-free nights per year. This search need not remain confined to the already established observatory sites only (for which some information on annual cloud-cover is available in literature), but can extend to some other places in the country, which may be more viable from other points of view, including some of the above-listed requirements. In addition, it is also desirable to have more recent and preferably concurrently-recorded cloud-cover data on all these candidate sites in order that more reliable inferences can be drawn regarding the suitability of a site. In the present communication, we first show that the cloud-imagery data, recently obtained by the INSAT series of satellites, is quite suitable for meeting these specifications. Based on these results, we then go on to establish that, among the nine locations investigated in this work, Gurushikar, Mount Abu, is the best astronomical site in India in respect of the availability of clear nights per year.

2. Data analysis and results

Nine candidate sites, listed in Table 1 alongwith their geographical coordinates and altitudes, were chosen for the present study, keeping in mind the overall implementa-

Table 1. A list of 9 potentially-promising locations for the proposed GRACE observatory.

Location	Longitude	Latitude	Altitude (m)
Leh	77°34′E	34°09′N	4100
Gulmarg	74°24′E	34°05′N	2743
Jammu	74°24′E	32°24′N	330
Solan	77°05′E	30°33′N	1000
Nainital	79°42′E	29°21′N	1927
Gurushikar	72°43′E	24°36′N	1700
Pachmahri	78°12′E	22°18′N	1350
Rangapur	78°43′E	19°49′N	554
Kavalur	78°49′E	12°34′N	725

tion strategy for the project GRACE. The cloud-imagery data used in the present analysis belongs to the 5-year period 1987–1991. These data have been generated and transmitted to ground by the Very High Resolution Radiometer (VHRR) onboard the INSAT-IB satellite for the period 1986 –July 1990 and thereafter via INSAT-ID satellite. The processed images are available from the Satellite Meteorological Unit, Indian Meteorological Department, in the form of black and white photographs taken at three-hour intervals in the visible band (550–750 nm) and in the infra-red (IR) band (10500–12500 nm).

For the present work, we have studied the IR cloud-imagery pictures taken at 21, 00, 03, 09 hrs (1ST). Fig. 1 shows a typical cloud photograph recorded in the IR-band and superimposed on a map of India, which is shown fitted inside a grid pattern formed by the parallels of longitude and latitude. Each individual cell in the grid pattern has dimensions of 5° (long.) × 5° (lat), corresponding to linear dimensions of 500 km × 500 km for a representative latitude of ~ 20°N. As the actual position of a location of interest can be fixed on the image-plane with an uncertainty of ~ 50 km, we have associated a ‘circle of influence’ of ~ 150 km around it. Next, each location has been graded on a scale of 1–4 on a daily basis at the abovereferred 4–epochs, depending on whether its corresponding ‘circle of influence’ is completely cloud-free (grade 1),or,is under a thick cloud-cover(white-patch;grade 4). The two intermediate grades, 2 and 3, refer to hazy sky conditions and partially (broken) cloudy-sky, in that order. Depending upon the grading obtained at each epoch, a particular night is classified as ‘excellent’ if all the four epochs have a grade of 1. Such a night is regarded as having 10 hrs of ‘clear-sky’. Similarly, if only the 3 consecutive night-epochs are graded as 1, the night is classified as ‘good’ and allotted a clear-sky time of eight hrs. Again, if only two consecutive epochs during the night turn out to have the grade 1, the night is termed as ‘fair’, with 4.5 hrs of clear-sky. Lastly, if only one epoch of two non-contiguous epochs turn out to have the grade 1, the night is referred to as ‘poor’, with no observation time possible.

We would like to invite attention to one ‘limitation’ of the procedure adopted here. While the (generally-encountered) large scale cloud complexes, overlapping partially or fully a given ‘circle of influence’, can be readily identified through the present technique, localized cloud-formations lying within this circle may be missed with the spatial resolution used here. In that sense, the results obtained here on clear-sky conditions are more likely to refer to combined photometric and spectroscopic sky

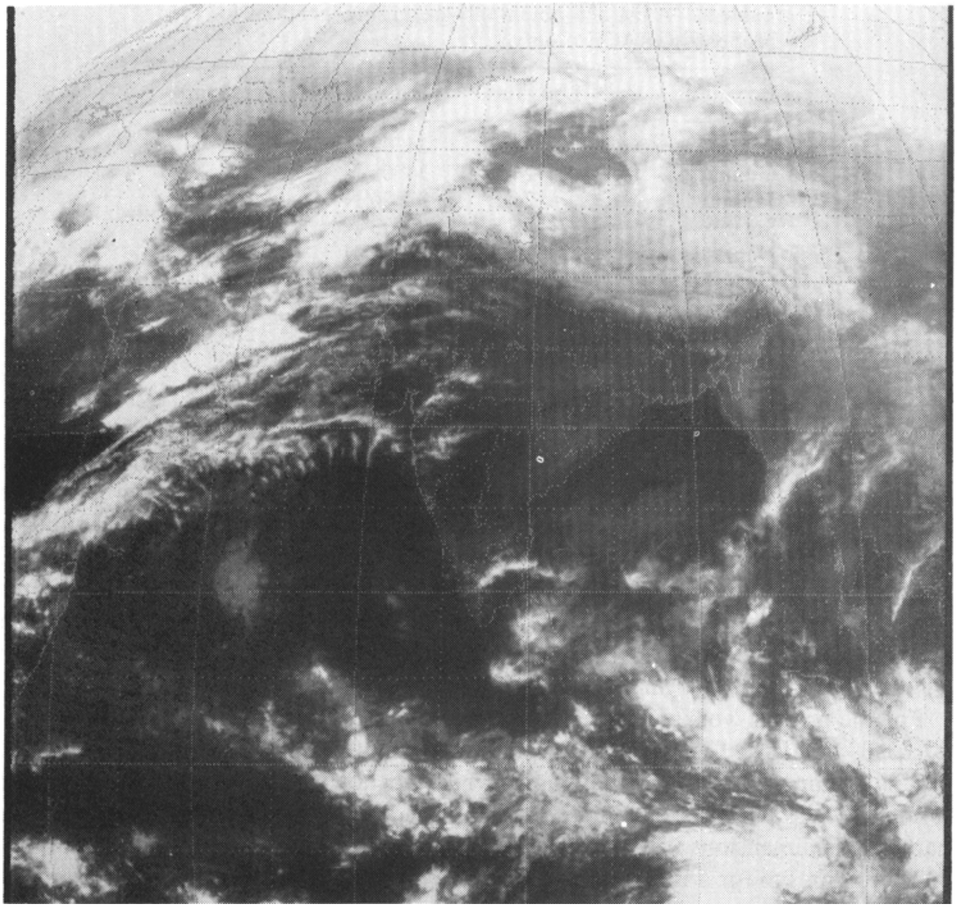

Figure 1. An INSAT cloud-imagery photograph recorded on 3 Dec. 1991 at 1200 hrs. in the IR band.

conditions and not to strictly photometric-skies only (Bhatnagar & Gandhi 1991). It will be shown later, from a comparison of the results obtained here with the reference data available for some established observatory locations like Nainital, Gurushikar and Kavalur, that this indeed seems to be the case. Another practical limitation of the technique also became evident during this work: while scanning the cloud imageries, it was difficult to distinguish between cloud features and snow-covered areas in the high-Himalayas. Because of this ambiguity, the analysis for Leh could not be completed with enough reliability. This has forced us to preclude this station from any further discussions here. In case of all other locations, the only ambiguity resulted by way of discrimination between a clear day and a hazy day, especially when the picture had a poor contrast. In all such doubtful cases, the location was graded as 2 or 3, so that the number of clear sky hours quoted here for that night may have been somewhat under-estimated (< 10%).

Figure 2 summarizes the results in the form of average number of clear, night-time hours per year (period: 1987–1991) for the other eight locations listed in Table 2. Taking the typical lunar cycle into account, only ~ 48% of this time would be

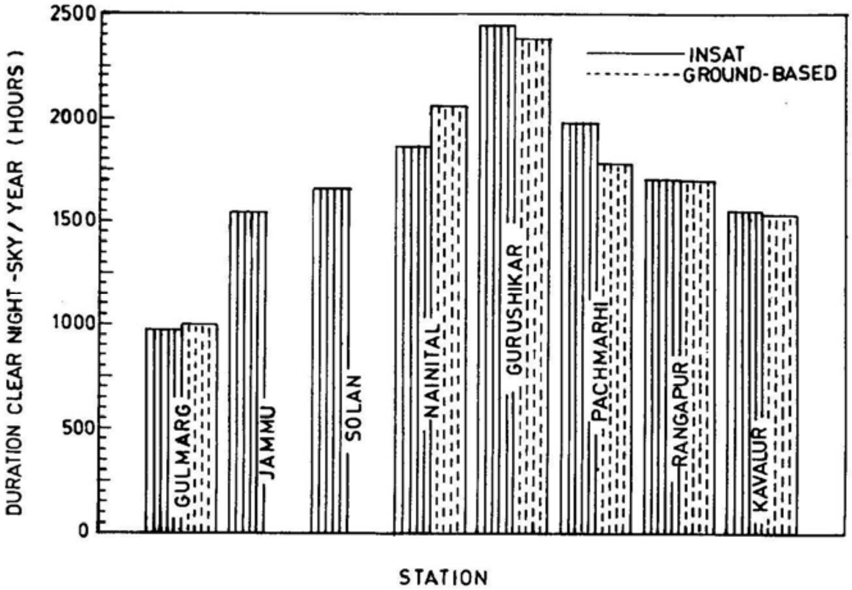

Figure 2. Number of 'clear night-sky' hours (spectroscopic sky) inferred from INSAT cloud-cover data are compared with results of some ground-based observations.

Table 2. Possible observation time per year for a given location inferred from INSAT cloud-cover data, is compared with the corresponding value quoted in literature from ground-based studies.

Site	Clear Night-sky (Hours) Photometric (a)	Spectroscopic (a)	Spectroscopic (b)	INSAT (c)
Leh	740	1760	1600	—
Gulmarg	—	—	1000*	975
Jammu	—	—	—	1543
Solan	—	—	—	1658
Nainital	1025	2060	1900	1862
Udaipur	1440	2250	—	—
Gurushikar	1760	2385	—	2453
Pachmarhi	915	1782	—	1977
Rangapur	—	—	1700	1704
Kavalur	245	1429	1535	1554

(a) Bhattacharya 1989.
(b) Bhatnagar & Gandhi 1991.
(c) Present work.
* Bhat 1982.

sufficiently dark for atmospheric Cerenkov work in the optical region. This correction factor applies more or less uniformly to all the stations referred to in this work. In view of the remarks made above that the present procedure should relate better with the combined photometric and spectroscopic skies rather than with the photometric skies only, we have also plotted in Fig. 2 the average number of spectroscopic hours per year published in literature for some well known observatory sites, viz. Gulmarg, Nainital, Gurushikar, Pachmarhi, Rangapur and Kavalur (Bhat 1982, Bhattacharya 1989 and Bhatnagar & Gandhi 1991; see also Table 2). The values quoted for Kavalur and Gulmarg are based on the actual ground-based cloud-cover measurements for the period 1972 to 1978. Those for the other stations have been derived from the climatological tables and refer to the pre-1967 period (Bhattacharya 1989). It is reassuring to note that the results obtained here from an examination of INSAT cloud-imagery data for the other four stations are in excellent agreement with the values quoted by Bhattacharya (1989) and Bhatnagar & Gandhi (1991), and this vindicates the reliability of the approach followed here, at least in a statistical sense.

The following important conclusion immediately follows from an examination of Fig. 2: Gurushikar offers the maximum number of clear nights per year among the Indian stations considered here, corresponding to approximately 2450 hrs of clear night-sky annually (hereonwards referred to as 'spectroscopic hours'). This may be compared with the annual average of (spectroscopic) observation time quoted for some of the best observatories in the world: 2800 hrs at Mauna Kea, 2600 hrs at Cerro Tololo, La Silla and Las Campanas, 2200 hrs at Mount Palmor and Kitt Peak and 2000 hrs at Siding Spring and Lick Observatory. Thus, aurushikar is found to compare reasonably well with these observatories in respect of this important parameter. In view of the lunar cycle referred to above, the total effective time per year for optical Cerenkov observations works out to be 2450 × 0.48 hrs, or, 1176 hrs at Gurushikar.

AnotAnother advantage of working at Gurushikar becomes evident from Fig. 3, which shows the monthly distribution of 'spectroscopic' hours averaged over the 5-year period 1987-91, at the eight Indian stations of interest to this work. It is seen that,

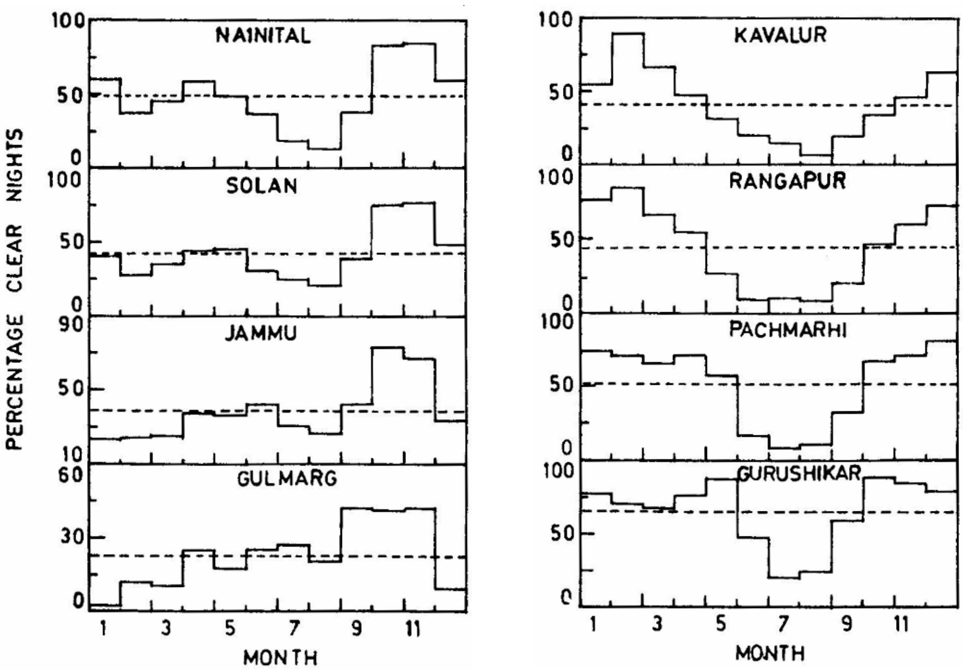

Figure 3. Monthly distribution of clear-nights for eight Indian locations. The dashed-line represents the annual average value.

in the case of the 4 sub-Himalayan stations, the average percentage of clear nights is < 40% per month at Gulmarg, < 50% at Jammu and Solan and < 60% at Nainital for almost 10 months in a year, the only two exceptions being the post-monsoon months of October and November. As can be expected, it is also evident from Fig. 3 that the effect of summer-monsoons becomes progressively more extensive in the monthly distribution of spectroscopic nights as one proceeds southwards from Gurushikar to Pachmarhi, Rangapur and Kavalur. As a result, the percentage of clear nights turns out to be maximum, between 60–90% for nine months at Gurushikar, with the monsoon affected period here being mainly limited to the months of July and August. This feature is an added attraction at Gurushikar, for, in principle, this gives a more uniform sky coverage and brings a wider range of candidate cosmic sources within the scope of meaningful investigations at this place (Sapru *et al.* 1993).

Figure 4 gives the yearly distribution of clear nights at the eight Indian stations for the period 1987–1991. The annual percentage of clear nights at each station is found to remain within ± 10% of the corresponding mean value. A closer examination of the figure suggests a systematic increase in the percentage of clear night-sky at most of the stations in 1989 (particularly so for non-Himalayan stations, responding mainly to summer monsoons) and a comparable decrease below the corresponding average level in 1991. The fact that these two deviations from the average behaviour are observed at most of the stations implies that they have a physical origin and are not due to statistical fluctuations. It is also an indication of the good sensitivity of the present technique.

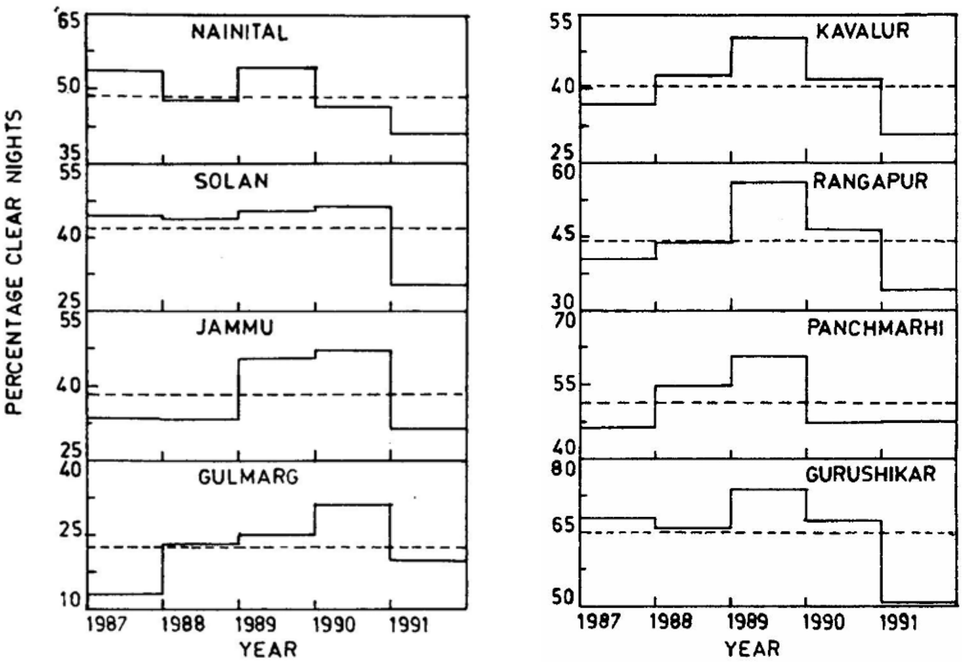

Figure 4. Yearly distribution of clear-nights for eight Indian locations. The dashed-line gives the average percentage of clear-nights for the period 1987-1991.

3. Conclusions

From an analysis of the INSAT satellite cloud-imagery data, collected for the 5-year period 1987–1991, it is shown that, from the point of view of cloud-free nights, Gurushikar is the best astronomical site in India yielding upto ~ 2400 spectroscopic hours of observations per calendar year. This time is distributed more or less uniformly over 9 months (September-May) of a year, thereby making it possible in principle, to study a wide range of interesting cosmic objects located in different parts of the sky in a purposeful manner through the optical atmospheric Cerenkov technique. In view of this encouraging trend, some in situ site-evaluation studies have been initiated at Gurushikar, within the premises of the existing Infrared Astronomy Observatory of the Physical Research Laboratory, Ahmedabad, with the main aim of seeking answers to conditions (2–5) listed in section 1. These studies include measurements of the daily dust-load (total particulate matter) and wind velocity, (both these factors can potentially constrain total observation time as also its monthly distribution), atmospheric extinction coefficient and the night sky light level. The results of this supplementary study, which are also quite promising, are being presented separately (Sapru *et al*. 1993).

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