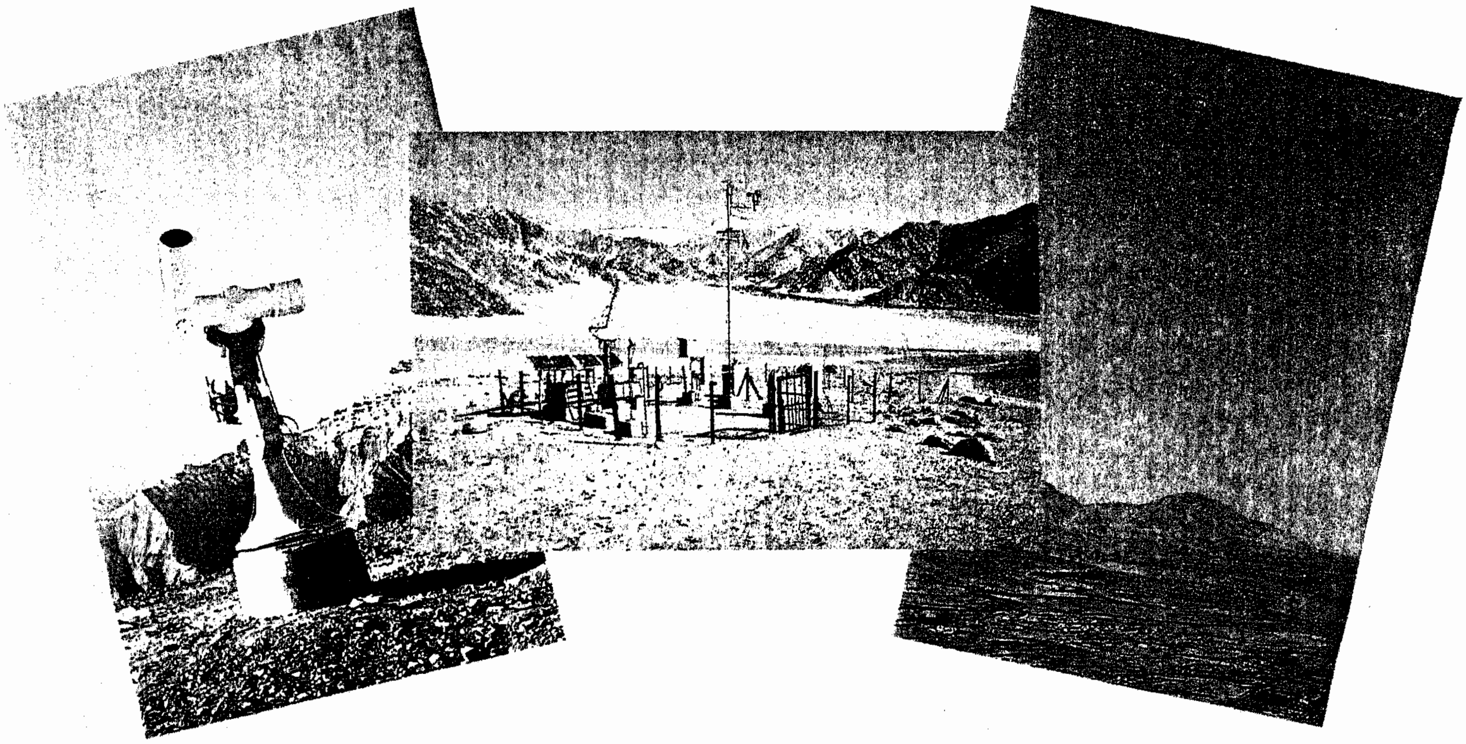
TECHNICAL REPORT ON

ASTRONOMICAL SITE SURVEY IN LEH - LADHAK (1984-1989)



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TECHNICAL REPORT ON THE DST PROJECT ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE ASTRONOMICAL OBSERVATORY FOR INFRA -RED AND OPTICAL STUDIES.

(APRIL 1984 TO OCTOBER 1989)

Compiled by

ARVIND BHATNAGAR AND S.L.GANDHI
Udaipur Solar Observatory,
Udaipur.

April 1991

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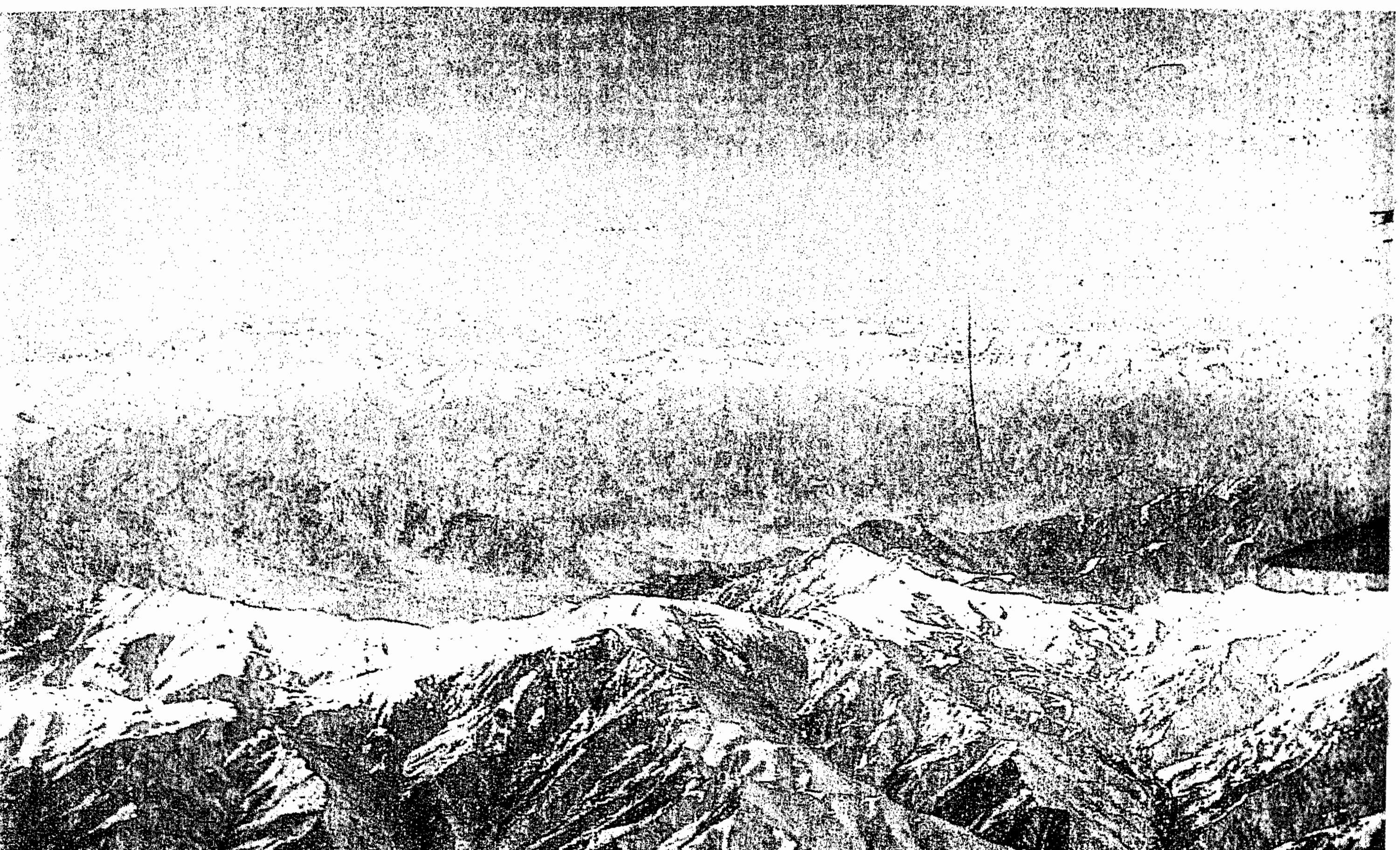

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CAN ASTRONOMER PURSUE HIS RESEARCH

- PERCIVAL LOWELL

CONTENTS

FOREWORD	V
ACKNOWLEDGEMENTS	VI
1. HISTORICAL BACKGROUND	1
2. PRELIMINARY RECONNAISSANCE	1
3. SEARCH FOR ALTERNATE SITE	3
4. DST APPROVAL OF THE PROJECT, BUDGET ETC.	3
5. PARAMETERS FOR SITE SURVEY	6
6. SPECIAL INSTRUMENTS AND SOFTWARE DEVELOPED FOR SITE SURVEY AND EQUIPMENT USED	7
7. COLLECTION OF DATA AND ANALYSIS	9
8. SPIN OFF FROM PROJECT WORK	20
9. PROBLEMS FACED, LESSONS LEARNT	22
10. COMPARISON OF RESULTS WITH OTHER HIGH ALTITUDE OBSERVATORIES OF THE WORLD	23
11. RECOMMENDATIONS	24
ANNEXURES	
LIST OF INSTITUTIONS AND INVESTIGATORS	26
COMPOSITION OF REVIEW-CUM-MONITORING COMMITTEE	27
COMPOSITION OF SCREENING COMMITTEE	27
COMPOSITION OF STEERING COMMITTEE	27
LIST OF PUBLICATIONS	28
BIBLIOGRAPHY	29
IMD 30 YEAR CLIMATOLOGICAL DATA FOR LEH	32
CLIMATOLOGICAL DATA FOR OCTOBER 1986 OCTOBER 1988 BASED ON SITE SURVEY OBSERVATIONS	

FOREWORD

Promotion of Astronomy and Astrophysics is one of the thrust areas of the Department of Science & Technology (DST). Astronomers from research institutions and Universities in the country were encouraged by DST to formulate proposals for a National High Altitude Astronomical Facility. Accordingly, leading astronomers representing the Indian Institute of Astrophysics (IIA), Tata Institute of Fundamental Research (TIFR), Physical Research Laboratory (PRL), Udaipur Solar Observatory (USO), U.P. State Observatory (UPSO), Osmania University and Punjabi University made a reconnaissance visit to Leh-Ladhak, in association with the Defence Research and Development Organisation (DRDO) in 1982. Subsequently, a multi-institutional project to pursue ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LEH-LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE ASTRONOMICAL OBSERVATORY FOR INFRA-RED AND OPTICAL STUDIES was sponsored by DST in 1984. Nine DST MONITORING-CUM-REVIEW COMMITTEE meetings were periodically held to take note of the progress of the project. A Workshop was held at UPSO Nainital in April 1985, to review the adopted and mid-term correction methodology. The DST also set up a Screening Committee under the Chairmanship of Prof. G. Srinivasan for evaluation of the work and to recommend corrective measures, if any. A meeting was also held in January 1987 under the Chairmanship of Dr. Vasant Gowariker, Secretary, DST to review the progress and take appropriate advance steps for implementing the recommendations at the end of the project. Accordingly, Prof J.C. Bhattacharyya prepared a concept report for a large national high altitude IR telescope.

This is one of the first systematic astronomical site surveys conducted in the country for location of a large telescope. A medium size telescope located at a good astronomical site can be several times more productive than a large telescope at a poor site. The DST was not only able to bring several institutions to collaborate and carry out the project work under one umbrella but also get valuable logistic support from DRDO. The Indian Meteorological Department (IMD) set up a METEOROLOGICAL OBSERVATORY and DATA COLLECTION PLATFORM (DCP) for continuous monitoring of meteorological data through INSAT-IB in record time. The Indian Air Force provided invaluable help in positioning a 6-inch coude telescope on Mt. Nimmu top by a helicopter and also provided useful Meteorological Data.

The equipment, methodology and the expertise developed during this project, will be useful in future site surveys for astronomical telescopes.

Finally, I will like to place on record my deep sense of appreciation to Dr. Arvind Bhatnagar and Shri S.L. Gandhi for the complete commitment, devotion and sacrifice with which they fulfilled their contributions to this project over an extended period of five years without any thought of credit or compensation.

R.R. DANIEL
Chairman
Review-Cum-Monitoring
Committee of the Project.

ACKNOWLEDGEMENTS

This multi-institutional project of site survey in Leh-Ladhak for an Astronomical Observatory, was sponsored by the Department of Science and Technology, Government of India. It was a very ambitious and challenging project, involving large number of people with varied expertise, institutions and organisations. The scientific objectives of the project were well defined from the beginning, but the mechanism to achieve these objectives remained rather nebulous, in spite of several meetings which took place before the project began. As the project started taking shape, very serious and unexpected problems cropped up, first due to the non-availability of the 24-inch telescope from the Punjabi University, shifting of the 20-inch Bhavnagar telescope from Kavalur to Leh, transportation of the FRP 5.6 metre diameter astronomical dome before the closure of roads due to snow (1984). Acute problems arose due to lack of logistic and manpower support to operate the field station at Leh and at Mt. Nimmu base camp. Further, poor communication facilities available in Leh-Ladhak made the problem even more difficult.

In spite of tremendous problems there was always a "silver lining" in the form of enormous encouragement and help received from a large number of senior scientists of the country, especially Prof. R.R. Daniel, Sr. Professor at TIFR, Bombay, Dr. Vasant Gowariker, Secretary DST, Prof. J. C. Bhattacharyya, Director IIA, Bangalore, Dr. P. J. Lavakare, Advisor, DST, Prof. S.P. Pandya, Director PRL, Ahmedabad.

We would like to mention briefly the historical backdrop of this project. In 1981, Dr. Raja Ramanna, the then Advisor to the Raksha Mantri enthusiastically endorsed this idea of site survey and offered all possible help, through their Field Research Laboratory in Leh. He put us (A. Bhatnagar) in touch with Dr. Krishnamurthy the then Chief Controller, and Shri S. L. Gandhi the then Director of Material and Agricultural Sciences, Defence Research and Development Organisation (DRDO). Dr. V. Arunachalum, the next Advisor to R.M., displayed much more enthusiasm and unstinted support for this project. Seeing Sri Gandhi's dynamism and readiness to go out of his way to shoulder responsibility, the project scientists were highly impressed and were encouraged to embark on this project.

The Department of Science and Technology took a very keen interest in this project. Were it not for Dr. Lavakare's constant monitoring and being always readily available for any help and advise, this project would not have been completed. Dr. Lavakare along with his number of colleagues at DST, notably Drs. K. R. Gupta, Sulbha Gupta and J. K. Sharma, took keen interest and helped us out through difficult periods.

At the time of formulating the scientific programme of the project, consideration of a very important component of the project namely - logistic problems were somehow under-estimated. This was perhaps, due to the inexperience of the scientists of working in difficult logistic conditions such as in Leh-Ladhak. We thankfully acknowledge the enormous help both in the form of logistics and manpower provided by the various laboratories of DRDO, namely the Defence Agriculture Research Laboratory (DARL), Almora and the Field Research Laboratory (FRL) Leh. Shri M. C. Joshi, Director DARL, took personal interest in this project and visited the project site many times and deputed several scientists, assistants and helpers to Leh-Ladhak for taking site survey observations, when astronomers from the participating institutions were not available. The Officer-Commanding of FRL posted from time-to-time took interest and provided valuable help. Notably Lt. Col. Rao, Lt. Col. Chinna and Major Shandal went out of their way to see that logistic problems were sorted out or at least minimized. A very significant contribution for arranging of air transportation to Leh, of the 20-inch telescope made by Lt. Col. M. S. Sanga, the then Assistant Director, Material and Agricultural sciences, DRDO can not be forgotten. The Station Commander of the Air Force base, Leh helped us in installing the 15-cm Zeiss coude telescope on Mt. Nimmu and help of Air Comm. Natrajan of the Air Head Quarters for providing cloud coverage data is acknowledged.

The enthusiasm of the then Director General of Meteorology - Shri S. K. Das for this project is worth mentioning. He along with the then DDGI, Pune Dr. Srivastava and Dr. Sreedharan, Director Instruments, I. Met. D., provided the meteorological instruments and arranged to establish a Met. Observatory in record time of less than 2 months at Mt. Nimmu Base camp in October 1984 and in 1985 the Data Collecting Platform (DCP). Number of scientists from I.Met.D., visited Leh site for checking and calibration of the instruments. The present DGM, Dr. S.M. Kulshrestha has continued giving full support and help for the project. Shri O.P.N. Calla and Shri S. S. Rana of the Space Application Centre, Ahmedabad also contributed to the project by providing a 22 GHz., radiometer for estimation of water vapour. For measuring the precipitable water vapour, a portable meter given to PRL by Prof. Westphal of Caltech, USA was used. The Department of Non-Conventional Energy Sources (DNES) got interested in this project and provided free of cost several solar photo voltaic power panels. These panels worked very satisfactorily for almost 4 years in Leh-Ladhak. The help of a local contractor - Shri T. Morup, who had taken the challenge of constructing the telescope pier on Mt. Nimmu and the rest house at the Base Camp, is acknowledged.

Last, but not the least, this project would not have started and been completed, were it not for enormous contributions made by a large number of individuals from the participating institutions, namely DRDO (FRL & DARL), IIA, Bangalore, TIFR, Bombay, PRL, Ahmedabad, UPSO, Nainital, Osmania University, Hyderabad, Punjabi University and of course USO, Udaipur. We would have liked to acknowledge and thank all the people by name who worked so hard and devotedly for several years under very harsh environmental conditions for the success of this project, but the limitation of space constrains us to do so.

A. Bhatnagar
Project Co-ordinator

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1. HISTORICAL BACKGROUND

The suggestion to look for an astronomical site in Ladhak region located more than 3,000 metres, above mean sea level was mooted in November 1981 at a meeting organized by ADCOS held under the Chairmanship of the late Prof. M. K. Vainu Bappu. At this meeting it was pointed out that the Ladhak region remains relatively clear during the monsoon period, when rest of the country experiences cloudy sky due to monsoon conditions. It was also noted that only at such high altitudes, precipitable atmospheric water vapour will be low enough for high quality infrared observations.

In a subsequent meeting on 29 April 1982, Prof. Bappu emphasised that a site survey should be undertaken to examine whether Leh-Ladhak region is as good a site as it is generally thought to be. He mentioned that "our aim should be to make such measurements and observations over a period, which will enable us to decide once for all, the quality of astronomical observations that can be made from Ladhak."

Other astronomers also had a similar view that Ladhak was likely to be a promising site for IR astronomical observations. This was partly based on the 30 years Meteorological Climatological Tables of observations from 1931 to 1960 for Leh. This table is reproduced in the Appendix giving Cloud Coverage, Rainfall, Wind and other meteorological parameters. The low rainfall and the number of clear days indicated that the site was worth a thorough investigation.

2. PRELIMINARY RECONNAISSANCE

In September 1982, a team of astronomers headed by Prof. R.R. Daniel visited Leh-Ladhak for a preliminary survey of the area. The team collected the following general information of this region:-

(a) CLOUD COVERAGE AND SKY TRANSPARENCY.

Leh-Ladhak is a Trans-Himalayan region, where generally monsoon does not reach and the annual precipitation is scanty. Also, because of the rarefied atmosphere, the sky is very dark whenever there are no clouds.

(b) AIR DRYNESS AND RESULTING WATER PRECIPITATION.

The entire area is a high altitude cold desert. The average annual rainfall as per the 30 years of climatological data is only 115 mm.

(c) WIND

The Leh valley is by and large free from gales and very high winds.

(d) NATURAL AIR POLLUTION

The dust content in the air seems to be low near Mt. Nimmu, which is about 25 km from Leh town, as there the terrain is generally gravel. However, it was pointed out that during summer months the dust from Sahara and other deserts sometimes may rise even up to 5,000-6,000 metres in the Himalayan region. Very preliminary examination indicated possibility of clarity of the sky though not as good as one would expect for an altitude of 4,000 metres. After the monsoon and snow fall the sky transparency usually improves considerably.

(e) NATURAL LIGHT POLLUTION

The 34° N latitude of Leh is not high enough to be affected by aurora borealis etc.

(f) SELECTION OF MT. NIMMU.

Leh is connected by road from Srinagar and Manali which is open during the summer months from July to October. During rest of the year, the access to Leh is only by air. The initial impression of the team was favourable. A quick survey of the region extending about 50 km, along the road on either side of Leh and inspection of possible sites in the accessible neigbourhood showed that Mt.Nimmu at a height of 4100 metres is potentially a most attractive site

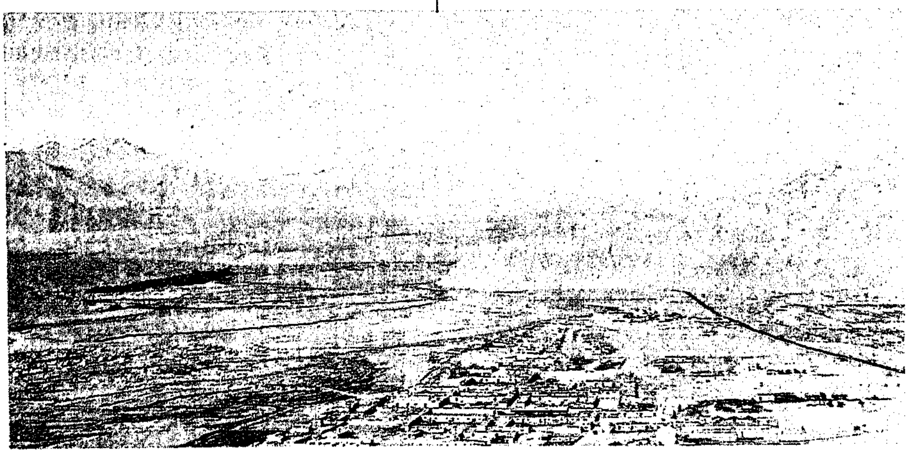


Figure 1. Panoramic view of Mt. Nimmu and surrounding region showing Leh-Srinagar highway.

due to the following considerations;

that, Mt. Nimmu is an isolated mountain peak, having no higher peak near the immediate vicinity of about 10 km radius. The top of Mt. Nimmu has a large flat area for locating number of telescopes and other facilities. The reconnaissance team went up to the top and confirmed the availability of a fairly large stretch of flat land at the top. This mountain peak is located in a long valley running east-west of more than 150 km long stretch. The shape of the peak is convex and therefore may provide laminar air flow.

(g) SEISMIC ACTIVITY OF THE REGION

Regarding the seismic activity, it is reported by WADIA INSTITUTE OF HIMALAYAN GEOLOGY that " the town of Leh lies along the Indus Suture Zone. Seismically the area has not witnessed any major seismic event in the recent past (as per published literature). The town and its surroundings, however fall in the influence of major events occurring in Pamir, Hindukush, Kinnaur and Kangra, e.g., in Kangra earthquake of 1905 it was in iso-seismal 5-6 while for Kinnaur earthquake of 1975 it lay in iso-seismal 4-5. For the Pamir and Hindukush earthquakes of 1939, it was in iso-seismal 3-4. Thus the town of Leh and surrounding lie in seismic zone of 4-5 intensity (maximum). According to Kaila and Narain (1976) the town is situated in between two seismic highs of Srinagar in the west and Kailash in the east. But their influences is also minimal. (low A value of 2 only)."

(h) ARTIFICIAL AIR AND LIGHT POLLUTION

Mt. Nimmu top is about 3 km away from Leh-Srinagar metalled highway and there appears to be hardly any danger of air pollution due to traffic and industry. The terrain near and around Mt. Nimmu is generally gravel and thus dust does not rise due to the road traffic.

Mt. Nimmu is about 25 km from the Leh town. There appears to be no danger due to artificial light pollution from the city lights as in the foreseeable future no industrialization is expected in that region. Leh has a population of about 15,000-20,000 and is situated in a valley surrounded by high mountains. Two high mountain ridges separate Leh and Mt. Nimmu. Hence the town is not directly visible from Mt. Nimmu peak.

(i) ACCESSIBILITY TO THE TOP

The road between Leh and Mt. Nimmu remains open even during winter months. Accessibility to the top did not appear to be insurmountable. The team felt that Mt. Nimmu satisfies the requirements for considerations as an astronomical observatory site.

The Department of Science & Technology took note of November 1981 ADCOS's meeting and the reconnaissance team's reports of September 1982. Subsequently, at the 1983 Ahmedabad meeting at PRL, it was decided by the scientists to formulate a multi-institutional project to pursue--

ASTRONOMICAL AND ATMOSPHERIC OBSERVATIONS IN LADHAK REGION WITH LONG TERM VIEW OF SETTING UP A NATIONAL HIGH ALTITUDE

ASTRONOMICAL OBSERVATORY FOR INFRA-RED AND OPTICAL STUDIES.

Figure 2. View of Mt. Nimmu top.

3. SEARCH FOR OTHER POSSIBLE SITES

The possibility of locating possible sites other than Mt. Nimmu in Ladhak was also explored. In 1985, a team carried out a survey of 232 km long region between Leh and Kargil and about 50 km on Leh-Manali road, to locate more suitable sites. The search was for a mountain peak, which could be made easily accessible from the Srinagar-Leh-Manali highway and has a fairly flat area on the top suitable for establishing a large observatory.

This team could not locate a site better than Mt. Nimmu in this region, because most of the prospective sites were surrounded by high mountain peaks and were quite inaccessible. The Mount Nimmu peak is easily accessible from the main highway and is only 25 km from Leh town and accessible throughout the year.

4. DST APPROVAL FOR THE PROJECT, BUDGET ETC.

This inter-institutional project of site survey for high altitude observatory in Leh-Ladhak for IR telescope, was finally formulated in February 1984, after several meetings and a workshop held in 1982, 1983 and in early 1984, of scientists from the participating institutions. The project was approved by DST in May 1984 and funds were released in August 1984. As this was an inter-institutional project, specific tasks required for implementation of the project were assigned to the various participating institutions and accordingly the necessary funds were made available to each of the eight institutions. The original and revised sanction of the budget by DST is given below :

	Institution	Original	Revised
		(Rupees in lahks)	
1.	Defence Research & Deve. Orgn.	11.02	11.52
2.	Udaipur Solar Observatory	7.77	12.54
3.	Physical Research Laboratory	0.98	0.60
4.	Tata Institute of Fundamental Res.	4.03	3.50
5.	Indian Institute of Astrophysics	4.54	4.80
6.	Punjabi University	0.35	0.27
7.	U.P. State Observatory	0.29	2.02
8.	Osmania University	0.61	0.45
	Total	29.59	35.70

As the project started taking shape, number of unforeseen problems cropped up. For example, it was proposed that the 60-cm Zeiss telescope of the Punjabi University, Patiala would be made available for the project for astronomical observations from Leh-Ladhak, but unfortunately this telescope was not available. Hence, an alternate solution was sought by making use of a very old 50-cm Bhavnagar telescope of IIA. It was a major problem to transport this heavy telescope by air from Bangalore to Leh and to reach there before August/September 1984. It was through the untiring efforts of Major M.S. Sanga and Mr. S.L. Gandhi, with the help of the Indian Air Force, that the telescope could be air lifted and positioned in October 1984 at Skara-Leh. The 5.6 metre diameter FRP astronomical dome could not be transported before the roads were closed in October 1984. Hence, the telescope had to be kept in a round 6-feet high wall enclosure for nearly 1 year without a proper dome. However, telescope was protected from rain and snow with the help of a FRP canopy, which had to be removed for taking observations. Due to the logistic difficulties, it was very difficult to make even minor alterations and repairs required for the telescope. It was due to the ingenuity and wide experience of the IIA workshop team, that the 50-cm telescope could be installed within 2-3 months. Although, a site near the base of Mt. Nimmu was selected for installation of the 50-cm telescope by a team of scientists in July 1984. But in view of the operational difficulties it was decided to keep the telescope at Skara-Leh near the DST-Laboratory-cum-guest house site For visiting scientists, observers and laboratory, a spacious house with 8 rooms was rented near the Field Research Laboratory in village Skara-Leh, which served as a Laboratory-cum-guest house.

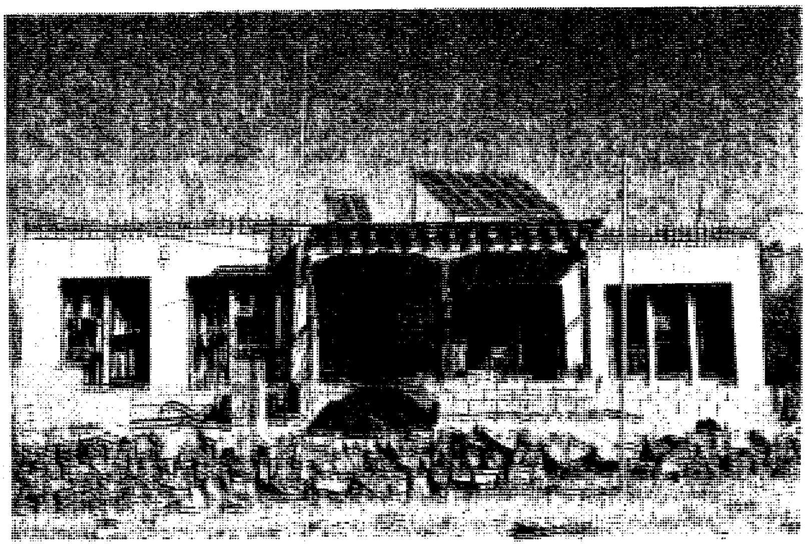


Figure 3. Base Laboratory-cum-Guest hostel at Skara-Leh site.

The project faced a major crisis in October 1984 when the Field Research Laboratory (FRL) of DRDO, declined to operate the grant and provide the necessary infrastructure support. At this stage the project had already "taken-off," a nice house for the laboratory-cum-guest house was rented, major instruments were positioned or were in the process of installation. Hence, this responsibility of running the station and to provide infrastructure support etc., was given to the Udaipur Solar Observatory and to the Project Coordinator.

On the manpower front, it was proposed in the project proposal that observers and scientists would be drawn from the participating astronomical institutions, who would stay at Leh for a period of 2 months and also take observations required for the site survey along with the 50-cm telescope. Hence, in the proposal, no provision was made for salaries of the project personnel. But in actual practice, no observers or scientists volunteered to stay at Leh-Ladhak for a period of 2 months. A search was made for suitable person or persons who had astronomical background and managerial capability to man the station. In November 1984, in view of the logistic difficulties, it was decided to appoint an observer and a manager from the local population on temporary basis, until some better arrangement could be made. Mr. Arvind Paranjpye from IIA, volunteered to stay at Leh for this project, but it was a major work for a single hand, hence a request was made, through Shri S.L. Gandhi to Shri M.C. Joshi, Director, Defence Agriculture Research Laboratory (DARL) Almora, to provide, 3 or 4 qualified scientific assistants for taking site survey observations and man the station. The Director, DARL indeed continuously provided scientific personnel and helpers for smooth running of the station. It may be mentioned that the astronomers for whom the efforts were being made, were most reluctant to stay at Leh-Ladhak for taking observations for the site-survey. Due to the logistic difficulties especially manpower and infrastructure problems, the site survey data obtained from November 1984 through August 1986, had large gaps. Some of the essential instruments, such as the Double Beam Telescope for seeing measurements and the Micro-thermal Tower and the mule track upto Mount Nimmu top were not available until mid 1986, therefore the project had to be extended by 2 years. In view of the possible delay in designing and fabrication of the Double Beam Telescope, it was decided in November 1985 to acquire a 15-cm aperture coude telescope from Zeiss, for "seeing" measurement using the polar trail method. This telescope was obtained on very high priority basis from Carl Zeiss, Jena, in April 1986. It was tested and arrangement for polar trail photography was made at Udaipur in May 1986 and transported to Leh-Ladhak in August 1986, when the road opened. The telescope was installed on Mt. Nimmu in September 1986, with the help of Air Force helicopters. The micro-thermal tower was installed in August 1986 and the meteorological instruments in September 1985, on top of Mt. Nimmu. Among the major difficulties in operating in Leh-Ladhak region is that the effective operating period for transportation of heavy equipment and building construction etc., is confined only to 4/5 months from July through November, out of the 12 months. If certain tasks could not be accomplished during the summer months, then they have to be postponed for the next year. Hence, this project was delayed by nearly 2 years, beyond that envisaged. After trying various possibilities to solve the manpower problem it was decided in early 1986, that regular observers (scientific assistants) and helpers should be employed for this DST project, who would be 100% responsible for site survey data collection and data analysis. Hence from June 1986 until the end of project, 3 scientific assistants for taking observations to be stationed at Leh-Ladhak and 2 scientific assistants for data analysis were employed by DARL, Almora and UPSO Nainital respectively. For liaison with DRDO, DARL, FRL, DST and management of the project, the services of Shri S.L. Gandhi, as an Honorary Project Officer was obtained.

5. PARAMETERS FOR SITE SURVEY

For any ground based major astronomical observatory, the site of the telescope is an extremely important parameter in view of the efficiency, quality and quantity of observations. A medium sized telescope located at a good astronomical site can be several times more productive than a large telescope at a poor site. The characteristics of site parameters are dictated by the type of astronomical observations being planned. In recent times, all over the world, number of extensive site surveys are being carried out to look for promising observatory sites for optical, Infrared, milli-meter and sub-millimeter wave astronomies. During the last three decades interest in Infrared wavelengths has grown to such an extent that most major observatory site surveys give high priority to Infrared (IR) observations. To qualify as a good site for IR work, it is essential that the precipitable water vapour (PWV) above the site (under clear sky conditions) should be around 1-2 mm for a good fraction of time. The amount of water vapour above a site depends in a complex way on the atmospheric stratification and global circulation pattern. However, logic and abundant evidence indicate that the first order effect is dependent on the elevation and to some extent on the latitude of the site. It has been observed that PWV decreases with increasing latitude.

In Figure 4 is shown the infrared absorption bands due to the atmospheric gases (O_2, H_2O, CO_2, CH_4, N_2O, O_3). It will be noticed that the major absorbing constituent is the water vapour in 5-7 micron and 18-100 micron spectral bands. Other terrestrial gases also significantly contribute. Thus by proper choice of the site, where the precipitable water vapour is minimum, it is possible to observe faint stellar sources in these IR and sub-millimeter spectral windows.

It is generally accepted that site parameters of purely atmospheric nature are:-

(i) cloud coverage,
(ii) air dryness and precipitation,
(iii) atmospheric turbulence (seeing)
(iv) sky brightness
(v) extinction, and
(vi) wind speed and direction.

Parameters linked essentially with location are:-

(i) altitude above the atmospheric inversion layer,
(ii) topography of the site,

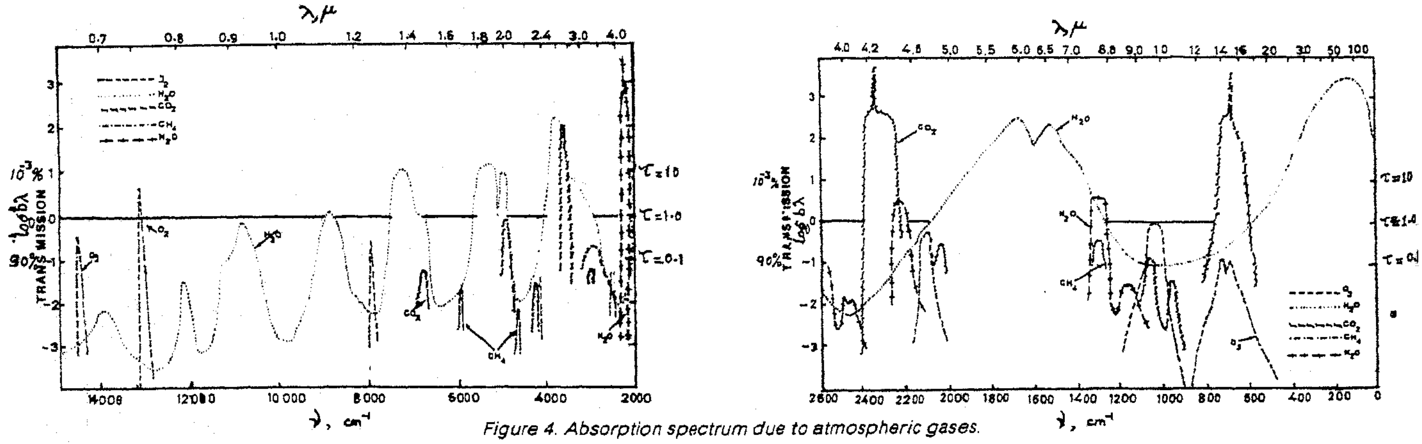


Figure 4. Absorption spectrum due to atmospheric gases.

(iii) temperature stability,
(iv) air pollution,
(v) light pollution, and
(vi) seismic activity.

Parameters connected with human created sources of interferences are:-

(i) artificial light pollution,and
(ii) artificial air pollution.

Parameters connected with actual operations are:-

(i) convenience of location,
(ii) availability of water, electricity and essential food supplies,
(iii) general accessibility of station to ensure maintenance of equipment etc., and
(iv) access by air and road.

6. SPECIAL INSTRUMENTS AND SOFTWARE DEVELOPED FOR SITE SURVEY AND EQUIPMENT USED

For astronomical site surveys, major instruments required are for meteorological and astronomical observations. The meteorological instruments are generally of standard design and are readily available and were provided by the Indian Meteorological Department, while for the astronomical observations the necessary equipment had to be designed, fabricated or acquired and modified for the required data. TIFR, USO, PRL and IIA groups made significant contributions in designing and fabrication of the necessary equipment. In the following is given a brief description of the various equipment developed for this site survey programme.

The Tata Institute of Fundamental Research (TIFR) built an ALL SKY CAMERA using a 180 degree Fish-eye lens attached to a 35 mm camera back, to photographically record the cloud coverage during night time for checking visual estimates made by observers.

The Udaipur Solar Observatory (USO) group also designed and fabricated a simple and inexpensive All Sky Camera using an aluminized convex mirror and a 35 mm camera. This group also developed an optical arrangement using 15-cm aperture Zeiss coude telescope, for polar trail photography and software for analysis of voluminous meteorological data. USO designed and fabricated an insulated light weight hut for observers at Mt. Nimmu top, making use of the natural solar heating.

For measuring the star motion resulting from turbulence in the atmosphere a double beam telescope was constructed for this project by the TIFR group. This group also fabricated microthermal sensors and a 12-metre high tower for measuring the temperature fluctuations of air above the ground at three heights (3.6, 7.2 and 12 metres).

Figure 5. All Sky Camera using aluminized convex mirror and 35 mm camera back.

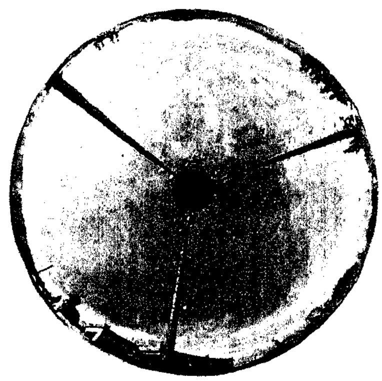


Figure 6. 360-degree daytime exposure of cloud coverage obtained using convex mirror all sky camera.

In TABLE I is given a list of equipment used for measuring various site survey parameters.

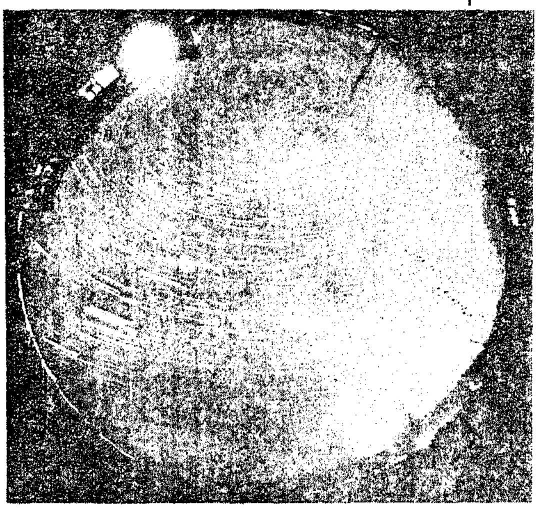


Figure 7. Star trails taken during clear sky using "Fish eye" lens all sky camera.

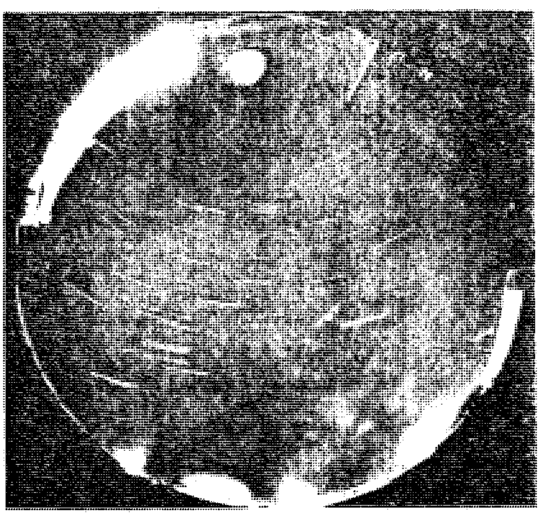


Figure 8. Star trails taken during partially clear sky.

TABLE I : LIST OF EQUIPMENT USED FOR SITE SURVEY

Equipment (Source)	Type of data acquired
1. METEOROLOGICAL	
(i) Anemometer and wind vane (IMD)	Wind speed and direction for instantaneous measurement.
(ii) Anemograph (IMD)	Wind speed (chart recording)
(iii) Thermograph (IMD)	Ambient temperature
(iv) Hygrograph (IMD)	Surface humidity
(v) Sunshine recorder (IMD)	Sunshine hours
(vi) Rain and snow gauge (IMD)	Rain & snowfall
(vii) Automatic Data Collecting Platform-DCP (IMD)	Met. data directly relayed by INSAT IB to Delhi (hourly)
(viii) All Sky Camera (TIFR)	Photographic record of cloud coverage
(ix) Microthermal Tower (TIFR)	Temperature fluctuation at 3 heights (3, 6 & 12 meters)
2. ASTRONOMICAL	
(i) Evan's day sky brightness photometer (USO)	For day sky brightness in terms of solar disk.
(ii) Westphal water vapour meter (PRL)	For measurement of precipitable water vapour
(iii) Night time "seeing"	Stellar "seeing" from Mt. Nimmu
(a) 15-cm Zeiss coude telescope using polar trail method (USO)	
(b) Double Beam Telescope (TIFR)	Differential star image motion from Mt. Nimmu
(iv) Night time sky brightness	
(a) Portable photometer (PRL)	Night sky brightness from Mt. Nimmu
(b) 20-inch Bhavnagar telescope (IIA)	Night sky brightness from Skara-Leh.
(v) Extinction	
(a) 20-inch Bhavnagar telescope	UBV and IR extinction measurements from Skara-Leh

7. COLLECTION OF DATA AND ANALYSIS.

(A) Weather Parameters

(i) Cloud Coverage

The estimation of the cloud coverage was made visually by observers from the Skara-Leh Observatory, Base camp and Mt. Nimmu top. As the distance from Skara-Leh and Mt. Nimmu is only about 25 km, the cloud coverage at both places remains generally the same. Observations were normally taken every 2 hours in terms of the total cloud coverage of the sky in octas, (8 octas indicate complete cloud coverage, while 0 octas means clear sky). Initially, visual observations were started from 15 November 1984 until September 1986. During this period, continuous observations could not be taken due to unavoidable circumstances. From October 1986 until the end of the project, in October 1988, comprehensive and systematic observations are available. To check on the visual observations of cloud coverage an All Sky Camera using a Fish-eye lens, covering 180 degrees of the sky was used on a few nights. The estimation of the cloud coverage with the All Sky Camera was made from the visibility of star trails on the exposures.

Hourly values of cloud coverage data are plotted in 2-dimensional panels for each month and are given in Part II of this report. Figures 11a and 11b show sample panels for a relatively cloudy month of February 1988 and for a clear month of October 1988. From these panels one could easily infer cyclic pattern of clear and cloudy spells, if any. For many years, the meteorological observations are being taken by the Indian Air Force (IAF) from the Leh airport. For comparison purposes the cloud coverage data obtained by IAF, was also acquired for the period 1985 through 1988.

The following criteria to estimate the photometric and spectroscopic hours and nights were adapted :

(i) Clear :
When cloud cover is zero octas for the complete night,

(ii) Partly clear :
When the cloud cover is zero octas for more than 4 continuous hours,

(iii) 3 Octas :
When the cloud coverage is 3 octas for more than 4 continuous hours,

(iv) Useless :
The nights other than the criteria given in (i), (ii) and (iii),

(iv) Photometric nights :
(a) nights in categories (i) and (ii) above,
(b) relative humidity of $<$ 90%,
(c) wind speed $<$ 50 km/hour,
(d) zenith extinction in V $<$ 0.3 mag.

(v) Spectroscopic nights :
(a) Photometric nights plus nights in category (iii),
(b) zenith extinction in 0.5 mag.

(vii) Photometric hours :
Number of night hours when the cloud coverage is zero octa for more than 4 consecutive hours.

(viii) Spectroscopic hours :
Number of night hours when the photometric hours and the cloud coverage is less than 3 octas for more than 4 continuous hours.

The criteria adapted for this site survey for consideration as photometric and spectroscopic nights and hours are more stringent as compared to the La Palma Observatory criteria. (ref. P. Murdian, 1985, Vistas in Astronomy, Vol. 28. p.449).

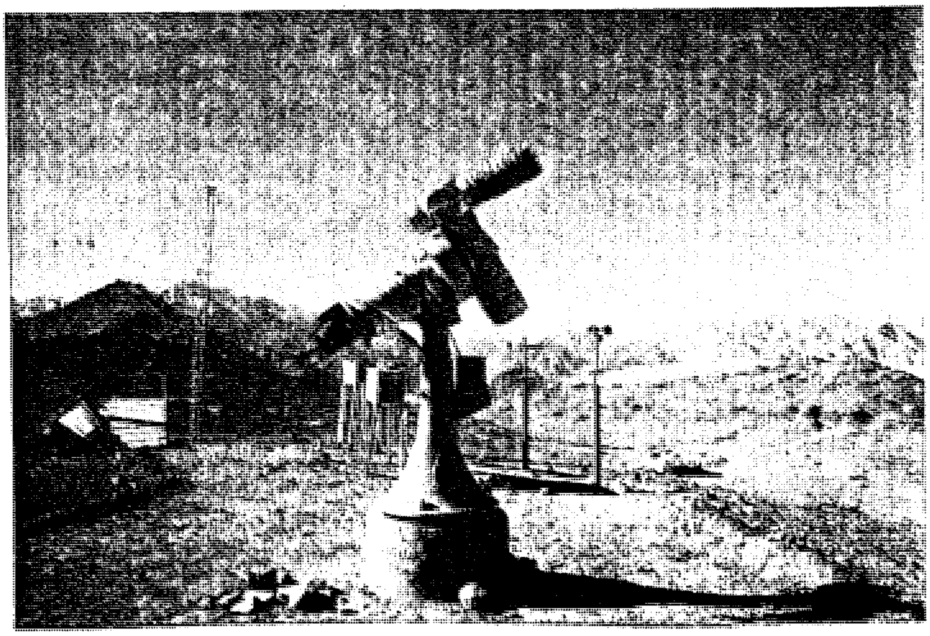


Figure 9. General view of Mt. Nimmu showing 15 cm coude telescope, microthermal tower and insulated hut.

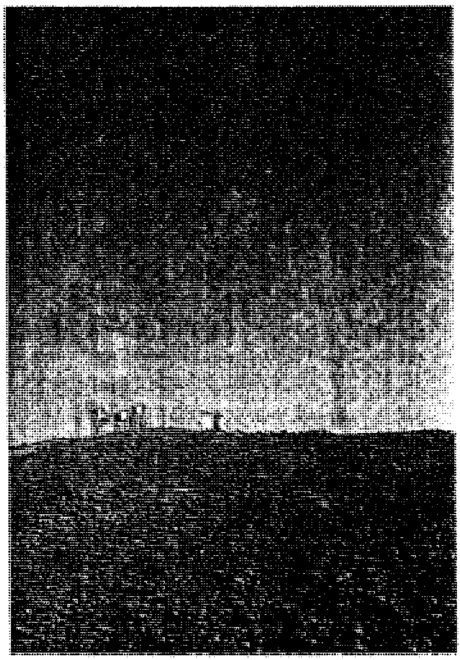


Figure 10. 12-metre high microthermal tower

SUMMARY OF CLOUD COVERAGE DATA :

(i) DAY TIME :

From the histograms for the period November 1984 to September 1986, it is found that 15% of the days were clear, 11% were partly clear, 9% were cloudy with less than 3 octas and 65% days were useless or completely cloudy. The histograms for the period from October 1986 to October 1988, indicate that 9% of the days were clear, 12% of days were partly clear, 19% were cloudy with less than 3 octas and 60% were useless days.

(ii) NIGHT TIME : From the analysis of the cloud coverage data for night time hours (i.e. from the end of astronomical twilight to the beginning of astronomical twilight), for the periods, (i) November 1984 to September 1986 and (ii) from October 1986 to October 1988, the following conclusions are drawn :

(a) For the period November 1984 to September 1986 :

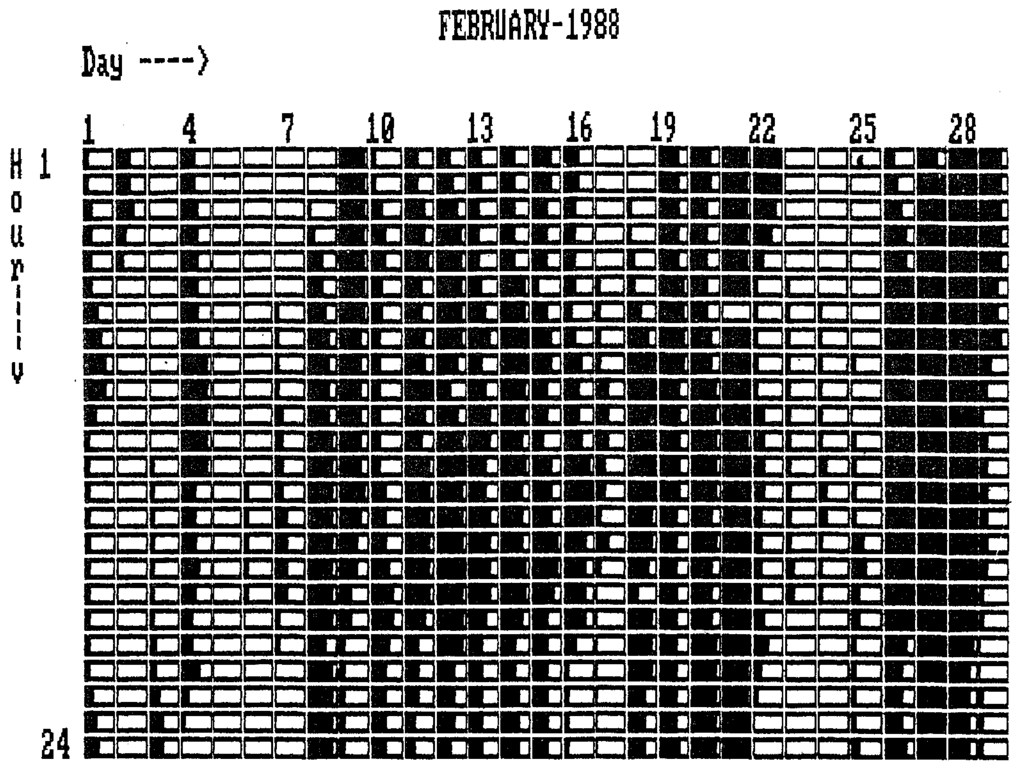
(i) 32% hours were photometric,
(ii) 39% hours were spectroscopic, and
(iii) 61% hours were found useless.

These compare well with independent cloud coverage observations made by the IIA team, observing with the 20 inch telescope. Their findings are :

(i) 32% hours were available for photometric, and
(ii) 44% hours were good for spectroscopic work.

(b) For period October 1986 to October 1988 :

(i) 27% of nights were photometric
(ii) 48% of nights were spectroscopic,
(iii) 26% hours were photometric, and
(iv) 50% hours were spectroscopic



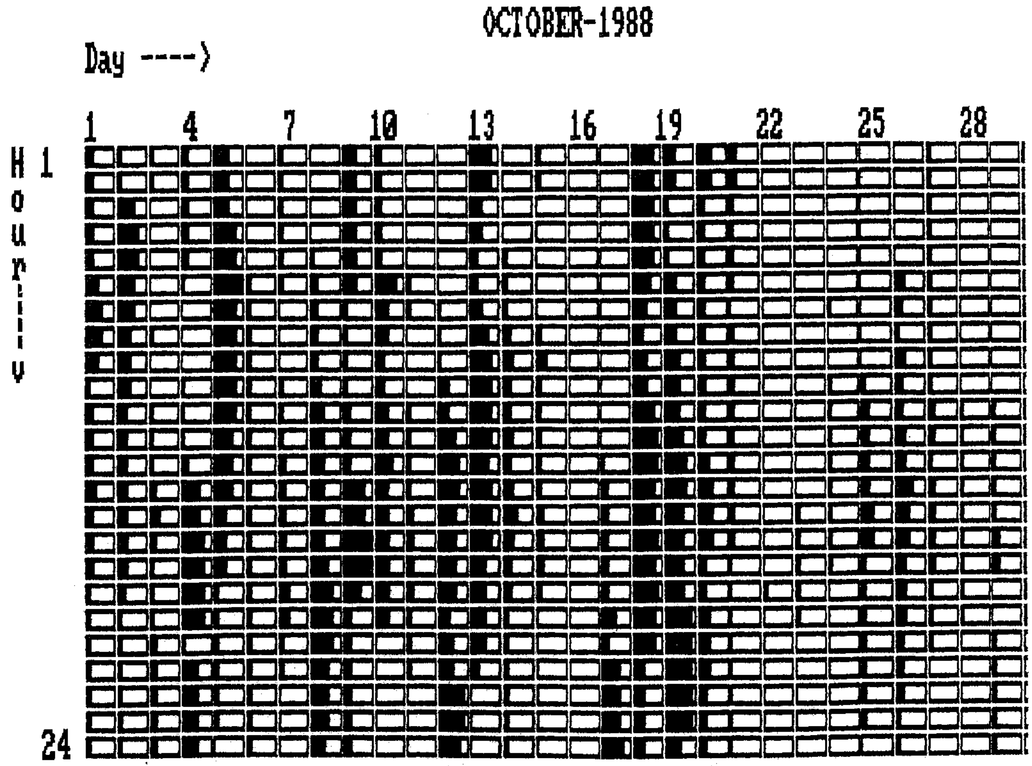


Figure 11. Panels displaying hourly cloud coverage. The filling of boxes indicate cloud coverage during the hour from 0-8 octas.

In TABLE II is given a summary of the average percentage and the total number of usable and useless hours and nights available annually and during variou seasons.

TABLE II : SUMMARY OF NIGHT TIME CLOUD COVERAGE DATA

	% HOURS				% of NIGHTS				
Year (season)	P	S	Use-able	Use-less	P	S	3 octas	Use-able	Use-less
1986 (IV)	31	30	61	39	20	12	15	47	53
1987 (I)	25	33	58	42	13	8	24	45	55
1987 (II)	27	18	45	55	17	9	16	42	58
1987 (III)	28	28	56	44	20	5	32	57	43
1987 (IV)	55	15	70	30	37	20	14	71	29
Yearly mean	35	23	58	42	21	11	22	54	46
1988 (I)	14	7	21	79	4	10	6	20	80
1988 (II)	19	32	51	49	15	6	35	56	44
1988 (III)	17	19	36	64	14	4	22	40	60
1988 (Oct.)	41	22	73	37	32	13	29	74	26
Yearly mean	19	18	37	63	13	7	22	42	58

Note :
In column 1 is given the year and in parenthesis the season i.e.
(I) January to March
(II) April to June
(III) July to September
(IV) October to December

P - means photometric hours/nights
S - means spectroscopic hours/nights

ANNUAL AVERAGE NUMBER OF HOURS AND NIGHTS
(October 1986 October 1988)

	No. of hrs.	No. of nights
PHOTOMETRIC	896	66
SPECTROSCOPIC	704*	33*
USABLE (3 OCTAS)	1600	173
USELESS	1600	193

* Total spectroscopic hours and nights will include both spectroscopic and photometric sky condition.

Figure 12. Meteorological observatory established in October 1984, at Mt. Nimmu Base camp.

(ii) AIR TEMPERATURE AND VARIATION

(a) Maximum and minimum temperature :

For this site survey the air temperature measurements were made using a recording type thermograph supplied and installed by IMet D in October 1984. Data are available for the period between November 1984 to 1986 from the Base camp and from September 1986 to October 1988 from Mt. Nimmu top. The analysis of the data shows that the maximum night time temperature at the Base camp ranges from +24°C to —22°C, where as the minimum temperature ranges from +20°C to —28°C during the whole year. While at Mt. Nimmu top, the maximum night time temperature ranges from +20°C to —23°C, where as the minimum night time temperature ranges from +14°C to —27°C. This corresponds well with the Climatological Tables for 30 years period (1931-1960). It is reported that in Leh the highest recorded air temperature was 34°C during July and minimum —28°C in January.

From the analysis of the data, it is seen that the temperature variation during night time generally remains between 2° to 4°C.

(iii) MICROTHERMAL FLUCTUATIONS ABOVE GROUND LEVEL

To determine the atmospheric structure-function, above the ground, microthermal sensors of platinum wire are used. They are mounted on towers or attached to tethered balloons or kites. The upper limit of test towers seems to be around 30 metres. Towers are good solution for studies between 3 to 30 metres above the ground and tethered balloons are used upto 500 metres and provide an overlap between Microthermal towers and acoustic sounders. The data from micro-thermal sensors mounted on the test towers are extremely useful to decide the height of the telescope above the ground. In view of the importance of microthermal data for site selection, the TIFR group designed and built three element microthermal sensors, mounted on a tower of 12 metres height. This instrument was designed to monitor the short time (fast) temperature variations of air and display the output on a chart recorder. The sensors are resistors of 600 ohms, made from tungsten wire of diameter 20 micron thickness and about 3 metres long. The three sensors were mounted on an aluminum tower, at heights of 3.6 m, 7.3 m and 11.0 m above the ground level and installed on Mt. Nimmu top in August 1986. This instrument is capable of detecting temperature fluctuations >0.05°C. The signals from the 3 thermal sensors are analysed in 4 frequency bands, ranging from 0.05 Hz to 5 Hz. Besides these signals are averaged for 2 minutes and recorded on a chart recorder, thus any short term spikes (<2 minutes) in temperature would not be seen in the record. The data were recorded on about 100 nights from August 1987 to September 1988. Following are the salient findings obtained from the analysis of the data :

(i) the RMS temperature fluctuations were less than 0.1°C on most of the nights,

(ii) for most of the nights (90%) the RMS fluctuations shown by the three sensors are similar, suggesting that a height of 12 metres is adequate to eliminate the effect due to large temperature fluctuation near the ground.

(iii) In Table III a summary of the results is given, indicating the number of observations of temperature fluctuations 0.1°C, between 0.1, 1.5 C, 0.15-0.2 C and 0.2 C, for night hours between
(a) 2100 and 0400 hours, and
(b) 2000 and 0500 hours.

TABLE III:
MICROTHERMAL TEMPERATURE FLUCTUATIONS

(a) For 2100 to 0400 hrs.

RMS temp. fluctuation	$<$ 0.1 C	0.1-0.15 C	0.15-0.2 C	$>$ 0.2 C
Top sensor	1513	6	3	0
Mid sensor	1482	17	6	17
Bottom sensor	1485	13	8	46

(b) For 2000 to 0500 hrs.

RMS temp. fluctuation	$<$ 0.1C	0.1-0.15 C	0.15-0.2 C	$>$ 0.2 C
Top sensor	1827	7	4	0
Mid sensor	1789	19	6	24
Bottom sensor	1753	18	9	59

(iv) RELATIVE HUMIDITY (RH)

The ground level relative humidity (RH) was measured using a recording hair hygrograph from the Base camp and also from the Mt. Nimmu top. The RH during the night time remains generally less than 60%. However, it was noted that during the winter season when the ambient temperature is below the freezing point, the relative humidity measurements are not reliable, but RH is expected to be very low.

(v) WIND SPEED AND DIRECTION

An anemometer and wind vane was installed in October, 1984 at the Base camp. The observations were recorded manually every 2 hours. The direction of the prevailing wind is mostly from the west to east during the afternoon hours, which continues in the same direction until the early hours of the night, thereafter the wind speed considerably decreases.

In October 1985, a recording anemograph was installed at Mt. Nimmu top. From the histograms plotted for the various ranges of wind speed, during different months, it is noted that the wind speed generally remains less than 30 km/hour during night time. However, high speed wind upto 50 km/hour is prevalent during July, August and September months, but mainly during the day time. Normally, the wind picks up high speed in the afternoon and may continue upto 8 or 9 pm, thereafter the wind dies out and it becomes calm around mid-night. Occasionally, higher winds may continue even upto early morning hours, but in no case wind speed higher than 62 km/hour was ever recorded.

(vi) SUNSHINE

A sunshine recorder was used to estimate the total duration of sunshine. The data obtained from this instrument was used to check the visual observations of the cloud coverage during the day.

(B) ASTRONOMICAL PARAMETERS
(i) SKY BRIGHTNESS

(a) DAY SKY BRIGHTNESS

Evan's sky photometer was used to visually measure the day sky brightness in terms of the solar disk. These observations were made 4 times a day from Skara-Leh or from Mt. Nimmu, whenever the sky conditions permitted. Marked decrease in the sky brightness values were noticed from Mt. Nimmu top as compared to Skara-Leh, confirming that 500 metres higher elevation considerably improves the sky condition. It may also be due to the fact that Skara-Leh site is located in a comparatively dusty environment, while the Mt. Nimmu terrain is mostly gravel. From the analysis of all the observations, it is noticed that:

12% show sky brightness $< 30 \times 10^{-6}$
28% observations between $30\text{-}60 \times 10^{-6}$
12% observations between $60\text{-}90 \times 10^{-6}$
11% observations between $90\text{-}120 \times 10^{-6}$
37% observations more than 200×10^{-6}

of the solar disk. Thus, more than 50% of the time, solar coronagraphic studies could be made from Mt. Nimmu. However, it may be mentioned that the observed day sky brightness was not sufficiently low, considering the high altitude of 4100 metres. The higher dust content in the atmosphere is perhaps due to the dust rising from the Sahara, Arabian and Rajasthan deserts. Apparently, the fine dust from these regions could rise upto even 6,000-7,000 metres height during the summer months. It is noticed that the sky condition considerably improves during the winter months and after rainy season.

(b) NIGHT SKY BRIGHTNESS

The dark night sky brightness was measured using the following two techniques:

(i) A portable night sky brightness measuring photometer was built by PRL group and observations were made on a few nights in July 1988, by the PRL team from Mt. Nimmu top. The data indicates an average sky brightness of 20.4 magnitude per square second of arc, in the V band filter.

However, this value seems to be rather high, which may be due to the summer month, when the dust content is comparatively high in the atmosphere in Leh-Ladhak region.

(ii) The night sky brightness measurements were made using also the 20-inch telescope by the IIA teams, through UBV filter at Skara-Leh. The average value of the sky brightness obtained mostly in September and October 1989 are as follows:

$V = 20.8 \pm 0.2$ mag. per sq. arc sec
$B = 21.4 \pm 0.2$ mag. per sq. arc sec
$U = 20.7 \pm 0.2$ mag. per sq. arc sec

The site of the 20-inch telescope was in relatively dusty location and also about 500 metres less than Mt. Nimmu, therefore one may perhaps expect increased brightness level of at least 0.25 magnitude from the Mt. Nimmu top.

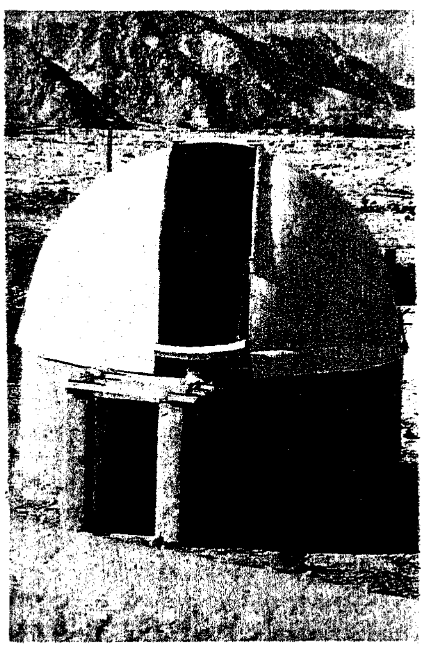


Figure 13. 20-inch Bhavnagar telescope with 5.6 metre FRP astronomical dome at the Skara-Leh site. (photo by K. T. Rajan)

(ii) PRECIPITABLE WATER VAPOUR (PWV) :

For measuring PWV, a water vapour meter (No.18) designed and built by Prof. Westphal and loaned to PRL was used. This instrument responds to the product of pressure (p) and water abundance (m) (pxm) by comparing the solar intensity in 1.86 micron atmospheric water vapour band, with the intensity in the nearby continuum at 1.65 micron. The limitation of this type of instrument is that it can be used only during the daytime. Thus, the diurnal variation of PWV remains a largely unknown factor. Normally, such water vapour meters tend to be inaccurate for low PWV, in the range of 1 mm or less. However, similar water vapour meters have been used in the past for other site surveys. Hence, it was considered quite appropriate for comparison purposes, in spite of it's limitations. This water vapour meter was taken to the Kitt Peak Solar Observatory for calibration with high precision spectroscopic determination of water vapour column density, using the double pass high resolution solar spectrograph available there. The observations were made during all seasons 4 to 5 times a day (whenever sky was clear).

These observations were made from Skara-Leh observatory (3,600 m) and from Mt. Nimmu top (4,100 m). A slight variation in the PWV was noticed from these two sites, due to the height difference of about 500 metres, this is considered marginal and within 10-15% of the instiumental sensitivity. Therefore, all observations made from Skara-Leh and Mt. Nimmu were combined. The PWV data were corrected for zenith angle and instrumental calibration. The seasonal variation of the zenith PWV (ZPWV) is quite noticeable, as during July, August and September (rainy season) the average value was around 2.5–3.0 mm, while during dry months of January, February, March, November and December the average value decreases to 1-1.5 mm. From the histograms of all the ZPWV observations it is concluded that :

15% observations indicate	< 1 mm
50% observations indicate	1-2 mm
27% observations indicate	2-3 mm
8% observations indicate	> 3 mm

(iii) PHOTOMETRIC QUALITY OF SKY: EXTINCTION

The extinction coefficients in U,B and V filters were determined using the 20-inch telescope at Skara-Leh site by the IIA teams, during their normal stellar photometric observations on 68 nights during 1985-1988.

The extinction coefficient K_v, K_b and K_u have been found to vary between 0.1-0.3, 0.2-0.4, and 0.4 -0.6 respectively, and the average values obtained are:

$K_v = 0.07 \pm 0.04$ mag (s.d.)
$K_b = 0.27 \pm 0.01$ mag (s.d.)
$K_u = 0.51 \pm 0.04$ mag (s.d.)

A seasonal variation of the extinction coefficient was also noticed. During July August, the extinction was higher compared to observations made in other months. Extinction coefficient in the Infrared bands of J,H, and K was also measured on a few nights in August 1988.

These observations indicate the following :
$K_J = 0.05 \pm 0.01$ mag
$K_H = 0.04 \pm 0.01$ mag
$K_K = 0.04 \pm 0.01$ mag

(iv) IR SKY RADIATION AND IR SKY NOISE

The IR sky radiation emission and sky noise measurements are very important for an IR observatory site selection. In the thermal infrared band both the emission from the sky and absorption due to the atmosphere, contribute toward limiting the quality of ground based IR observations. The emission and absorption by the terrestrial atmosphere are directly related. In the case of atmospheric windows, where the water vapour absorption is relatively weak but where the water vapour is a major absorber, the relationship between emission and sky absorption is monotonic (lower emission means less absorption). Variations in the emission or absorption within the atmospheric windows at 5, 10, 20 microns and longer wavelengths are dominated by the variations in the water vapour content of the atmosphere. Merrill (refer to NNTT report) has measured the IR sky background radiations with NOAO's IR Sky Background Monitor (IRSB monitor) in 11, 18 and 25 microns wave bands and tried to drive a correlation between the precipitable water vapour and IR sky radiation. In Figure 2 of Merrill's paper "A PreliminaryAssessment of NOAO/NNTTIR Sky Background Monitor Performance", shows a relation between the emissivity at 18.5 micron and the precipitable water vapour (PWV). For low PWV the IR emissivity is also low.

For this site selection, it was not possible to acquire an IR Sky Background Monitor, therefore the actual values of IR sky emissivity are not available. However, one is able to derive some estimates of the IR emissivity from the PWV observations. Generally, the zenith PWV value at Mt. Nimmu remains less than 1.5-2 mm, therefore it may be presumed that the IR sky radiation would be also quite low.

(v) ASTRONOMICAL 'SEEING'

The astronomical night time seeing has been measured from Mt. Nimmu top using the following two methods:

(1) From polar trails :

Walker's 'polar trail' method (1970) has been widely used for several site surveys, and it provides seeing measures comparable on a world-wide basis. Further, the technique is simple for remote sites and requires minimum infra-structure. A 15-cm aperture f/15 refracting Zeiss coude telescope was used, with a 9 mm focal length eye piece enlarging lens to yield an image scale of 15 arc sec/mm, exactly the same as Walker's polar trail experiment. It was very difficult to transport the heavy 15 cm coude telescope to Mt. Nimmu top, because of non-availability of a proper road. Therefore, the telescope was dismantled and carried by a helicopter directly to the top of Mt. Nimmu, in September 1986. The telescope was mounted on a one meter high pillar, without a dome. Thus the objective lens was about 3.5 m above the ground level. The Polar trail exposures were made every two hours through a RG-2 filter and exposed for 10 minutes, on ORWO 25 ASA fine grain film and developed for 4 minutes in 50% diluted D-19 developer at 20°C. These exposures were made every two hours during the night, whenever the sky condition and wind (less than 40 km/hour) permitted.

The detailed analysis of polar trail observations for estimating the stellar 'seeing' indicates that the best seeing of about 1 arc second is available during October, November and December months, (obtained by comparing with Walker's polar trails). However, the median value of all the observations is between 2-3 arc seconds. Seasonal variation of 'seeing' has been also noticed. Generally, the seeing is poor during the summer months. The variation in observed seeing due to wind speed, temperature and relative humidity was studied. With higher wind speeds the seeing seems to deteriorate. At lower ambient air temperature the seeing seems to improve, which substantiates that the seeing improves during the winter months. The relative humidity does not seem to have any noticeable effect on seeing.

(ii) Double Beam Telescope (DBT)

From the measurement of differential image motion of stars, it is possible to determine with precision the image quality and from it one could infer the stellar seeing. A double beam telescope, utilizing this principle of differential star motion was designed and built by the TIFR group. This instrument was installed on Mt. Nimmu in August 1988. As it was made available only towards the end of the project, hence observations on only 14 nights could be taken during August and September 1988.

The salient results of these observations are summarized in Table IV.

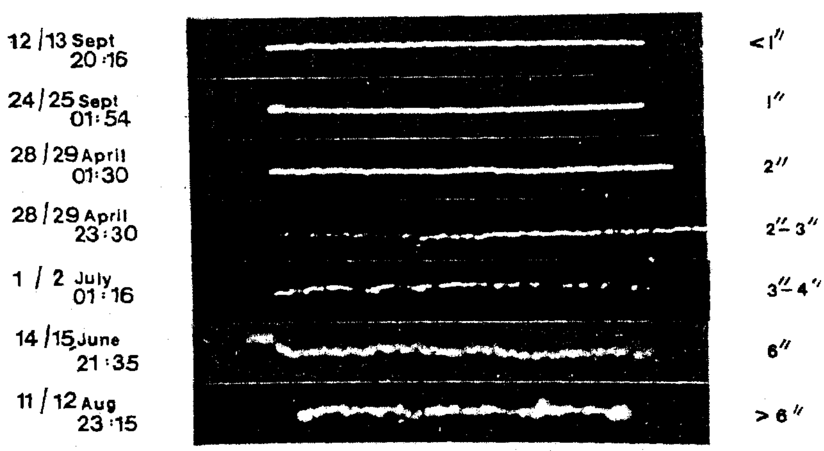


Figure 14. Sample polar trails exposures taken from Mt. Nimmu indicating variation of seeing.

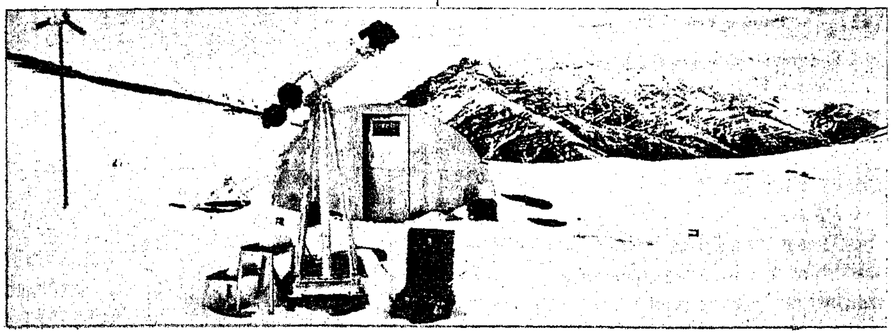


Figure 15. Double beam telescope at Mt. Nimmu. Seen in the background are insulated hut and wind charger. (Photo by B.C.Bhatt).

TABLE V : A COMPARISON OF 'SEEING' ESTIMATES OBTAINED BY DOUBLE BEAM TELESCOPE AND POLAR TRAIL METHODS

Date	Double beam data		Polar trail data		Wind speed & direction
1988	Time IST	Seeing Arc sec.	Time IST	Seeing Arc sec.	km/h
10/8	21:30	1″-2″	—	—	
11/8	21:00	2″-3″	21:00	6″	35 NW
	21:00	1″-2″	—	—	
	00:20	2″-3″	23:15	6″	
	03:00	1″			
	03:00	1″-2″			
12/8	21:00	1″-2″	21:15	6″	35 NW
13/8	00:00	1″-2″	23:00	4″-6″	25
	00:00	1″	01:00	2″-3″	20
18/8	22:30	1″	21:59	2″	30
	22:30	1″-2″			
19/8	00:40	1″-2″	01:12	2″-3″	32 NW
	00:40	1″			
19/8	21:00	1″	21:05	6″	35
	21:00	1″-2″	21:30	2″-3″	
20/8	21:00	1″			
	24:00	2″-3″			
	21:00	1″			
	24:00	2″-3″			
24/8	23:50	10″	21:35	10″	42 NW
			00:43	6″	38 NW
			02:13	6″	44 NW
29/8	20:30	1″-2″	21:15	2″-3″	15 NW
			23:00	2″-3″	25 NW
30/8	20:15	1″-2″	20:45	6″	35
	23:45	1″-2″	00:01	2″-3″	35
31/8	20:15	1″	20:45	4″-6″	25 NW
	23:31	1″	23:40	2″-3″	20 NW
01/9	02:30	1″-2″	01:00	2″-3″	20 W
	03:00	1″			
06/9	19:57	2″-3″	21:03	2″-3″	32 W
07/9	20:13	2″-3″	20:59	2″	30 W
	23:10	2″-2″	23:00	No image	
			00:54	2″-3″	36 NW

TABLE IV :
SEEING ESTIMATES FROM DBT IN SECONDS OF ARC.

No. of samples*	(seeing) (35 El)	(seeing) (90 El)**
3	0.7″	0.5″
43	0.7-1.1	0.5-0.8
58	1.1-1.6	0.8-1.1
71	1.6-2.0	1.1-1.4
141	2.0-2.7	1.4-1.9
96	2.7-3.6	1.9-2.6
91	3.6-4.7	2.6-3.4
23	4.7-6.0	3.4-4.3

* each samples averages 16 seconds of time.
** extrapolated to zenith.

It may be noted that TABLE IV is for long exposure image sizes for 35° degrees elevation (for polaris) and the zenith (90°) The original data is for the relative image motion and it has been converted using the formulae from literature to get the above Table (Ulick, B.L. and Davison, W.B., 1985, PASP, 97, 609)

The conversion factors are :

One dim. image motion for35°El	0.5	0.7	0.9	1.15	1.45	1.8	2.25	2.75
Est. long exp.image size for35°El	0.92	1.36	1.81	2.32	3.16	4.1	5.3	6.7

A comparison of 'seeing' estimates obtained by the double beam telescope and polar trail method was made and is given in the TABLE V. Further, the two methods yield slightly different parameters. The polar trail method gives an integrated effect of image blurring and image motion, while the double beam telescope yields only image motion. The seeing estimates obtained by the two methods do not generally tally. This may be due to the location of the two telescopes, as the 15-cm Zeiss coude polar trail telescope was mounted on the top of Mt. Nimmu and was about 3.5 metres above the ground, while the double beam telescope was mounted some 100 metres away, in a depressed area below the top of the peak and the telescope objectives were relatively near the ground level.

8. SPIN OFF FROM PROJECT WORK

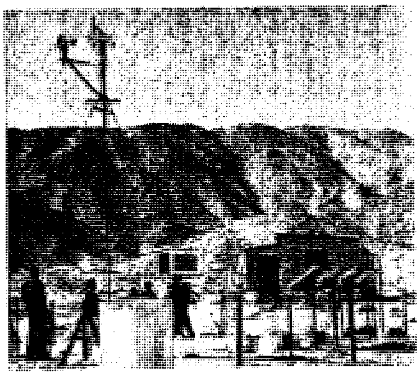


Figure 16. Rest house-cum-laboratory space at Mt. Nimmu base camp.

(i) The completion of this multi-institutional project, involving all major astronomical institutions in the country, to work for a common goal of site survey for a National High Altitude Observatory is a trend setter. The Department of Science and Technology motivated several scientific groups to develop techniques and special instruments such as the DOUBLE BEAM TELESCOPE, MICRO-THERMAL TOWER, ALL SKY CAMERA etc., which would be extremely valuable for future investigations of this nature. This was possible largely due to the personal interest taken by Prof. R.R. Daniel and Dr. P.J. Lavakare, Advisor to DST and importantly the commitment and initiative of the scientific community.

During the course of this investigation, several workshops and meetings were held of the participating institutions. A comprehensive search for SITE SURVEY LITERATURE has resulted in locating more than 40 important references. This bibliography will be of valuable guidance for future investigations.

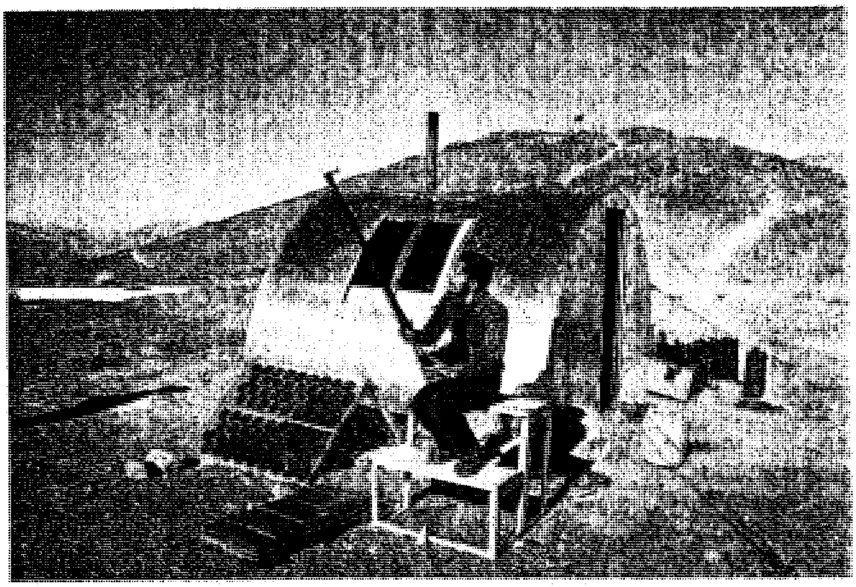


Figure 17. Insulated hut and solar voltaic panels on Mt. Nimmu top.

(ii) Establishment of Base Camp

The Mt. Nimmu top is 4100 metres above sea level, while the base is at 3800 metres.Pending construction of an access track to Mt. Nimmu, it was decided in 1984, to install the Meteorological instruments at the base of Mt. Nimmu. A small two room house with "Trombe walls" to utilise solar energy for keeping the house warm was constructed. This house could accommodate 3-4 people and proved useful as a "Base Camp" for all operations on top of the mountain. The weather station and the D.C.P. were installed at the base camp in October 1984 and October 1985 respectively.

(iii) Development of access road

Serious problems were faced to make an approach track to Mt. Nimmu top. At one time, it was felt that it would be desirable to abandon plan for taking observations from the top and be content with operating from the Base camp. The cost estimates of just making a survey and mapping of shortest route to the top by a government agency, was several lakhs of rupees and therefore the cost of construction of a road was beyond the budget estimates of the entire project. However, a dedicated team of 6 to 10 people from the local Field Research Laboratory (DRDO), were able to make a "mule track" in about 30 days, at a cost of just a few thousand rupees. The track in course of time was widened to transport even heavy equipment and the components for the insulated hut that was later erected on Mt. Nimmu top.

(iv) Insulated hut on Mt. Nimmu top

The field observers stationed on Mt. Nimmu needed a shelter. Initially an improvised bunker dug out in the ground and covered with FRP 15 feet canopy was used to shelter the staff, this was highly unsatisfactory. Later, an insulated hut 9'x 12' was designed by USO group and fabricated at PRL workshop. This was installed in October 1987. The temperature inside this hut was reasonably comfortable

Figure 18. First landing of a helicopter on Mt. Nimmu top in August 1986.

Figure 19. Helicopter lowering the heavy pier of the 15 cm coude telescope on Mt. Nimmu top.

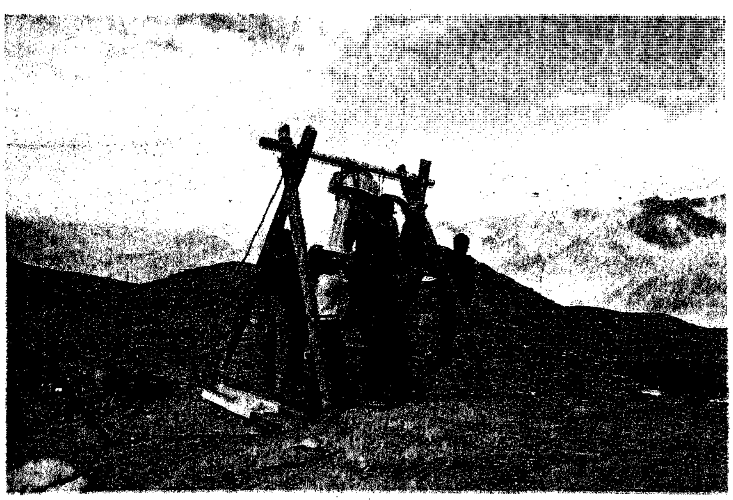


Figure 20. Coude telescope being installed on Mt. Nimmu.

(10°-12°C), even during the winter months, when the temperature outside was -20°C. It had a large double walled glass opening to trap solar energy inside and was heavily insulated to ensure good comfort and warmth. The shelter was used to keep sensitive instruments and could accommodate two or three observers and also some space for cooking food.

(v) Transportation of telescope

The 15-cm coude Zeiss telescope is too heavy and bulky and the track up to the mountain top was not wide enough to transport it. Hence the assistance of the Indian Air Force was sought to transport the telescope by a helicopter. A small helipad was also built on the top. Thus Mt. Nimmu peak has become accessible by air!

(vi) Power requirement.

Photovoltaic power panels were provided by DNES and were used to provide electric power to operate essential equipment and for lighting purposes at Skara-Leh observatory. Portable generating sets both at Skara-Leh base observatory and at Mt. Nimmu top were also available. Some of the sensitive instruments on top of Mt. Nimmu were fed by another set of photovoltaic panels as well as by wind chargers, provided by DARL, Almora.

(vii) Water requirement.

Water for the base camp and Mt. Nimmu top had to be carried in jerrycans all the way from Skara-Leh observatory. Attempts were also made to "harvest" the snow fall by digging a collection area on Mt. Nimmu top and lining the dug out portion with a plastic film and by melting snow.

(viii) Sanitary system.

Septic tanks were dug out at Skara-Leh observatory and at the base camp, but they did not work during winter months.

(ix) Transport

The observers invariably had to walk up the 3 km stretch from the

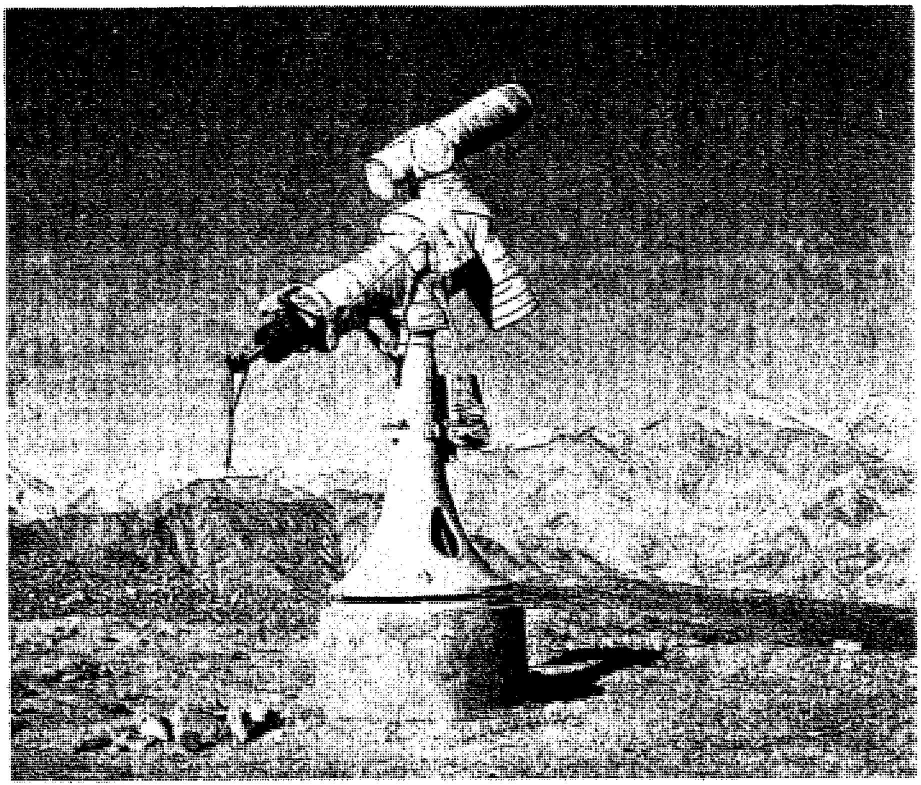


Figure 21. 15 cm aperture Zeiss coude telescope in conjunction with image enlarging system on Mt. Nimmu top.

base camp to Mt. Nimmu top. However, occasionally mules were also available. Water, food materials, fuel and equipment were generally hauled up by local people, mules and yaks.

9. PROBLEMS FACED LESSONS LEARNT

The project team faced several problems in :

(a) establishing a base camp at Mt. Nimmu base,

(b) developing of access road to Mt. Nimmu top,

(c) providing shelter to observers at Mt. Nimmu top, where the temperature drops to below -20°C.

(d) arranging reliable power supply for operating sensitive instruments, and

(e) transport, water and provision of reasonable sanitary living conditions.

It is felt that for any future investigation in a very difficult and hostile climatic conditions, the problems connected with creation of infra-structure and facilities should be first carefully examined and solutions sought, before embarking on a major programme of this nature.

Important lessons have been learnt during the course of the project. Foremost among them are the following :

(i) All prospective sites must be first subject to a preliminary examination of the cloud coverage, other meteorological quantities and logistic problems. If we had made a serious attempt to get all available cloud cover data for Leh and made an analysis of them, we might not have undertaken this project.

(ii) The state-of-the-art of the space photography have now advanced to a stage where even 5 km resolution photographs are readily available. The future investigations of this nature should utilize these data to evaluate the topography and cloud cover before large man-power and financial commitments are made.

(iii) DST's efforts for this multi-institutional project provided rich dividends. It is recommended that this trend of co-operative multi-institutional programmes be kept up. However, it would be desirable to have at least one dedicated young scientist associated on a full-time basis, for such future investigations. Association of the field workers who were involved in this project, if available, may provide useful help particularly in avoiding pitfalls learnt from their personal experiences.

10. COMPARISON OF RESULTS WITH OTHER HIGH ALTITUDE OBSERVATORIES OF THE WORLD

To evaluate the suitability of Mt. Nimmu for a high altitude astronomical observatory site, all important and necessary parameters (except for the measurement of IR sky radiation in 10 microns and longer wavebands) have been obtained, in an exhaustive manner for over two years and covered all seasons.

The results of this site survey were compared with other established high altitude observatories in the world (e.g. Mauna Kea, Hawaii and La Palma in Canary islands).

A comparison of the usable hours and nights available for photometric and spectroscopic work, at various observatory sites is given in TABLE VI.

From a detailed analysis of the data and comparing with established high quality observatory sites in the world, it is concluded that the 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 coefficient in UBVIJH bands, and
(ix) microthermal temperature fluctuations.

Due to the low percentage of the available clear weather, this site may not be acceptable for optical observational astronomy.

TABLE VI : COMPARISON OF ASTRONOMICAL SITES

Location	Altitude (metres)	Lat. & long.	Average no. hours/year (photo.& spectro.) (per year)	% of useful nights per year
1. Mt. Nimmu	4100	+34° 09′ 77° 34′E	1600	52
2. Kavalur	725	+12° 34′ 78° 49′E	1535	41
3. Gurushikhar	1700	+24° 36′ 72°43′E	1900	58
4. Nainital	1927	+29° 21′ 79° 42′E	1900	65
5. Japal-Rangapur	554	+17° 6′ 78° 43′E	1700	58
6. Mauna Kea	4215	+19° 49′ 155° 28′W	2800	87
7. Las Campanas	2280	-29° 00′ 70° 42′W	2510	78
8. Cerro-Tololo	2215	-30° 10′ 70° 49′W		78
9. Mt. Palomar	1706	+33° 21′ 116° 51′W	2200	68
10. La Palma	2300	+28° 45′ 17° 52′W	2410	75

11. RECOMMENDATIONS FOR THE FUTURE

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 observatories. Even within India, other comparable observatories seem to be marginally better than Mt. Nimmu.

ANNEXURES

LIST OF INVESTIGATORS AND INSTITUTIONS

NAME OF INSTITUTION	NAME OF INVESTIGATORS
1. TATA INSTITUTE OF FUNDAMENTAL RESEARCH, BOMBAY	R. R. DANIEL S.N. TANDON
2. INDIAN INSTITUTE OF ASTROPHYSICS, BANGALORE.	J. C. BHATTACHARYYA JAGDEV SINGH
3. PHYSICAL RESEARCH LABORATORY, AHMEDABAD.	P. V. KULKARNI J. N. DESAI
4. U.P. STATE OBSERVATORY, NAINITAL.	M. C. PANDEY H. S. MAHRA
5. OSMANIA UNIVERSITY, HYDERABAD.	M. B. K. SARMA K. D. ABHYANKAR
6. PUNJABI UNIVERSITY, PATIALA.	H. S. GURM
7. DEFENCE RESEARCH AND DEVELOPMENT ORGANISATION	S. L. GANDHI M. C. JOSHI
8. MEDIA METEROLOGICAL DEPARTMENT	DIRECTOR GENERAL
9. UDAIPUR SOLAR OBSERVATORY UDAIPUR. (Nodal institution)	A. BHATNAGAR

REVIEW-CUM-MONITORING COMMITTEE
FOR PROJECT ASTRONOMY LEH-LADHAK

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4.	PROF. S. N. TANDON	TIFR
5.	DR. M. C. PANDE	UPSO
6.	DR. H. S. MAHRA	UPSO
7.	DR. S. M. KULSHRESTHA	IMD
8.	DR. M. C. JOSHI	DARL
9.	PROF. A. BHATNAGAR Project Coordinator	USO
10.	SHRI S. L. GANDHI	Project Officer

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PROF. J. C. BHATTACHARYYA	IIA
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PROF. R. R. DANIEL	TIFR
DR. M. K. TIWARI	ISRO, HQ

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7.	PROF. M. S. VARDYA	TIFR
8.	SHRI S. L. GANDHI	Special Invitee
9.	DR. K. R: GUPTA	DST Convenor

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    - (iii) The Physics of seeing: Application of theory to site evaluation and testing, Roddier, F., p. 12
    - (iv) Determination of the quasi-instantaneous estimate of the Fried parameter from high spatial resolution astronomical observations: Christou, J.C. and Keith Heg, E., p. 64
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    - (vi) Seeing measurements with a pupil plane rotation shearing interferometer: Roddier, C., and Roddier, F., p. 77
    - (vii) Seeing measurements with the multiple mirror telescope: Ulick, B.L., p. 82
    - (viii) The physics of seeing: Coulman, C.E., p. 2
    - (ix) Characteristics of the observatory site of the Max-Planck Institut fur Astronomie: Elsaser, H., p. 122
    - (x) Characteristics of optimum sites Walker, M. F., p. 128
    - (xi) Out of site out of mind the common sense of site selection: Woolf, N.J., p. 119

(xii) NNTT site evaluation project : An overview: Merrill Michael,K., p. 30

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CLIMATOLOGICAL TABLE

STATION : Leh LAT. 34 09' N. LONG. 77 34' E. HEIGHT ABOVE M.S.L. 3514 METRES BASED ON OBSERVATIONS FROM 1931 TO 1960

MONTH	STATION LEVEL PRES-SURE	AIR TEMPERATURE MEAN (OF) DRY BULB	WET BULB	DAILY MAX.	DAILY MIN.	HIGHEST IN THE MONTH	LOWEST IN THE MONTH	EXTREMES HIGHEST	DATE AND YEAR	LOWEST	DATE AND YEAR	HUMIDITY RELATIVE HUMIDITY	VAPOUR PRESSUR	CLOUD AMOUNT ALL CLOUDS	LOW CLOUDS	RAINFALL MONTHLY TOTAL	RAINY DAYS	TOTAL IN WETTEST WITH YEAR	TOTAL IN DRIEST WITH YEAR	HEAVIEST 24 HOURS	AND YEAR	MEAN WIND SPEED
	mb	C	C	C	C	C	C	C		C		%	mb	Oktas of sky		mm		mm	mm	mm		km p h
JANUARY I	665.0	-11.2	-13.0	-2.8	-14.0	3.2	-19.0	8.3	29	-28.3	11	61	1.5	5.2	1.4	11.8	1.4	41.4	0	24.4	28	3.4
II	663.9	-5.6	-7.9						1916		1899	51	2.1	4.5	1.3			1893			1893	
FEBRUARY I	664.6	-8.7	-10.4	0.8	-11.8	6.5	-16.8	12.8	28	-25.6	2	59	1.9	4.8	1.4	8.6	1.1	42.2	0	16.8	25	3.8
II	662.7	-1.3	-4.7						1953		1943	46	2.3	4.6	1.1			1896			1903	
MARCH I	665.5	-2.4	-5.9	6.4	-6.3	12.5	-12.0	19.4	29	-19.4	8	55	2.7	4.5	1.2	11.9	1.5	38.6	0	16.0	2	5.3
II	663.0	4.3	-0.7						1908		1903	43	3.3	5.1	1.4			1903			1930	
APRIL I	667.4	3.8	-0.4	12.4	-1.2	17.3	-5.2	23.9	29	-12.8	2	50	3.9	3.7	0.8	6.5	0.8	32.0	0	22.1	14	6.7
II	664.6	9.2	2.4						1941		1903	32	3.3	4.9	1.4			1896			1896	
MAY I	667.6	8.8	2.6	17.1	2.8	21.8	-0.9	28.9	23	-4.4	16	39	4.2	3.4	1.0	6.5	0.7	68.6	0	22.3	14	6.8
II	664.0	13.6	5.3						1893		1886	27	4.1	4.7	1.6			1897			1951	
JUNE I	665.8	12.6	5.6	21.1	6.7	27.0	2.4	33.9	9	-1.1	4	39	5.6	3.1	0.9	4.3	0.5	28.7	0	19.6	30	6.5
II	662.3	18.5	8.1						1882		1886	24	5.1	3.5	1.2			1894			1955	
JULY I	664.6	15.9	9.4	24.7	10.2	29.8	5.8	33.3	9	0.6	8	49	8.5	3.7	1.3	15.7	1.9	75.4	0	25.6	28	5.2
II	661.6	21.7	11.7						1883		1929	34	7.8	3.7	1.4			1948			1882	
AUGUST I	665.2	14.8	9.3	24.2	9.6	28.6	5.9	32.2	2	2.8	25	54	8.9	4.2	1.2	19.5	2.3	111.5	0	51.3	22	4.8
II	661.6	21.3	12.2						1946		1941	36	7.9	4.1	1.5			1933			1933	
SEPT- I	667.3	10.6	4.9	20.9	5.4	24.4	0.9	30.6	4	-4.4	30	47	5.8	2.9	0.9	12.2	1.4	68.6	0	25.9	19	4.6
EMBER II	663.7	18.6	9.5						1883		1940	32	6.3	2.8	1.1			1893			1893	
OCTOBER I	669.5	4.3	-0.6	14.2	-0.9	19.7	-5.3	25.6	2	-7.8	30	45	3.5	2.1	0.5	7.1	0.5	88.4	0	39.1	5	5.0
II	665.8	10.7	3.2						1916		1923	28	3.4	2.5	0.8			1955			1955	
NOVEMBER I	668.6	-3.2	-6.0	7.8	-6.6	12.5	-10.5	20.0	1	-13.9	29	45	2.3	2.6	0.5	2.9	0.4	16.2	0	16.2	4	5.0
II	666.1	4.3	-1.0						1929		1934	34	2.7	3.1	0.5			1959			1959	
DECEMBER I	666.9	-8.1	-10.5	1.6	-11.1	6.7	-16.2	10.8	3	-25.6	25	54	1.7	4.4	0.9	8.0	1.0	35.3	0	15.2	23	3.8
II	665.1	-1.6	-4.3						1891		1937	42	2.2	4.2	1.1			1944			1944	
ANNUAL I TOTAL OR	666.5	3.1	-1.3	12.5	-1.4	30.0	-20.8	33.9		-28.3		50	4.2	3.7	1.0	115.0	13.3	231.1	25.4	51.3		5.1
MEAN II	663.7	9.5	2.8									36	4.2	3.9	1.2			1894	1889			
NUMBER I	30	30	30	30	30	30	30	80		80		30	30	30	20	30	30	80	80	80		30
OF YEARS II	10	10	10									10	10	10	10							

MONTH	WEATHER PHENOMENA* No. OF DAYS WITH						WIND No. OF DAYS WITH WIND SPEED (Km.p.h.)				PERCENTAGE No. OF DAYS OF WIND FROM									CLOUD No. OF DAYS WITH CLOUD AMOUNT (ALL CLOUDS) OKTAS					No. OF DAYS WITH LOW CLOUD AMOUNT OKTAS						VISIBILITY * No. OF DAYS WITH VISIBILITY				
	PRECIPITATION 0.3mm MORE	HAIL	THUNDER	FOG	DUST STM	SQU	62 OR MOR	20-61	1-19	0	N	NE	E	SE	S	SW	W	NW	CALM	0	T-2	3-5	6-7	8	0	T-2	3-5	6-7	8	FOG 8	UP TO 1 km	1-4 kms	4-10 kms	10-20 kms	OVER 20 kms
JANUARY I	6	0	0	0.1	0.1	0	0	0	13	18	9	19	7	0	3	2	2	0	58	5	3	5	9	9	16	7	6	1	1	0	0.6	3	3	8	16
II							0	0	18	13	1	9	2	5	16	22	3	1	41	4	5	7	7	8	16	7	5	2	1	0	0.7	2	2	12	14
FEBRUARY I	4	0	0	0	0	0.1	0	0	10	18	8	12	6	0	5	2	3	0	64	5	3	5	8	7	16	5	6	0	0	1	0.5	3	1.9	7	16
II							0	0	20	8	2	5	2	1	10	35	7	5	33	4	5	5	8	6	16	7	5	0	0	0	0.3	1.7	2	7	17
MARCH I	4	0.1	0	0.3	0.2	0.1	0	1	14	16	5	8	6	2	16	6	3	0	54	6	3	7	8	7	19	6	4	1	1	0	0.5	1.8	2	7	20
II							0	0	27	4	8	10	1	2	12	30	12	12	13	2	4	6	10	9	17	7	6	1	0	0	0.5	1.2	2	10	17
APRIL I	3	0.5	0.1	0	0.8	0.1	0	1	15	14	3	3	4	2	21	11	5	1	50	7	5	7	7	4	20	7	3	0	0	0	0.3	1.0	1.1	7	21
II							0	0	28	2	12	11	1	3	7	28	18	13	7	1	5	9	10	5	15	9	5	1	0	0	0.3	0.8	1.6	8	19
MAY I	3	1.0	0.5	0	0.2	0.2	0	0	17	14	2	2	2	4	25	13	6	0	46	9	5	7	7	3	18	8	5	0	0	0	0.1	1.0	1.4	5	23
II							0	1	28	2	11	13	1	2	7	27	15	16	8	2	5	9	10	5	14	10	6	1	0	0	0.1	0.9	2	8	20
JUNE I	2	0.1	1.8	0	0.1	0	0	0	13	17	2	2	2	2	16	13	6	0	57	7	8	7	6	2	17	10	3	0	0	0	0	0.7	1.6	4	23
II							0	0	29	1	8	12	1	2	5	29	23	14	6	4	8	10	7	1	17	9	4	0	0	0	0	0.7	2	6	21
JULY I	4	0.1	0.9	0	0.1	0	0	0	9	22	1	3	2	3	9	8	3	0	71	6	7	6	8	4	17	8	5	1	0	0	0.1	0.9	2	5	23
II							0	0	24	7	4	10	1	1	6	26	21	7	24	3	8	9	7	4	17	8	6	0	0	0	0.1	1.1	3	6	21
AUGUST I	5	0.1	0.8	0	0	0	0	0	10	21	2	4	1	2	9	10	3	0	69	4	6	7	10	4	15	11	5	0	0	0	0	0.6	2	5	23
II							0	0	23	8	2	6	1	2	8	29	20	5	27	2	7	10	9	3	14	11	5	1	0	0	0.2	0.5	3	7	20
SEPTEMBER I	3	0.4	0.1	0	0	0	0	0	11	19	2	6	3	2	12	7	3	0	65	10	7	6	4	3	20	6	4	0	0	0	0	0.8	1.1	3	25
II							0	0	24	6	1	6	0	2	8	38	16	6	23	6	10	8	3	3	17	9	4	0	0	0	0.2	1.2	1.6	5	22
OCTOBER I	1.6	0	0	0	0	0	0	0	12	19	2	5	5	2	11	7	3	0	65	16	5	5	3	2	23	6	2	0	0	0	0.3	0.5	0.6	4	26
II							0	0	27	4	3	3	0	2	11	45	19	6	11	11	8	6	5	1	19	9	2	1	0	0	0.4	0.8	0.6	7	22
NOVEMBER I	0.9	0	0	0	0	0	0	0	13	17	8	15	7	1	7	2	1	0	59	13	5	4	6	2	24	4	2	0	0	0	0.1	0.7	0.6	5	24
II							0	0	24	6	1	3	0	3	12	45	7	7	22	9	7	6	6	2	23	4	3	0	0	0	0	0.7	0.7	10	19
DECEMBER I	5	0	0	0.1	0	0	0	0	14	17	9	16	8	0	3	2	2	0	60	7	3	5	9	7	18	6	6	0	1	0	0.5	2	2	5	21
II							0	0	19	12	2	10	1	2	11	26	3	2	43	5	5	6	8	7	19	6	5	1	0	0	0.3	1.6	3	11	15
ANNUAL I TOTAL OR MEAN	41	2	4	0.5	1.5	0.5	0	2	151	212	5	8	5	2	11	7	3	0	59	95	60	71	85	54	223	84	51	3	3	1	3	16	19	65	261
II							0	1	291	73	5	8	1	2	9	32	14	8	21	54	77	91	90	54	204	96	56	8	1	0	3	13	24	97	227
NUMBER I OF YEARS			17						22							24						24					16					24			
II									11							13						13					13					13			

CLIMATOLOGICAL TABLE

STATION : Mt. Nimmu top (Leh) LAT. 34 09' N. LONG. 77 54' E. HEIGHT ABOVE M.S.L. 4070 METRES BASED ON OBSERVATIONS FROM OCTOBER 1986 TO OCTOBER 1988

MONTH	STATION LEVEL PRES-SURE	AIR TEMPERATURE MEAN (OF) DRY BULB	WET BULB	DAILY MAX.	DAILY MIN.	HIGHEST IN THE MONTH	LOWEST IN THE MONTH	EXTREMES HIGHEST	DATE AND YEAR	LOWEST	DATE AND YEAR	HUMIDITY RELATIVE HUMIDITY	VAPOUR PRESSUR	CLOUD AMOUNT ALL CLOUDS	LOW CLOUDS	RAINFALL MONTHLY TOTAL	RAINY DAYS	TOTAL IN WETTEST WITH YEAR	TOTAL IN DRIEST WITH YEAR	HEAVIEST 24 HOURS	AND YEAR	MEAN WIND SPEED
	mb	C	C	C	C	C	C	C		C		%	mb	Oktas of sky		mm		mm	mm	mm		km p h
JANUARY I / II				-9.1	-15.7	-3.8	-22.5	-2.5	27 1987	-28.0	9 1987			4.6								10.0
FEBRUARY I / II				4.9	-11.2	-3.3	-12.8	2.0	23 1987	-13.5	17 1987			5.3								15.0
MARCH I / II				-3.2	-10.5	3.0	-15.0	6.5	28 1987	-18.0	27 1988			5.4								13.9
APRIL I / II				4.9	-2.8	11.3	-7.3	14.0	29 1988	-7.5	1 1988			4.5								21.7
MAY I / II				8.6	0.7	15.0	-4.0	17.0	30 1988	-4.0	10 1987			4.9								22.0
JUNE I / II				12.5	4.8	21.0	0.0	24.5	26 1988	-0.5	9 1987			3.9								24.8
JULY I / II				18.4	8.7	24.8	4.0	25.0	23 1987	2.0	16 1987			4.7								25.5
AUGUST I / II				18.3	9.2	24.0	4.8	25.5	14 1988	4.5	25 1988			4.8								26.3
SEPT- I / EMBER II				14.8	5.2	21.0	-2.5	21.5	5 1987	-2.5	28 1987			3.3								25.5
OCTOBER I / II				6.4	-2.6	12.5	-6.8	15.0	6 1987	-8.5	31 1987			3.0								16.1
NOVEMBER I / II				1.1	-6.6	6.0	-11.3	8.5	2 1986	-12.5	28 1986			2.4								15.4
DECEMBER I / II				-5.6	-12.1	1.3	-19.3	3.5	6 1986	-24.0	23 1986			4.2								11.1
ANNUAL I / TOTAL OR MEAN II				5.2	-2.7	24.8	-22.5	25.5		-28.0				4.3								18.9
NUMBER I / OF YEARS II																						

STATION : Mt. Nimmu,top (Leh) Contd.

MONTH	WEATHER PHENOMENA* No. OF DAYS WITH PRECIPITATION 0.3mm MORE	HAIL	THUNDER	FOG	DUST STM	SQU	WIND: No. OF DAYS WITH WIND SPEED (Km.p.h.) 62 OR MOR	20-61	1-19	0
JANUARY							0	3	28	0
FEBRUARY							0	5	23	0
MARCH							0	7	24	0
APRIL							0	20	10	0
MAY							0	23	8	0
JUNE							0	25	5	0
JULY							0	24	7	0
AUGUST							0	27	4	0
SEPTEMBER							0	26	4	0
OCTOBER							0	15	15	1
NOVEMBER							0	9	20	1
DECEMBER							0	3	28	0
ANNUAL TOTAL OR MEAN							0	187	176	2
NUMBER OF YEARS										

MONTH	WIND: PERCENTAGE No. OF DAYS OF WIND FROM N	NE	E	SE	S	SW	W	NW	CALM
JANUARY									
FEBRUARY									
MARCH									
APRIL									
MAY									
JUNE									
JULY									
AUGUST									
SEPTEMBER									
OCTOBER									
NOVEMBER									
DECEMBER									
ANNUAL TOTAL OR MEAN									
NUMBER OF YEARS									

MONTH	CLOUD: No. OF DAYS WITH CLOUD AMOUNT (ALL CLOUDS) OKTAS 0	T-2	3-5	6-7	8
JANUARY	4	5	9	7	6
FEBRUARY	1	4	7	9	7
MARCH	1	2	10	11	7
APRIL	3	4	11	7	5
MAY	0	6	6	12	7
JUNE	5	4	13	6	2
JULY	3	5	9	6	8
AUGUST	1	4	13	10	3
SEPTEMBER	5	9	8	4	4
OCTOBER	6	9	8	6	2
NOVEMBER	15	4	4	4	3
DECEMBER	3	9	8	5	6
ANNUAL TOTAL OR MEAN	47	65	106	87	60
NUMBER OF YEARS					

MONTH	CLOUD: No. OF DAYS WITH LOW CLOUD AMOUNT OKTAS 0	T-2	3-5	6-7	8	FOG 8	VISIBILITY*: No. OF DAYS WITH VISIBILITY UP TO 1 km	1-4 kms	4-10 kms	10-20 kms	OVER 20 kms
JANUARY											
FEBRUARY											
MARCH											
APRIL											
MAY											
JUNE											
JULY											
AUGUST											
SEPTEMBER											
OCTOBER											
NOVEMBER											
DECEMBER											
ANNUAL TOTAL OR MEAN											
NUMBER OF YEARS											