2.3 SITE SURVEY FOR AN INFRARED OBSERVATORY*

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The Infrared region is generally divided in three or four broad wavelength regions as:

1. Near Infrared between 1 μm-7μm
2. Mid Infrared between 8 μm-25μm
3. Far Infrared between 26 μm-300μm
4. Submilimeter region beyond 0.3mm

These regions of the electromagnetic spectrum have strong absorption bands due to terrestrial water vapour and atmospheric gases like; O_2, O_3, N_2O, CO_2. Figures 1 (a) and (b) show the opacity at sea level for 1 cm of precipitable water in a vertical column. In Figure 1 (a) the spectrum extends from 0.7 μm to 4.0 μm and in Figure 1 (b) it extends from 4.0 μm to 100 μm. There are number of "windows" in this portion of near and mid-infrared regions of the spectrum, where absorption due to water vapour is minimum. The opacity in the clearer spectrum region is

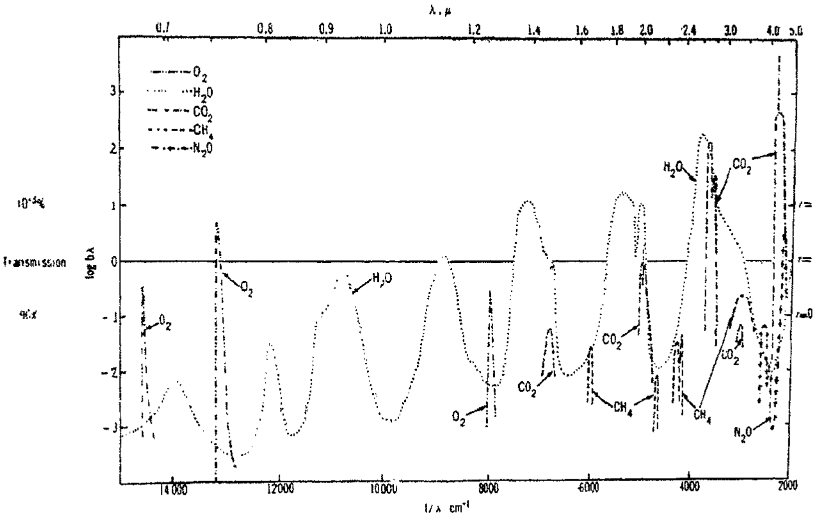

Fig 1 (a) — Infrared band absorption of atmospheric gases at sea level.

dominated by the pressure-induced wings of lines and under these conditions the opacity (k) is proportional to $WP^{\frac{1}{2}}$, where W is the amount of absorber and P the gas pressure. Thus if one observes from dry and higher altitudes, one could decrease or eliminate the absorption contribution due to the water vapour. From high mountain and dryer sites say with 1 mm of precipitable water, H_2O opacity is reduced by a factor of about 10 over Figures I (a) and (b). The opacity due to CO_2, O_8 retain almost the same strength as at sea level.

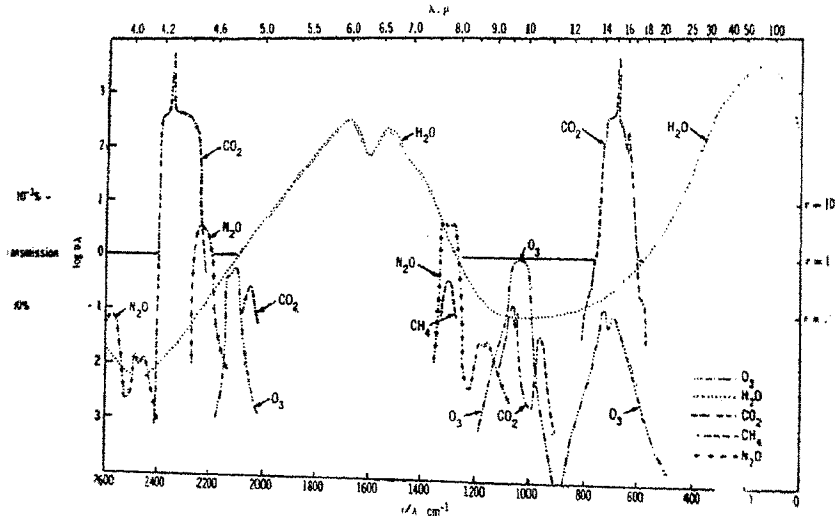

Fig 1 (b) — Infrared band absorption of atmospheric gases at sea level.

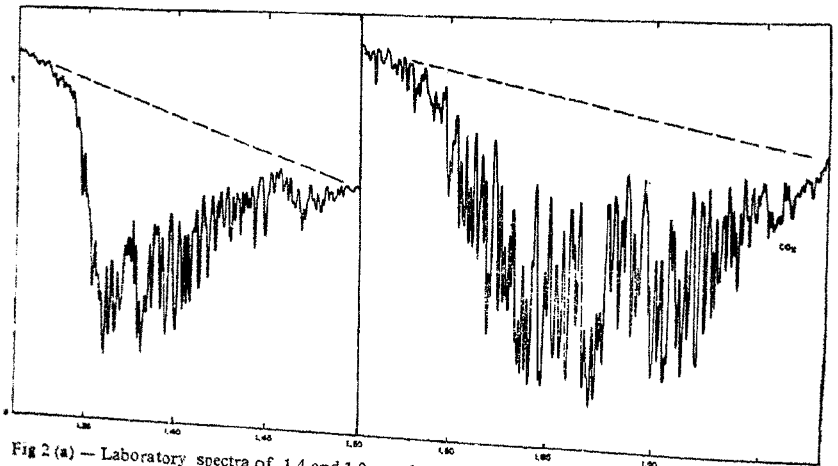

Fig 2 (a) — Laboratory spectra of 1.4 and 1.9 μm bands of H_2O, total air path length 159 metres, 940 mb, 1.0 mm precipitable H_2O, equivalent to 1.3 mm at 720 mb, or about 9,000 ft.).

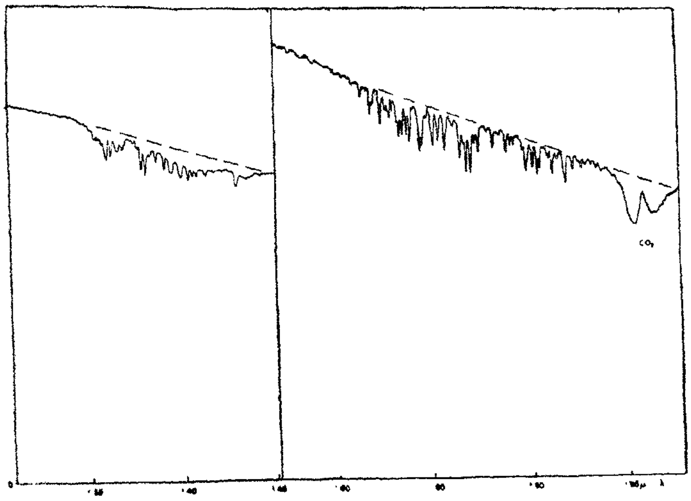

Fig 2 (b)— Laboratory spectra of 1.4 and 1.9 μm bands of H_2O, total air path length 2.4 meters, 940 mb, 0.014 m precipitable H_2O (equivalent to typical aircraft altitude of 40,000 ft)

In Figures 2 (a) and (b) are shown the laboratory water vapour spectrum in 1.4 μm and 1.9 μm wavelength bands (after Kuiper 1970). In Figure 2 (a) the absorption spectrum is equivalent to observations made from a height of about 9000 ft with 1.3 mm precipitable water. Kuiper (1970) has obtained number of laboratory atmospheric absorption spectra with various pressure and equivalent water vapour content. In Figure 2 (b) the spectrum corresponds to airplane altitudes of about 40,000 ft and precipitable water of 0.006 - 0.01 mm, conspicuous decrease in H_2O absorption n 1.4 μm and 1.9 μm bands is achieved as the altitude and dryness increase. It is generally accepted that a useful criterion is to demand that the telluric absorption be less than 0.5, to give a reasonable precision in observations. Even at 40,000 ft level, the CO_2 contribution does not decrease appreciably.

There are number of platforms from which infrared (IR) observations have been and can be conducted, with peculiar advantages and disadvantages, for example from:

1. Ground based-from high and dry mountain sites, say between the height of 12,000-14,000 ft, above sea level.
2. Airplane (height of 40,000 ft).
3. Balloon altitudes (100,000 ft)
4. Rockets (100 kms), and from
5. Satellites.

As one goes down this list, one is faced with the limitation of the flexibility of programme and instrumentation while gain in wavelength and transmission in infrared is achieved. Large telescopes and spectrographs cannot be flown in airplane, balloon and rockets. Stratospheric airplanes can make observations in all spectral bands. However, the most accessible altitudes of 35,000-40,000 ft are marginal for 25-700, μm region. The airplane windows restrict the view and only a limited programme of observing few objects rather than for survey work could be conducted during each flight, that may last for say 2-4 hours. In case of balloons, specialised instrumentation has to be developed and lack of pointing and guiding accuracy could be a serious draw back, one should also be prepared for damage and loss of equipment. The number of flights that could be flown within a reasonable budget are also generally limited to say 2-3 per year. Rockets are best compromise, as they attain near satellite height and are relatively less expensive, but give short observing time. They are good for exploring the back-ground flux in different spectral bands in IR survey work. Satellite platforms are undoubtedly best in view of what has been achieved from the Sky-lab missions.

The observations from the ground are restricted to certain spectral bands with one large gap from 25 to 700 μm, Atmospheric emission is large and fluctuating. In part, these disadvantages are compensated by relatively low cost of a major installation and by the flexibility of programmes, those are available from ground based stations.

The requirements for the near and mid-infrared ground based observatory site are:

1. High altitude site should have low water vapour content over appreciable time during the observing period.

2. "Seeing" in IR should be good, as image blurring would decrease the signal-to-noise ratio for IR detectors.

3. "Sky noise" should be minimum at IR wavelengths. For a NASA sponsored IR site survey programme, Westphal (1972) has developed a useful criterion for 'sky noise' at 8 to 14 μm wavelength band. He measured the average of the rms power difference between two fixed sky beams of 4 arc minutes diameter separated by 10 arc minutes. If the noise power difference was less than 5x10^{-7} W cm^{-2} sterad^{-1}, it was considered good for IR work longer than 3.5 μm if the noise power difference was less than 1 x 10^{-7} W cm^{-2} sterad^{-1} the sky conditions were considered excellent for IR observation in 10 to 20 μm windows. Sky noise in infrared may be caused due to mixing of different air masses over the site and would cause fluctuating emission in infrared.

4. Sky brightness at 10 μm and 20 μm windows has to be very low for detection of faint infrared sources. Since the background flux due to atmosphere depends on the temperature and optical depth of the atmosphere, it is expected that high and dry mountains will have low levels of the sky brightness.

5. Accessibility is a very important consideration which involves proximity to college, university, suitable transportation, nearby support facilities, availability of coolant, housing etc.

Considering that the IR groundbased observing site shall be within the geographical boundries of India, an analysis of the radiosonde data obtained by the India Meteorological Department over a period of 6 to 7 years (Mokashi 1968) has been made for preliminary potential IR - sites, where the precipitable water vapour would be minimum over appreciable fraction of time during the year. These radio-sonde observations are made twice daily by number of stations in India.

In Figure 3 (a) and 3 (b) are shown the isopleth contours of the mean precipitable water in grams or cms for each month, over the Indian subcontinent. Even during the dryest months of December, January, February and March the precipi-

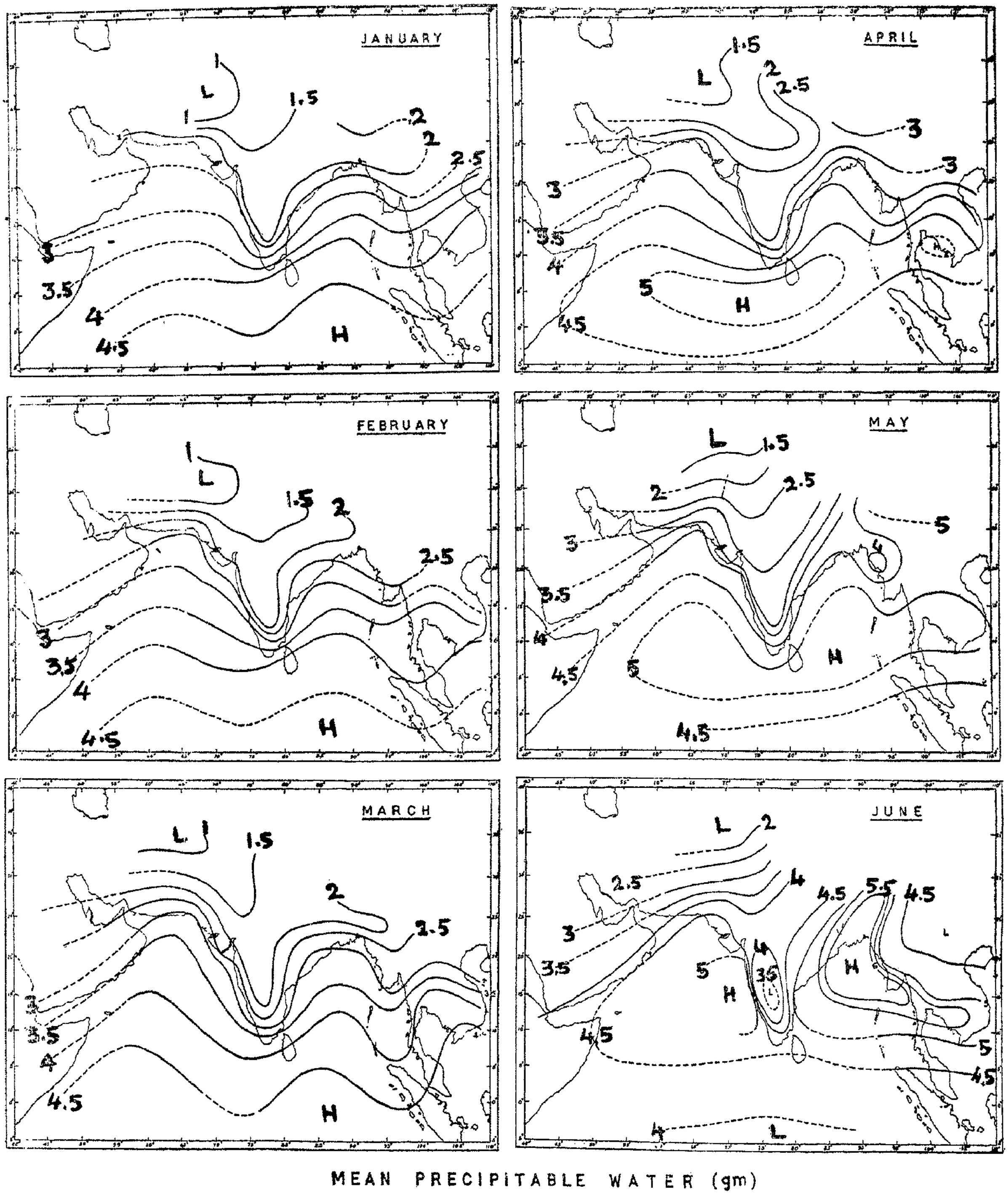

Fig. 3 (a) — Isopleth contours of mean precipitable water in grm for each month over Indian sub-continent.

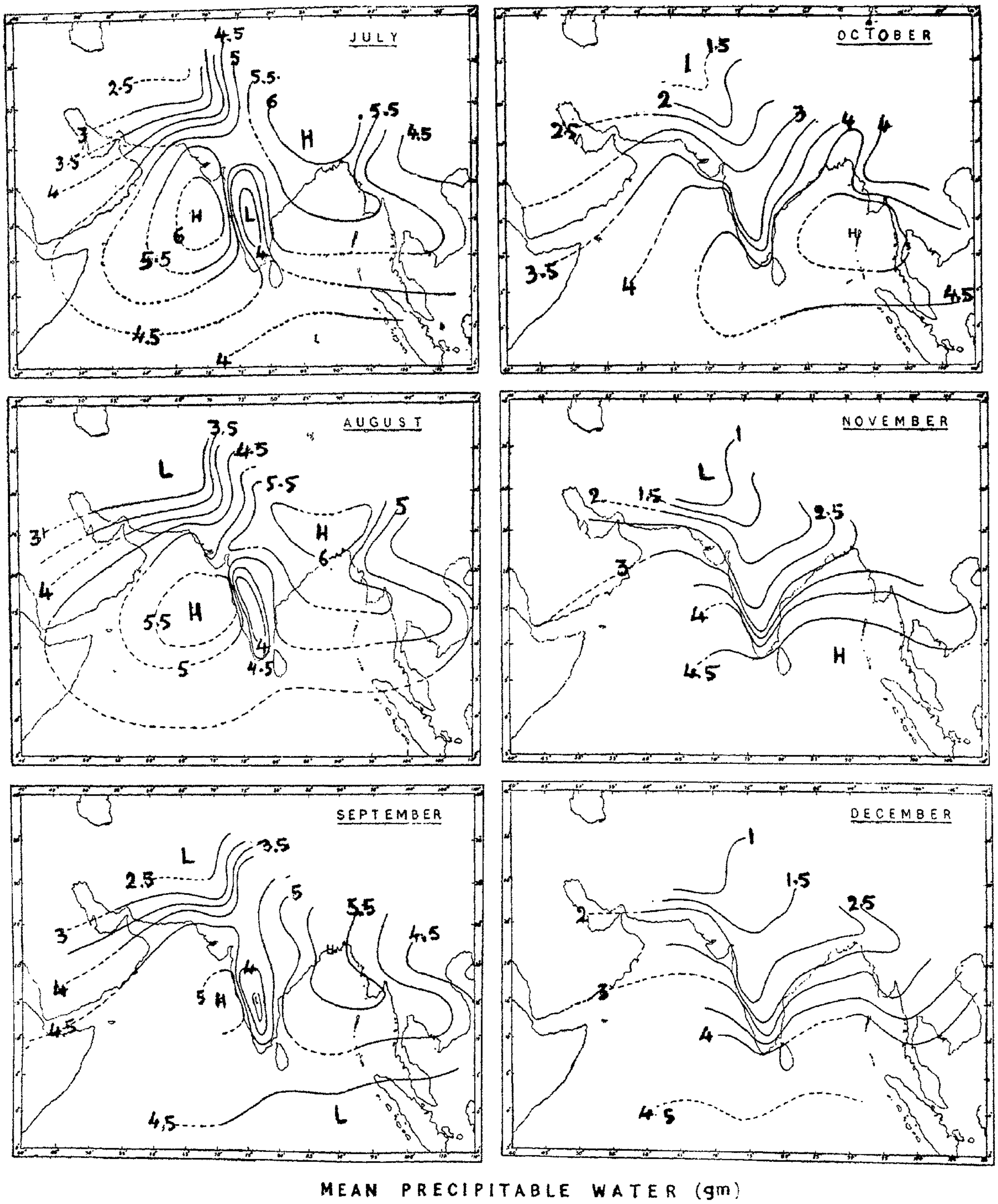

Fig. 3 (b)—Isopleth contours of mean precipitable water in grm for each month over Indian sub-continent.

table water remains above 2.5 cms south of 15° latitude. In the north and northwest regions the mean precipitable water remains between 1 to 2 cms, during the dry seasons. Of course, this is a very coarse and averaged out data, and does not take account of the local low humidity conditions that might be present at a particular location. Generally in the upper atmosphere above 3,000-4,000 ft the atmosphere becomes pretty mixed up, thus interpolation for any particular place may not be too bad an approximation.

Considering the accessibility aspect and present available support facilities in the country, we have computed the average precipitable water for each month that may be present over 12 potential sites from the India Meteorological Department data. In Table 1 is given the height of the station in feet, mean atmospheric pressure in millibar, mean precipitable water for each month, except for the monsoon months (July and August) when it is expected that astronomers will close the observatory and analyse the data. In computing the total precipitable water over each station, integration over only those isobaric layers is made which are above the station. The radiosonde data of the nearest station is considered representative of the site. In this table, except for the Afarwat peak which is about 4 kms from Gulmarg all other stations are accessible during major portion of the time. Even Afarwat Peak at 14,000 ft, could be developed, if a ropeway is provided from Gulmarg, which could serve as a base station at 9,000 ft. Mt.Abu is selected as there is already a field station

TABLE 1

TOTAL PRECIPITABLE WATER IN MM (MONTHLY AVERAGE) OVER SOME POSSIBLE INFRARED SITES IN INDIA.

STATION	(h/ft)	mb	JAN	FEB	MAR	APR	MAY	JUN	SEP	OCT	NOV	DEC
Mt Abu (Ahmedabad) *	5,500	825	5.8	5.6	7.1	9.3	11.8	15.7	18.0	10.5	7.8	7.5
Nainital (Delhi)	6,200	805	5.1	5.2	8.0	8.8	10.4	17.5	18.6	8.8	5.4	5.3
Mukteswar @ (Delhi)	8,500	740	2.6	3.0	4.6	4.2	5.5	9.0	9.8	4.1	2.7	2.6
Srinagar (Srinagar)	6,400	800	7.0	6.6	10.0	10.2	10.2	10.7	10.6	10.0	6.4	6.8
Gulmarg (Srinagar)	9,000	725	2.8	3.7	6.8	7.4	6.3	9.0	9.0	5.2	3.1	4.5
Khelinmarg (Srinagar)	10,500	680	2.7	2.7	5.7	6.5	5.5	8.8	7.3	4.5	2.7	3.5
Afarwat Peak (Srinagar)	14,000	600	1.1	1.1	2.8	3.7	2.3	3.9	3.2	1.8	1.2	1.6
Leh (Srinagar)	11,500	660	2.3	2.3	4.9	5.5	4.7	7.7	6.8	3.8	2.3	3.0
Kodaikanal (Madras)	7,500	770	7.5	7.0	7.0	10.0	13.9	18.7	17.9	15.4	12.4	8.9
Ooty (Trivandrum)	8,500	740	6.3	5.9	5.8	8.4	11.6	15.7	14.4	13.3	10.4	7.8
Kavalur (Bangalore)	2,500	930	18.2	19.1	20.0	27.3	32.6	35.3	34.4	33.1	25.1	22.8
Rangapur (Hyderabad)	2,230	910	13.6	13.3	15.4	19.0	24.1	35.6	35.2	24.8	15.6	13.6

* Station name in parenthesis indicates the nearest radio-sonde station available for this report.

@ This should refer to China Peak, Naini Tal.

TABLE II

Precipitable H_2O in vertical column (mm)

	h in feet	p (mb)	January	
			5%	50%
Palomar (California)	5,600	825	1.8	3.4
Kitt Peak (Arizono)	6,750	789	1.7	2.7
Mt. Agassiz (Arizona)	12,356	639	0.6	1.5
Mauna Kea (Hawaii)	13,800	600	1.2	1.5
Jungfraujoch (Swit)	11,500	650	0.5	1.5
Tenerife (Canery Is.)	12,000	645	1.1	3.4

of the Physical Research Laboratory and is easily accessible from Ahmedabad. Naini-Tal has already an established observatory and an IR field site at nearby Mukteshwar or at China Peak could be operated. Srinagar has an established Atomic Energy laboratory and at Gulmarg a high altitude laboratory is already functioning. Gulmarg and Srinagar stations could be used as base camps for high altitude IR field sites at Leh, Kelinmerg and Afarwat Peak. Kodaikanal, Ooty, Kavalur and Rangapur sites have already established ground based astronomical facilities, thus IR site survey at these sites could be conducted easily.

From Table I one could notice that none of the stations show 1.0 mm precipitable water level, except for the Afarwat peak. In fact this table gives you the worst possible situation that could exist, as we have given here only the average values of all data and no consideration is taken of the days when precipitable water content was very low and separated out from the average.

In Table II is shown corresponding figures for some IR sites in America and Europe obtained by Kuiper (1970).

From this table you will notice that it is only 5 percentiles of the "average best" during the dryest season, that even at Mauna Kea (13,800 ft) (Morrison et. al. 1973), the precipitable water remains about 1.0 mm. Jungfraujoch is better as one could reach 0.5 mm but cloud coverage at Jungfraujoch is large.

I am sure that if a thorough site survey is made of some of the promising sites in India, it is possible that large number of usable nights would be available where the precipitable H_2O would be less than or about 1.0 mm at high and dry mountain sites. These data refer to day time observations, we would get further reduction in humidity during the night for high altitude stations.

The radio-sonde observations are perhaps acceptable for a preliminary IR survey for potential sites, but it would be essential that actual water vapour content be measured from each site. An instrument to measure the water vapour absorption in 1.2 μm H_2O band has been developed at ITM Poona.

It is also necessary to obtain estimates of "seeing", this could be done by measuring micro-thermal fluctuations of the air mass above the site by a very sensitive low time constant thermometer.

Simultaneously sky noise and sky emission in 10-14 μm band should be measured at each site.

It is evident that high altitude and dry mountain site would be necessary for an infrared observatory for near and mid-infrared region studies. Very high altitudes create physiological problems too. To give you an example of the loss of efficiency due to high altitude exposure, Armstrong (from Kuiper 1970) has given the following data:

	LOSS OF EFFICIENCY					
Exp (hrs)	0%	20%	40%	60%	80%	100%
1	9 *	12	14	16	18	20
6	9	12	14	15	16	18
18	9	11	14	15	15	16

* Elevations in 1,000 ft.

With 60% efficiency one could work for 6 hours at 14,000 ft altitude. This figure seems to be a good compromise between gain obtained from high mountain altitudes and efficiency.

In the end I would say that, it is essential that a thorough Infrared site survey programme on a national basis should be undertaken for any serious ground based IR observations in India.

References

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Mokashi, R.Y., 1968, India Meteorological Department, Scientific Report No. *75*.

Morrison, I.R., Murphy, R.E. Chuikshank, D.P., Sinton, W.M., and Martin, T.Z., 1973, Publ. A.S.P., *85*, 255.

Westphal, J., 1972, Preliminary Report of the Ten micron Infrared Sky noise Survey (California Institute of Technology).

Discussion

Ananthakrishnan: (1) Is the diurnal variation of the atmospheric water vapour content important? (2) Does the average reading from radio sonde give a true representation of water vapour content?

Bhatnagar : (1) Yes. (2) No, only to a first approximation and good guide for further investigation.

Bhattacharya : I think that the role of precipitable water content in the air is being overemphasised. In the near infrared region windows can be used with 3-4 mm of precipitable water without much absorption. Observation in the absorption band is not possible from any ground based site. Another point, in your chart the northern parts of India appear very suitable for IR observatory site. But due to the western disturbances sweeping across this region in winter, the clear skies are not very common. This makes near IR studies not quite possible in these locations.