

Measurement of Various Atmospheric Parameters During a Total Solar Eclipse

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ABSTRACT

The measurements of solar radiation in the IR spectral region is of great significance in understanding physics, chemistry and the radiation budget of the atmosphere. The occurrence of a total solar eclipse on October 24, 1995 at New Delhi provided a unique opportunity to take some special solar radiation measurements in an infrared spectral region with the use of an IR photometer, the experiments were conducted during, after and before the total eclipse at Neem Ka Thana (75° 47'E, 27° 47'N) and New Delhi (77° 13'E, 28° 39'N) in the spectral ranges of 0.75 to 1.6 μm and 2.5 to 14.5 μm respectively. The measurements were used to estimate the water vapour (0.94 μm and 1.14 μm), Ozone (9.6 μm) etc. A significant variation in IR solar irradiance at various window wavelengths during the solar eclipse was observed. Also measurements of temperature and humidity were made. In the present paper, the experimental set-up and results are discussed in detail.

(Key Words: Total solar eclipse 1995, Water vapour, Ozone, IR radiation, Sun photometer, Gravity waves)

1. INTRODUCTION

The atmospheric conditions during a solar eclipse change when the moon's shadow, moving with supersonic speed, cuts off solar radiation. Chimonas and Hines (1970) suggested that on account of this solar radiation cut-off, the cooling of the atmosphere takes place around 45 km, and at a lower troposphere, it generates atmospheric gravity waves. Although previous attempts to detect gravity waves at upper atmospheric heights have been more or less successful, such attempts at ground level have produced inconclusive results. Many authors (Anderson *et al.*, 1972; Chimonas, 1973; Reddy, 1982) have pointed out that for the generation of gravity waves, absorption by water vapour may well be a much stronger source than UV radiation absorption by Ozone in the stratosphere. During the solar eclipse of February 16, 1982,

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the detection of gravity waves at ground level was reported by Kunhikrishnan and Murthy, 1982; Reddy, 1982; Venkatachari *et al.*, 1982. They explained that one possible reason for the generation of gravity waves of large amplitude was on account of the large amount of water vapour present at the time of the solar eclipse at the experimental site. Reddy, 1982; and Mims and Mims, 1993; suggested monitoring water vapour during eclipse time in order to determine the possible generation of waves arising from temperature changes in the lower troposphere. In other words, it can be said that all of the previous authors recognized the potential importance of the amount of water vapour content present at eclipse time as a source of strength for the generation of gravity waves. The Monitoring of Ozone by Stranz, 1961; Bojkov, 1968; Oshervich *et al.*, 1974 during earlier solar eclipses reported slight increases in Ozone after a maximum phase. In view of the above, the occurrence of a total solar eclipse on October 24, 1995 provided yet another unique opportunity to monitor water vapour, Ozone and the variations in solar radiation at various wavelengths in the infrared (IR) region.

In the present study the infrared solar absorption spectra were taken using two Sun-photometers, one for Ozone at New Delhi and the other for water vapour monitoring at Neem Ka Thana in Rajasthan during, after and before the solar eclipse, i.e, from October 23, to October 26, 1995. The measurement of the total atmospheric water vapour and total Ozone from the Earth's surface was made by comparing the solar radiation intensity at two narrow spectral wavelengths - one at the centre of the absorption band and the other within the atmospheric window just outside the absorption band which was taken as a reference. The present paper discusses the salient features of the experimental set-up along with the results obtained.

1.1 The Solar Eclipse on Oct. 24, 1995 in India (Indian Meteorological Department, IMD, 1995):

The solar eclipse of October 24, 1995 began at 07:22 hours IST and ended at 12:43 IST. The partial phases of the eclipse covered the region bounded approximately by longitude 36° E and 173° W and latitude 70° N and 30° S encompassing the extreme North East of Africa, central, South and eastern Asia, although not the North Eastern part, the Indian Ocean, the northern half of Australia and the western Pacific Ocean as shown in Figure 1 (IMD, 1995). It was noted that the Sun was totally obscured by the moon's disc from a narrow path over which the umbral cone of the moon's shadow swept across the earth. At approximately 08:23 hrs. IST on Oct. 24, 1995 the center of the umbra touched the earth at sunrise at a point south of Teheran (51° 6' E, 34° 50' N) having a path of totality 19 km wide and 25 seconds in duration at this point. The central line after crossing Iran, Afghanistan and Pakistan reached the north western end of India roughly around 08:30 hrs. The total phase in India, as shown in Figure 2, extends over the north Indian plain passing north of Bikaner, over Alwar, Bharatpur and Dholpur in Rajasthan, over into Uttar Pradesh and eventually passing south of Agra, over Bhind (MP), Jalaun (Orai), Hamirpur and Allahabad in UP, Daltenganj in Bihar, Puruliya and Diamond Harbour in West Bengal. The duration of

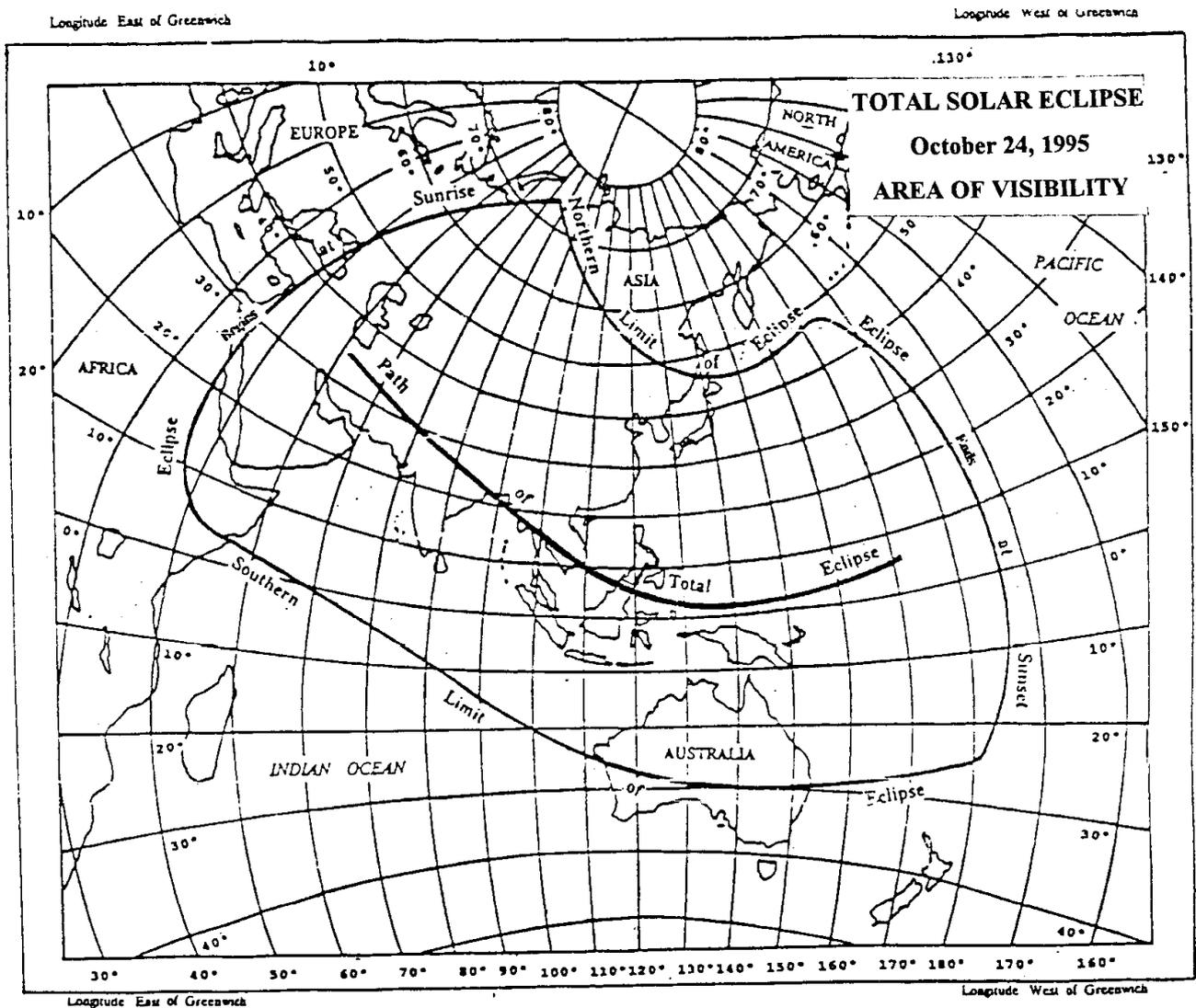


Fig. 1. Map showing area of visibility of the total and partial solar eclipse on October 24, 1995.

totality along the central line in India varied from 48 seconds in the west (Rajasthan) to about 82 seconds in the east (West Bengal). The central path crossed West Bengal via southern Bangla-Desh and entered Burma, Thailand South China Sea, the northern tip of Borneo, the Celebes Sea and the Pacific Ocean. The maximum duration of totality was of 134 seconds at 10:10 hrs IST close to Borneo in the South China Sea where the width was 81 km. The central eclipse ended at 11:42 hrs IST when the umbral cone left Earth over the Pacific Ocean ($171^{\circ} 48' E$, $5^{\circ} 39' N$), while the eclipse ended when the moon's shadow finally left earth at sunset over Pacific Ocean ($158^{\circ} 8' E$, $1^{\circ} 40' S$).

On the basis of the India Meteorological Department Report (IMD, 1995) of the total solar eclipse the probability of cloud free conditions was higher in Rajasthan than in West Bengal, and accordingly the site selection to conduct experiments in this study was done in August 1995. The details of the solar eclipse at the two experimental sites are given below:

Place	Longitude	Latitude	Eclipse began IST h m s	Totality began IST h m s	Totality began IST h m s	Eclipse began IST h m s	Duration in sec. of totality
Neem ka Thana	75° 47' E	27° 47' N	07 24 10	08 32 20	08 33 10	09 50 30	50
				Greatest phase	Obscuration		
New Delhi	77° 13' E	28° 39' N	07 24 50	08 34 08	95.754 %	09 52 25	

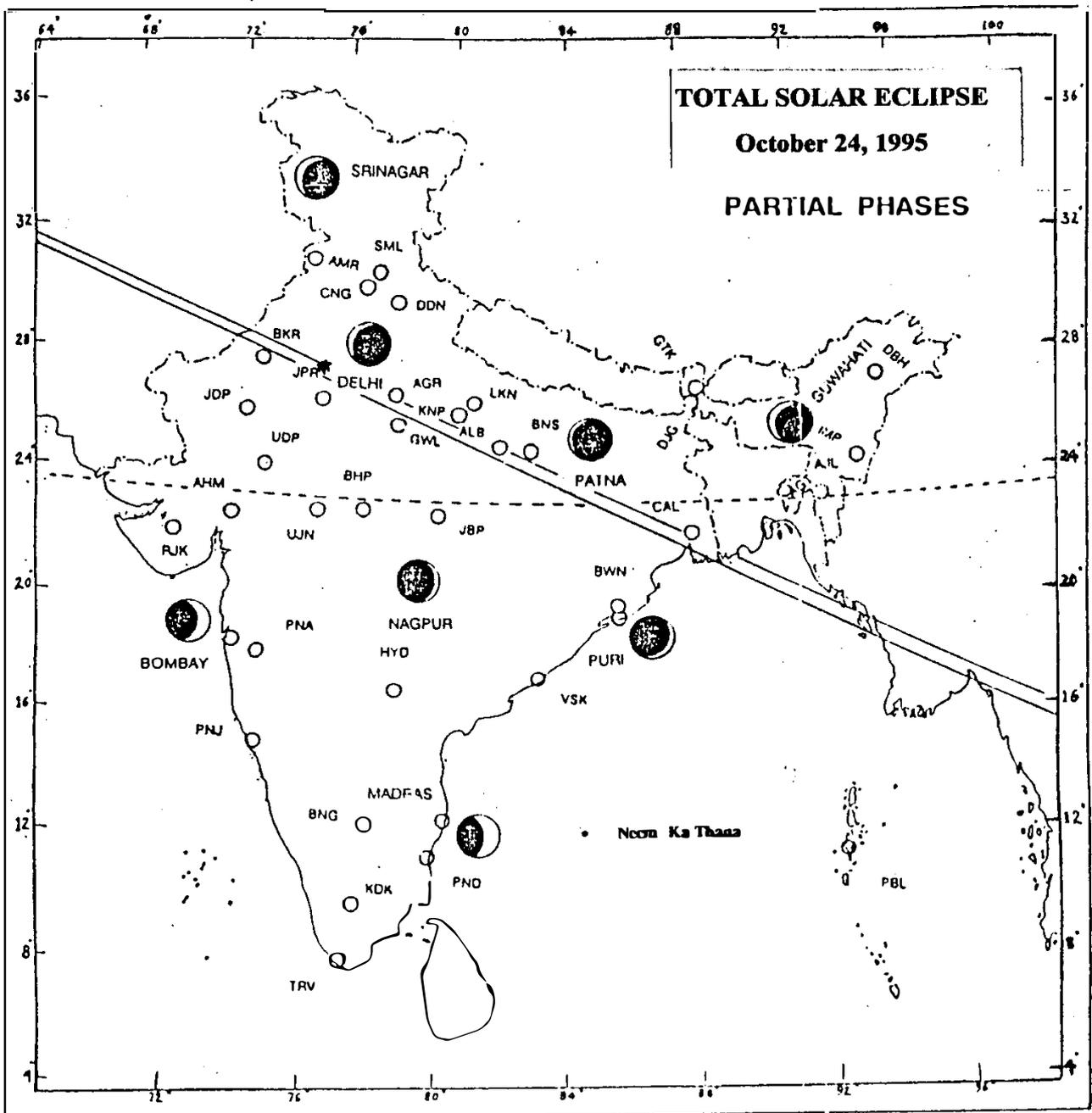


Fig. 2. Path of the total and partial solar eclipse on October 24, 1995 over India.

2. EXPERIMENTAL SET-UP

The systems used to monitor the IR solar spectra during the solar eclipse at National Physical Laboratory, New Delhi (NPL) and Neem Ka Thana were slightly different and are described in the following:

2.1 NPL, New Delhi

The block diagram of the system is depicted in Figure 3. The components of the system include a Sun tracker (Heliostat), circular variable filter, chopper, pyroelectric detector, lock-in-amplifier and PC based data acquisition system etc. The circular variable filter is motor-driven which allows for continuous wavelength scanning from 2.5 to 14.5 μm spectral region in 20 minutes but also has the provision for 1 - minute and 10-minute scans. The signal is synchronously detected using a lock-in-amplifier. A heliostat mounted on a tower outside the laboratory was used to solar radiation reflected in a fixed direction in the laboratory. The solar radiation was chopped with 10 Hz and focused by ZnSe lens on a detector. The interference narrow band pass circular variable filters covering the spectral range in the 2.5 to 14.5 μm region is in 3 segments (Table 1). The spectral performance of each of the individual segments is described below. Each segment slightly overlaps the adjacent segment in wavelength to provide continuous coverage of the 2.54 to 14.5 μm region. The solar absorp-

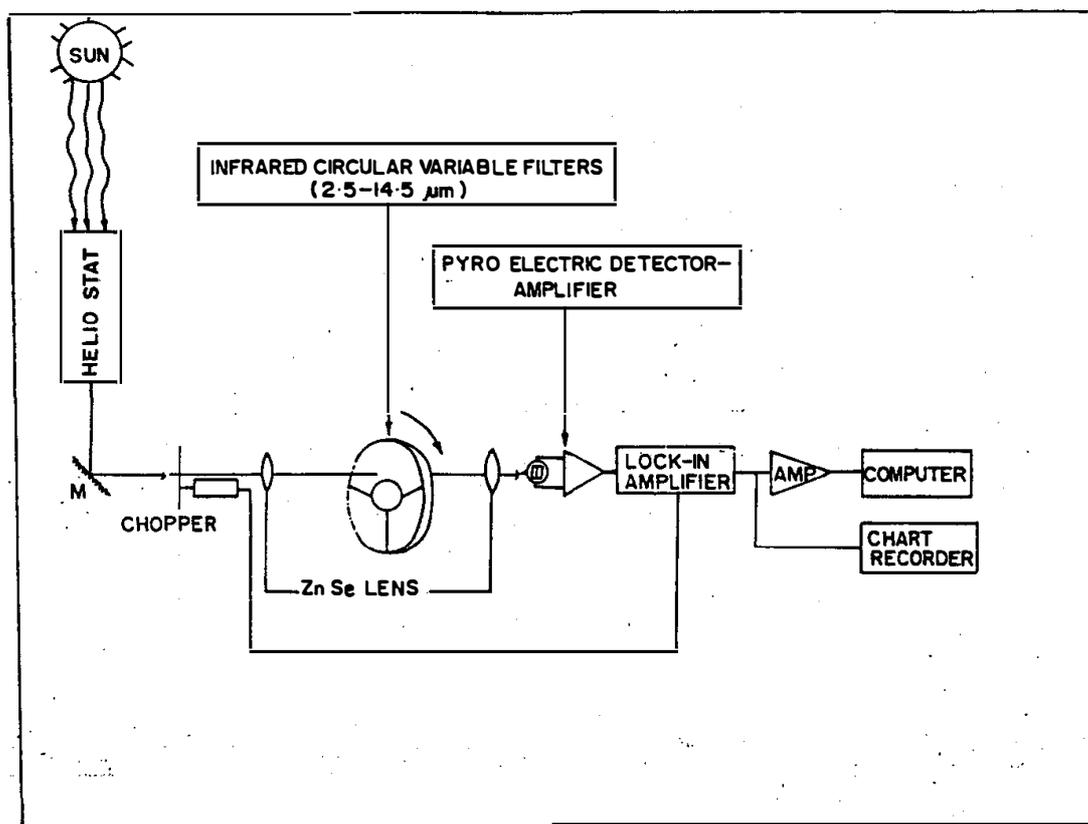


Fig. 3. Block diagram of the infrared radiation monitoring system.

tion spectra were taken in the above range during partial solar and control days. The details of the circular variable infrared filters and detector are given in Tables 1 and 2, respectively.

2.2 S.N.K.P. Govt. College, Neem Ka Thana

The IR Sun photometer used at the S.N.K.P. Government College, Neem Ka Thana, was almost similar to that, described above except that, instead of a circular variable IR filter, a high resolution grating monochromator with a focal length of 240 mm was used to obtain the IR solar absorption spectra from 0.75 μm to 1.6 μm . The block diagram of the system is shown in Figure 4.

The typical spectra obtained using the two Sun photo meters at NPL, New Delhi and the S.N.K.P. College, Neem Ka Thana, are shown in Figs.5 and 6, respectively. The experiments were conducted on the premises of the S.N.K.P. Govt. College at Neem Ka Thana, which was in the totality path, and at NPL, New Delhi which had a partial eclipse with a maximum obscuration of 95.75%.

Table 1. Parameters of the circular variable filters.

S No.	Specification	Segment I	Segment II	Segment III
1.	Spectral range in μm	2.5 - 4.5	4.4 - 8	7.9 - 14.5
2.	Half width	1.35 %	1.35 %	1.8 %
3.	Transmittance	25.00 %	30.00 %	30.0 %
4.	Transmittance out of band	0.10 %	0.10 %	0.1 %
5.	Substrate	Quartz	Germanium	Ge

Table 2. Characteristics of the detector.

1.	Wavelength range	0.001 to 1000 μm
2.	With Intran window	1.5 to 14.5 μm
3.	Maximum input AV power	0.05 watt
4.	Current responsivity	7.1 A/W
5.	NEP (10.6 μm , 10 Hz, 1 Hz BW)	6×10^{10} W/ Hz ^{1/2}

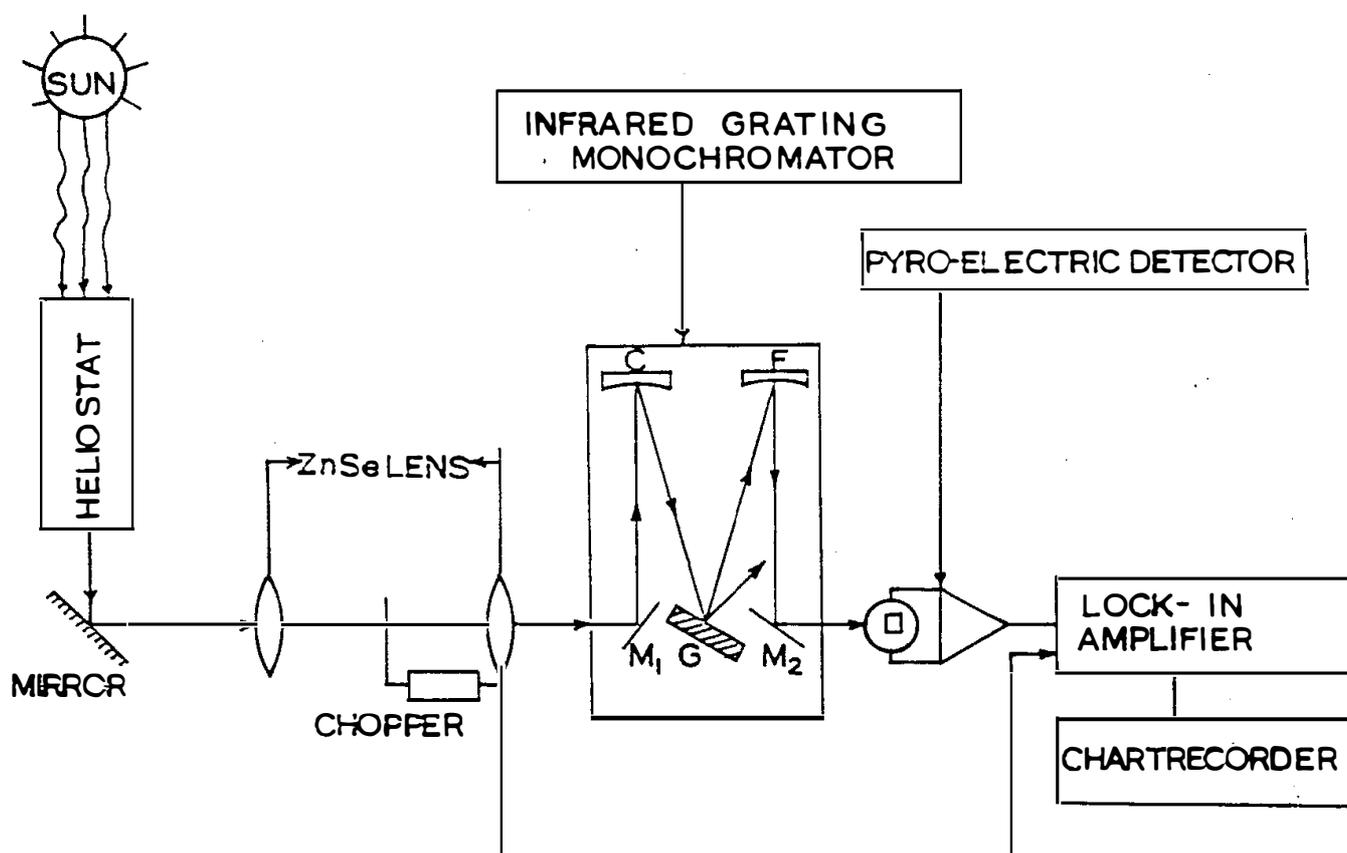


Fig. 4. Block diagram of the Infrared grating spectrometer.

3. RESULTS AND DISCUSSION

The IR solar spectra obtained from October 22 to October 26, 1995 were used to determine various atmospheric parameters. A digital Vaisala hygrometer (model NO. HMI 33) was also used to measure the temperature and relative humidity during the period.

3.1 Temperature and Humidity

The ambient atmospheric air temperature and relative humidity were measured using a digital temperature and humidity sensor at 1 meter above the second floor of the SNKP Govt. College building during, before and after the solar eclipse day from the 23rd to the 26th of October 1995 at Neem Ka Thana. The typical variations in temperature and humidity are shown in Figure 7 for different days. It is evident that the relative humidity increased, while the temperature decreased during the eclipse.

The actual temperature drop from the start of the eclipse to its maximum phase is only 1.5°C. However, the temperature difference around 08:30 hrs (totality) on October 24, 1996 and other control days is 6 to 8°C. The temperature variation observed at Neem Ka Thana was in agreement with that observed by Anderson *et al* 1972. Anderson *et al* 1972, detected a temperature decrease of 3°C with a minimum slightly after totality in the earlier solar eclipse

on March 7, 1970 around noon time. The relative humidity increased by only 4% during the eclipse period. However, the relative humidity difference on the control days and the eclipse day around 08:30 hrs (totality) is found to be 8 to 10 %.

3.2 Water Vapour

The infrared solar radiation absorption spectra in the spectral range of 0.75 - 1.6 μm showed well documented absorption bands of water vapour at 0.935 μm , 1.14 μm and 1.38 μm (Figure 6). The attenuation of IR radiation at 1.14 μm was used in the estimation of water vapour during, before and after the solar eclipse at Neem Ka Thana. The typical variations in water vapour during the control days and eclipse day are depicted in Figure 8. Utilizing a theoretical model, Chimonas (1973) made an attempt to explain the observations of Anderson *et al.* (1972) regarding the gravity waves at round level during the March 7, 1970 solar eclipse. He argued that above normal tropospheric water vapour content during eclipse

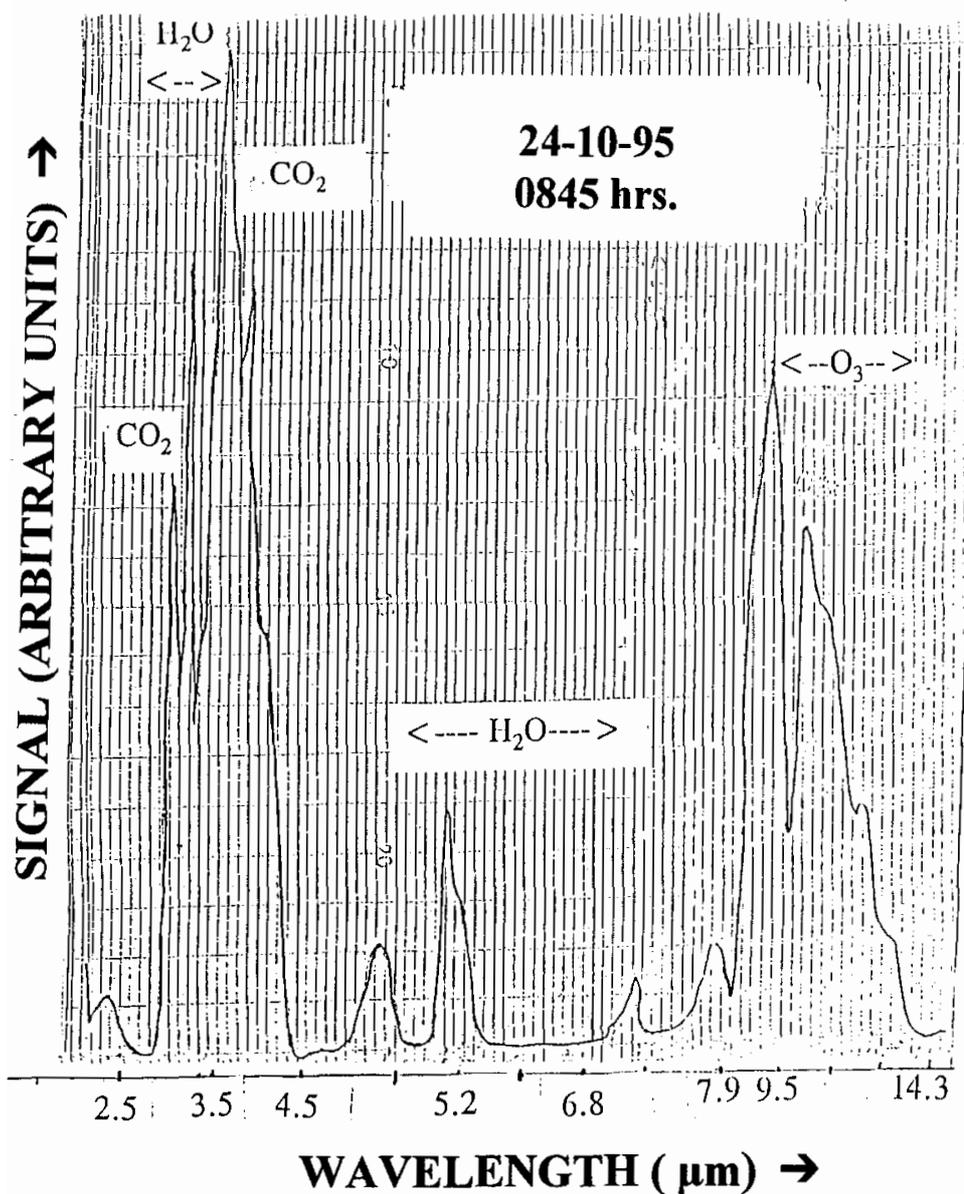


Fig. 5. Observed infrared spectrum from 2.5 to 14.5 μm at NPL, New Delhi.

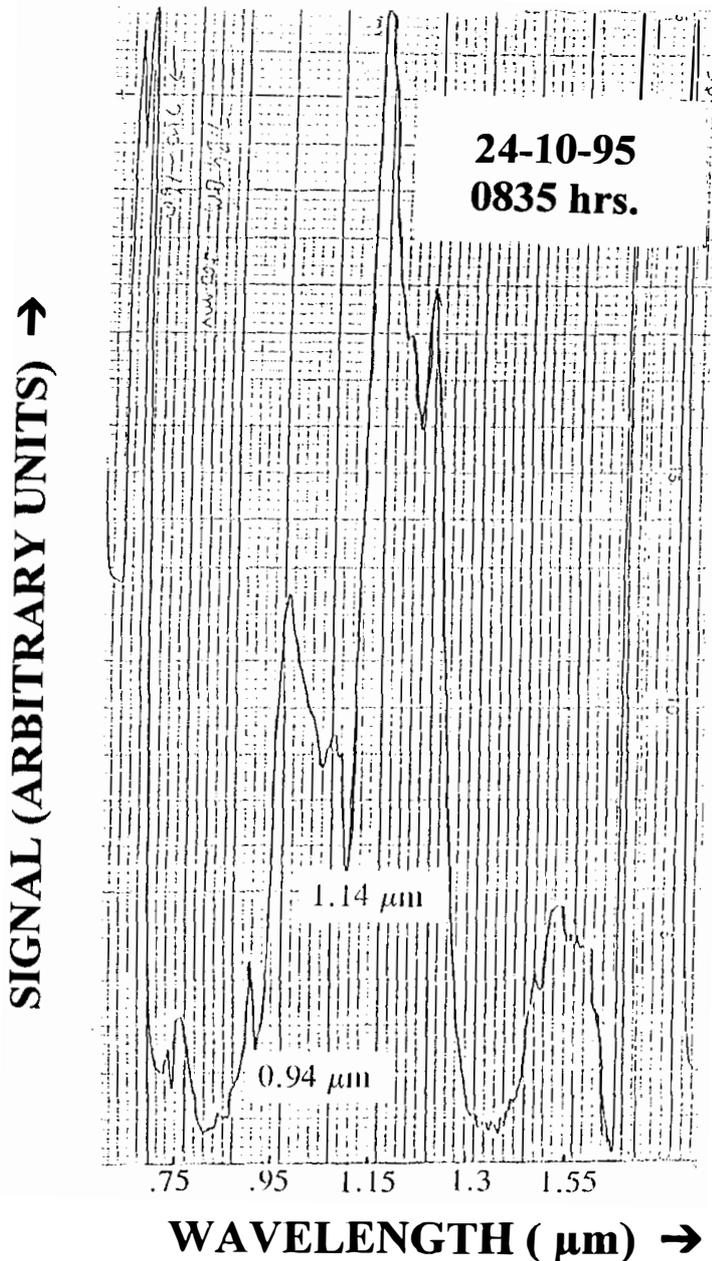


Fig. 6. Observed infrared spectrum from 0.7 to 1.6 μm at Neem Ka Thana.

time might have been responsible for the generation of those gravity waves of large amplitude. In their results, Reddy (1982), Kunhikrishnan and Murthy (1982) also explained that large amounts of water vapour present at the coastal locations of eclipse sites may have been adequate for the generation of gravity waves during the solar eclipse of February 16, 1980.

During the eclipse time at Neem Ka Thana, Venkatachari *et al* (1996) operated a microbarograph unit above the second floor of the SNKP Government College building to detect gravity waves. The micro-barograph unit was about 25 meters away from the Sun-photometer. No evidence of gravity waves was found. Based on the measurements in this study, the total water vapour content varied roughly from 0.5 gm/cm^2 ($1 \text{ gm/cm}^2 = 1 \text{ pr-cm} = 10 \text{ pr-mm}$) to 1.2 gm/cm^2 during the period of the eclipse. A decrease in the water vapour content at the time of totality (0.7 gm/cm^2) was also noted. However, it should be stated that this amount of total water vapour content, was perhaps, not sufficient to generate gravity waves above the

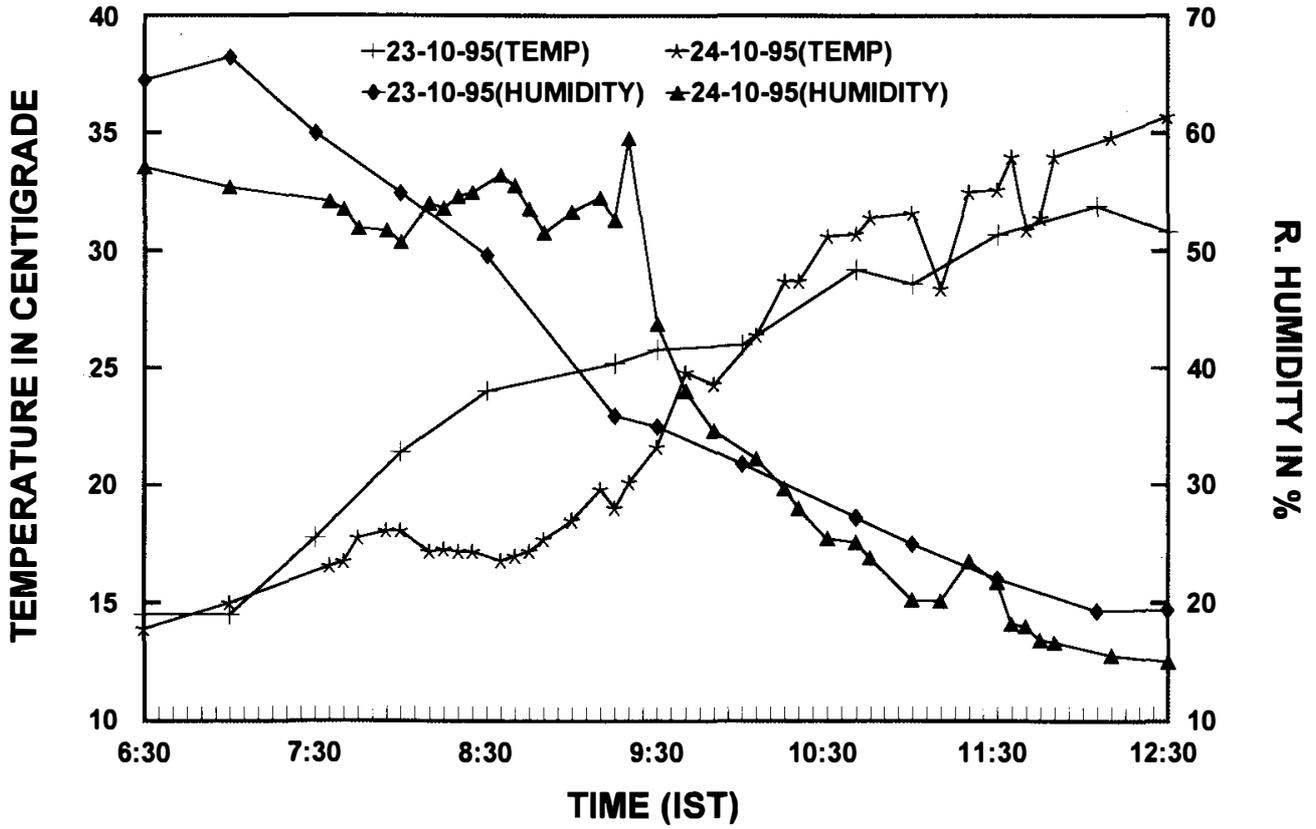


Fig. 7. Temperature and humidity variations on the control and eclipse days at Neem Ka Thana.

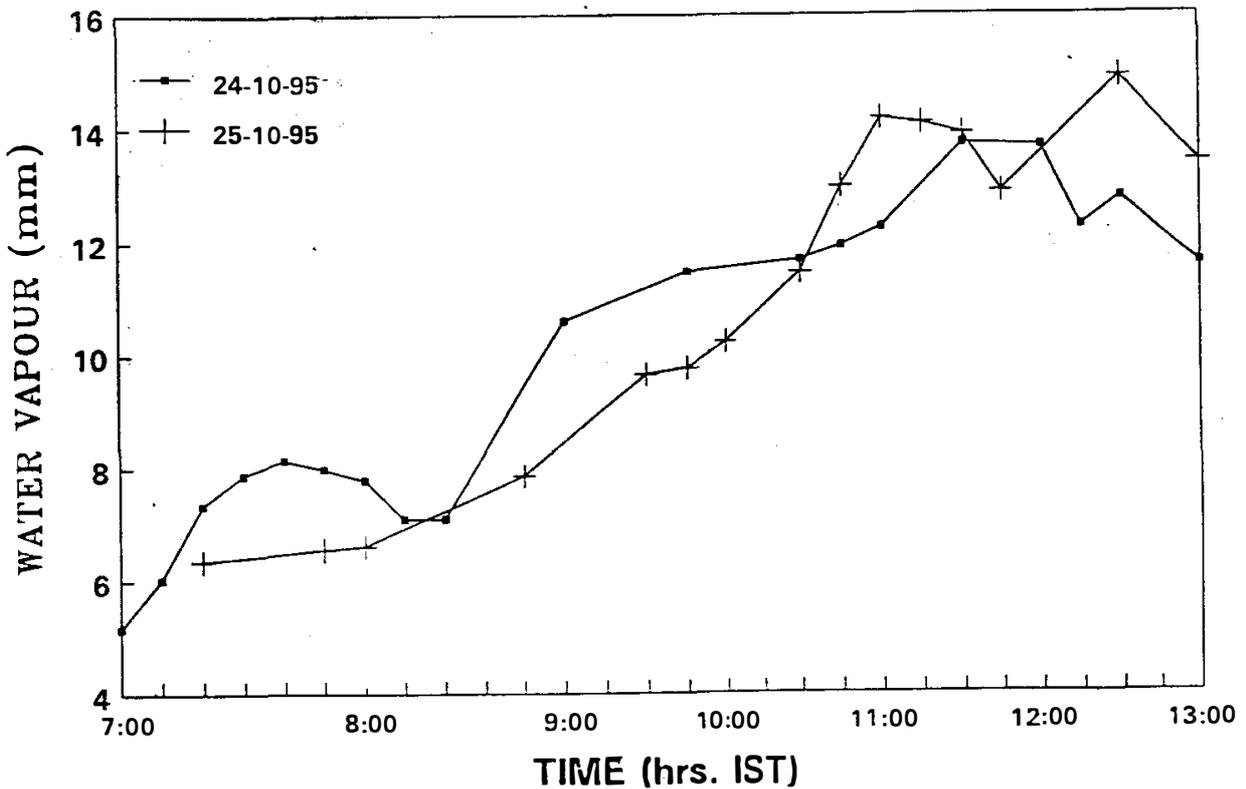


Fig. 8. Variations in water vapour on the control and eclipse days at Neem Ka Thana.

background noise level of pressure fluctuations brought on by other weather processes. The eclipse at Neem Ka Thana started around the morning hour of 07:24 IST. The atmosphere was cool, and the total water vapour content was about 0.8 gm/cm^2 . On the other hand, in contrast, the eclipse on February 16, 1980 started around 14:30 hours IST in the afternoon when the atmosphere was hot and generally contained a maximum amount of water vapour.

3.3 Ozone

The solar absorption spectra taken during the partial solar eclipse and control days from $2.5 \mu\text{m}$ to $14.5 \mu\text{m}$ show (Figure 5) a well defined $9.6 \mu\text{m}$ absorption band of Ozone. The $9.6 \mu\text{m}$ Ozone absorption band in the solar spectrum fell in the window region ($8 - 14 \mu\text{m}$) where there was no major absorption by other constituents. The $9.6 \mu\text{m}$ band was used to estimate total column Ozone at NPL, New Delhi as depicted in Figure 9. Mims and Mims (1993) reported a series of fluctuations in the Ozonosphere following the third contact during the total solar eclipse of July 11, 1991. However, the present authors did not observe any appreciable variation in Ozone on the solar eclipse day. Nevertheless, it was seen that the total Ozone on the eclipse day is slightly higher than on the control days.

3.4 IR Solar Radiation

I. Neem Ka Thana

The IR solar radiation was measured in the spectral range of 0.76 to $1.7 \mu\text{m}$ from October 23 to October 26, 1995. The variations in IR solar radiation at $1.2 \mu\text{m}$ on October 24, 1995 and the next day are depicted in Figure 10. It was found that IR solar radiation starts to

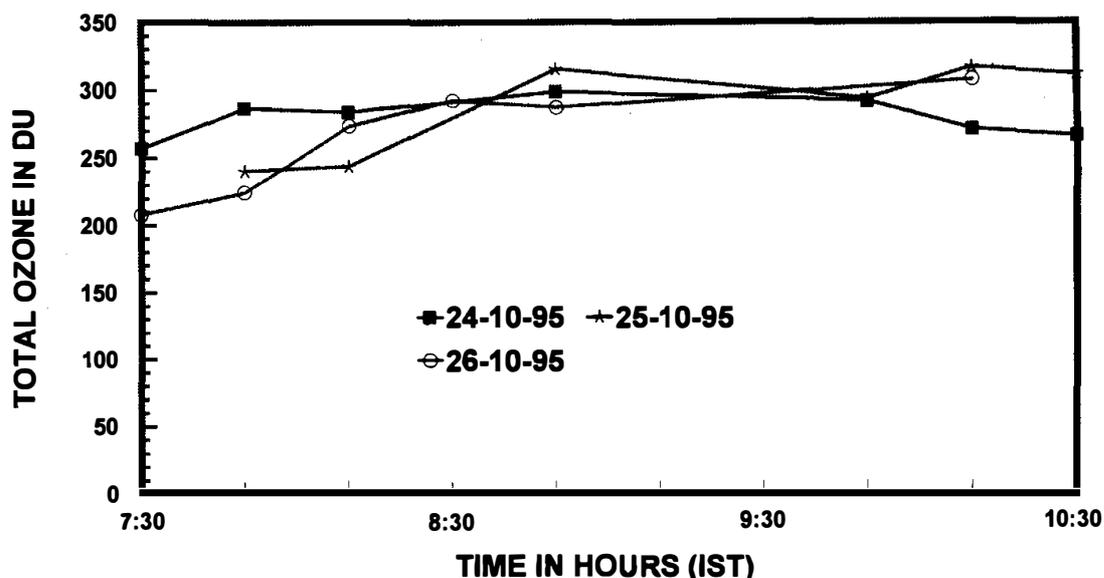


Fig. 9. Variations in total Ozone at New Delhi on control days and during the solar eclipse on October 24, 1995.

decrease as soon as the solar eclipse begins and is at its minimum during the totality but returns to normal after the end of the eclipse.

II. NPL, New Delhi

The variations in the IR Solar radiation measured at NPL, New Delhi on October 23 and 24, 1995 at $9.72 \mu\text{m}$ and $9.48 \mu\text{m}$ are shown in Figure 11. It is found that IR radiation drastically decreases during the solar eclipse and is at its minimum during the maximum obscuration around 8:30 hours. The IR solar radiation reaches its normal value at the end of the eclipse.

3.5 Shadow Bands

Efforts were made to see the shadow bands by spreading 3 meter square white sheets on the roof of the SNKP Govt. College, but no sign of shadow bands was seen.

3.6 Solar Dust Ring

The existence of a dust ring around the Sun has often been shown by means of both theoretical (Russell, 1929; Over, 1958; Peterson, 1963) and experimental work (Peterson, 1967; Peterson, 1969; MacQueen, 1968). It has been suggested that enhanced infrared radia-

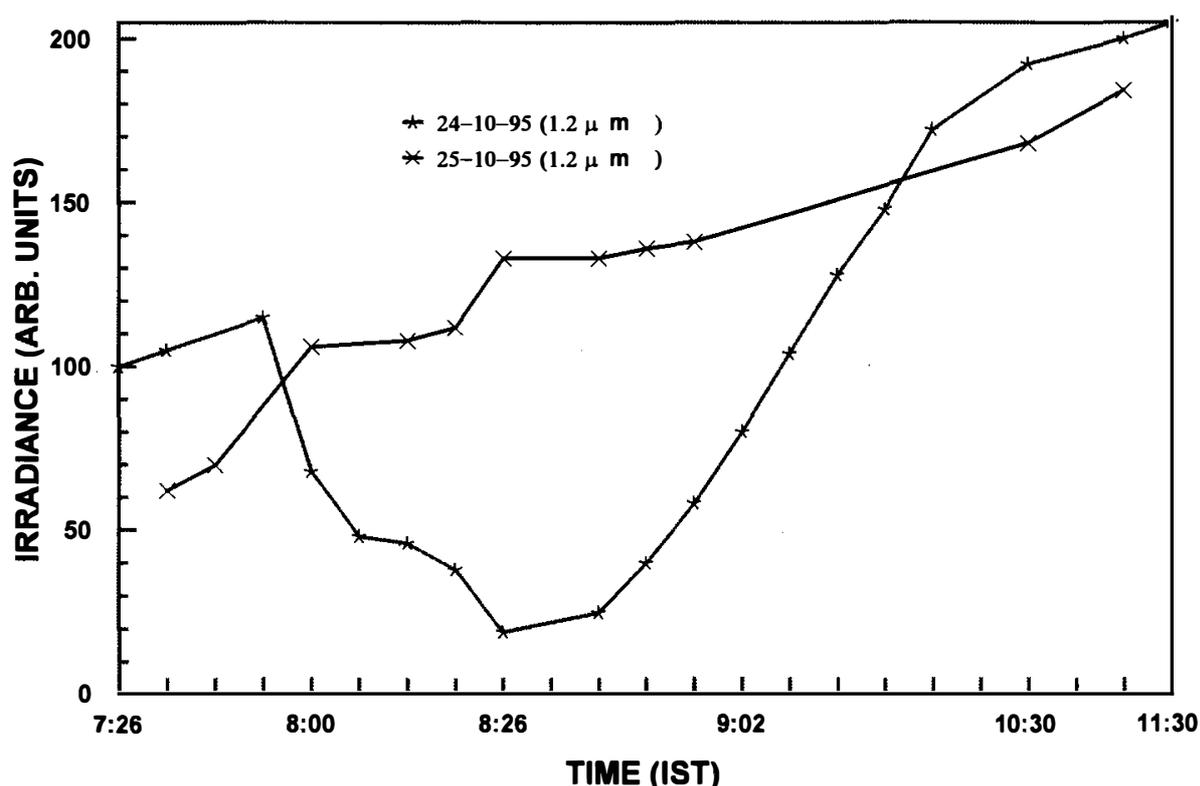


Fig. 10. Variations in the IR solar radiation at $1.2 \mu\text{m}$ on control and eclipse days at Neem Ka Thana.

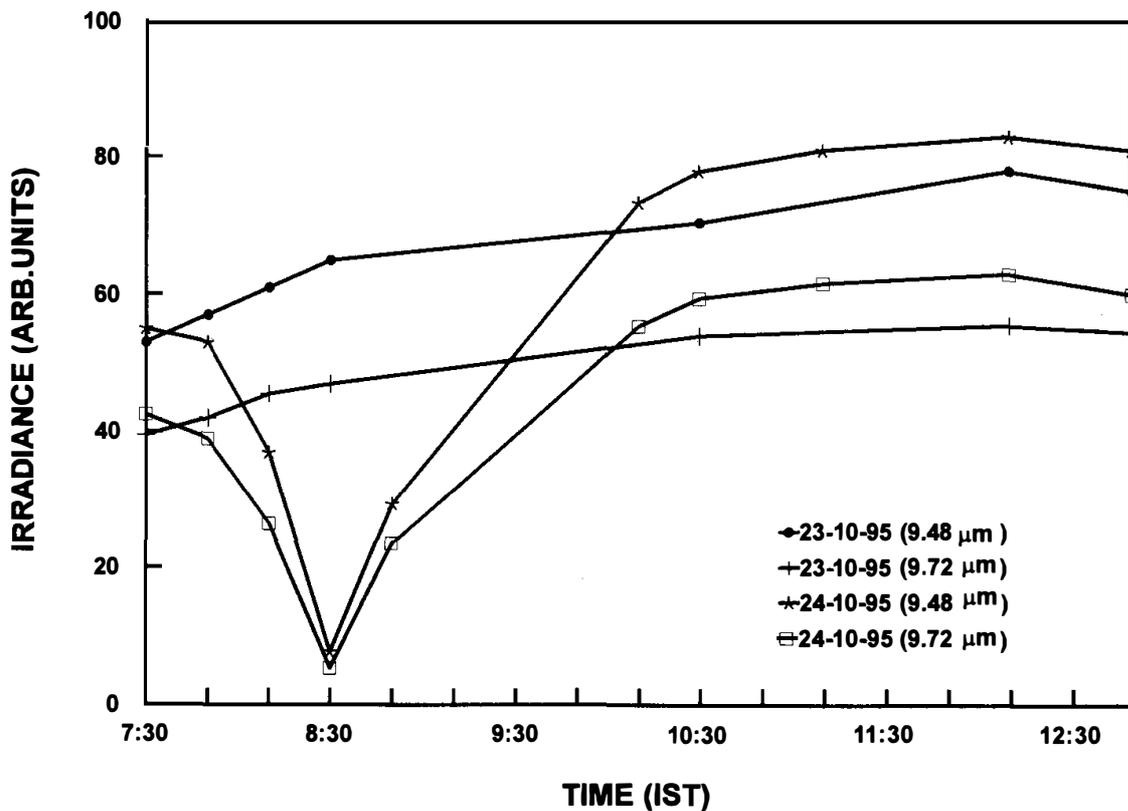


Fig. 11. Variations in the IR solar radiation at 9.48 μm and 9.72 μm on the control and eclipse days at New Delhi.

tion observed during a solar eclipse at a distance of $4R_0$ from the centre of the Sun is due to the sublimation of dust grains as they spiral into the Sun because of the Poynting-Robertson effect. However, this enhanced radiation has not always been evident; in some cases, it has been present, while in others it has not. (Rao *et al.*, 1981; Debi Prasad, 1995). In this study, observations were carried out to see the existence of dust ring during a total solar eclipse at Neem Ka Thana monitoring IR radiation at 2.2 μm using an IR Sun photometer. The results show some radiation on both sides away from the Sun, but the signal level was very low and it was very difficult to draw any conclusions from the observations regarding the existence of the dust ring around the Sun. Also, as the scanning across the solar disk was done manually, there may have been an error in the estimation of the distance from the Sun's centre. As such, efforts to measure various atmospheric parameters will be made again during the next total solar eclipse in 1999 but better instrumentation will be used.

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