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Solar Irradiance Measurement and Estimation of Aerosol and Ozone in Antarctica During Austral Summer of 1991-92

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Abstract

Solar irradiance has been measured in Antarctica during the eleventh Indian expedition using a number of instruments covering a range from 295nm to 14.5µm i.e. UVB, visible and infrared. The measurements have been analysed to estimate the aerosol content, aerosol size distribution and gross total ozone in the Antarctic atmosphere. Results analysed by computer, have been discussed separately depending upon the wavelength range under contention. The results show increasing trend of aerosolss over the past years, higher ozone presence compared to that of Delhi and ozone values comparable to those obtained from TOMS.

Introduction

Recently the world has seen a sudden awakening to global changes caused by increase of green house gases and depletion of ozone catalyzed by anthropogenic gases. The discovery of "ozone-hole" Dy Farman et al.(1985) has proved a milestone in global awareness of the ecological problems faced by the planet. During the eleventh Indian expedition to Antarctica, solar irradiance covering a range from 295nm (UVB) to 14,5 (µm (IR) was recorded by using a number of instruments like Sunphotometer (368nm, 500nm, 675nm, 778nm), UVB Sunphotometer (295nm, 392nm, 310nm), Spectroradiometer (280nm to 368nm) and IR Sunphotometer (2.5m - 14.5m). Different parts of the spectrum provide information about different aspects of the problem.

Experimental Set-up

The following apparatus were used for the observations.

(a) Sunphotometer

It is 'EKO'Japan make instrument which can operate at four different wavelengths viz., 368 nm (UV), 500 nm (visible), 675 nm (visible) and 778 nm (IR). It can be operated by holding in hand or fixing the instrument on a stand. It has four narrow band filters to measure solar irradiance at the above mentioned four wavelengths. The filter positions can be changed by rotating a knob which also indicates the kind of filter in line. In order to take the observations the instrument is pointed towards the Sun, orientation is adjusted so that the light spot falls inside the specified circle. At this position the Sun is set in the optimum alignment The instrument is set in 'Hold'position so that it records the maximum value of the signal around the optimum setting. Depending upon the intensity of the signal, instrument can be set at gainl/gain10 positions. Gain10 position multiplies the incoming signal by 1000. The measurements have been taken at hourly Interval far 8 hours on clear days. The instrument is also provided with an in-built thermometer to note the ambient temperature at the time of observation which is required for temperature correction white deriving the turbidity.

ih) UV - B Sunphotometer

The instrument is designed and developed at the National Physical Laboratory, New Delhi. It consists of three filters with peak wavelengths at 310nm, 302nrn and 295nm. The radiation after passing through filters falls on a photo-multiplier tube. Filters are brought into the field of view by a lever as it is pushed stepwise into the instrument. The P.M. tube is operated at900VDC to record the signal. The instrument can be aligned towards the Sun using the movements along horizontal and vertical axes. Power required for the instrument is provided by a D.C. power supply unit 'Aplab 7333' make. Two types of neutral density filters were used to reduce the intensity of solar radiations to observational level. The output is read on a sensitive microvoltmeter at the maximum output position, which is finally converted into Watt/cm^2/nm by multiplying by a calibration factor. The measurements were taken on sunny days at hourly interval between 0800 and 1700 hrs. During the austral summer of 1991 -92 a total of 23 days" observations were taken:

(c) *Spectroradiometric measurements*

The spectroradiometric Model 742 is procured from Optronic Labs. Inc. USA. it consists of three parts:

i) Optical head
ii) Electronic control
iii) Data logger

It is a versatile instrument which can measure solar irradiance from 200nm to 800nm in a continuous fashion. First, the zero level is adjusted to abourt6 .0V. Then the optical head is aligned to the Sun and desired wavelength adjusted at the electronic unit. This tunes the optical head to the desired wavelength. Data is printed by the data logger. Because of the partial failure of the system in our case, the data was recorded manually from the display at electronic unit.

Measurements were taken from 04.1.92 to 12.2.92 on sunny days (23 days), five times a day. They were limited to UV - B range of the spectrum viz., 280nm, 290nm,295nm, 300nm, 305nm, 310nm, 315nm, 320nm and 368nm for cross

(d) Infrared Sunphoiometer

The transmission of the atmosphere in IR region is of great importance in view of the study of heat balance, thermal' structure, abundance of constituents etc. Principal absorbers of IR are H_2O, CQ_2, 0_3. In addition to these, CH4, CO and N2O occur as minor constituents. N_2 and O_2 have no dipole moment and so possess no IR rotation-vibration bonds. Molecular scattering of radiations is important for smaller wavelengths near visible but for longer wavelengths absorption by atmospheric gases like H_2O, CO_2, 0_3, N_2O, CO, CH_4 is important whereas absorption and scattering by'aerosols is low. This IR Sunphotometer studies the constituents of air by recording their absorption spectra falling in IR region.

The block diagram of the system is shown in Fig 1. It consists of Sun tracker, circular variable filter, chopper, pyroelectric detector, lock-in amplifier and recorder. The filter is motor driven and allows continuous scanning of wavelengths from 2.5 µm to 14.5µm in 20 steps. The signal is synchronously detected using lock-in amplifier. A heliostat mounted outside is used to direct sunlight into a 'Newtonian Telescope' which concentrates it on the apparatus constantly.

Results and Discussion

(a) The radiation coming from Sun suffers extinction as it travels through the atmosphere. Atmospheric turbidity is defined as the extinction of direct solar radiation by existing aerosols. The direct solar intensity varies with wavelength, amount of suspended particles and their radii. Aerosol extinction coefficient can be calculated as :-

$$I\lambda = I_O\ \lambda\ e^{-(Tm\ \lambda + T_O\ \lambda + T_R\ \lambda)\ m} \qquad . \ . \ .(1)$$

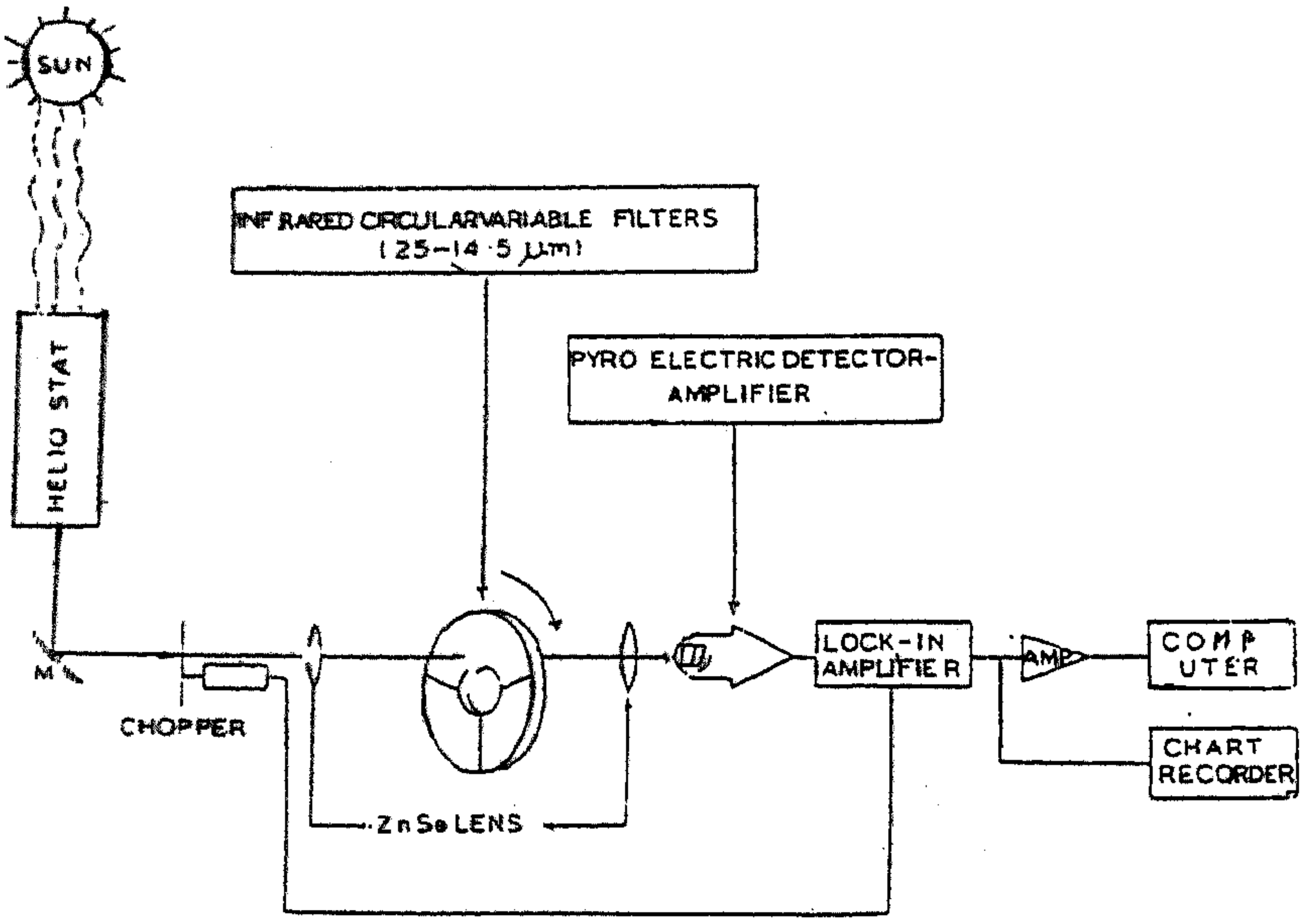

Fig 1; The bock diagram of infra-red radiation monitoring system.

where,

Iλ, = The irradiance at the observing point.

Ioλ = The extra-terrestrial irradiance at the mean Sun-Earth distance.

Tmλ = The extinction coefficient due to aerosols.

Toλ = The absorption coefficient due to ozone.

TRλ = The Rayleigh scattering coefficient.

m = The absolute airmass.

Sunphotometer does not measure absolute irradiance but a reading proportional to 'Iλ'.Ioλ is the meter reading at airmass 'O' Values of TRλ and Toλ obtained from literature are as follows:

Wavelength (nm)	368	500	675	778
Tr	0.4945	0.1391	0.0410	0.0231
To	0	0.0114	0.0144	0

Also,

$$m=\frac{1}{\mathrm{Sin}h+0.15\,(h-3.885)^{-1.253}} \qquad ....(2)$$

where h = solar elevation in degree &

$\sin h = \sin L . \sin S + \cos L . \cos S . \cos t$ ... (3)

where L = Latitude of the place

S = Declination of the Sun

t = true solar time = (local time - local noon) x 15°

From equation (1) $Tm\lambda$ can be calculated as follows:

$Tm\lambda, = 1/m \; In \; Io\lambda / I\lambda - (To\lambda, + T_R\lambda)$ ... (4)

'λ' should be such that no absorption takes place by CO2 and water vapours

For practical determination of Tm , the following equation is more useful than that of (4).

$$Tm\lambda = \frac{In \; (En \; \lambda / E\lambda S)}{m} - (P/Po \;\; T_R\lambda \; + \; T_O\lambda)$$

where

$Eo\lambda$, = Calibration factor

$E\lambda$ = Meter reading

P = The station pressure

Po = The standard pressure at sea level viz. 1013.2 mb

S = Correction factor for mean Sun - Earth distance (provided with instrument)

The value of Eoλ is provided with the instrument but it is liable to change with time. It was recalibrated in Antarctica as well as later in N.P.L. The results are as follows:-

Wavelength	Calibration factors		Available with the instrument
	At NPL	At Antarctica	
368 nm	0.016	0.032	0.128
500 nm	0.35	0.40	0.533
675 nm	0.11	0.13	1.054
778 nm	0.59	0.70	0.637

Values at NPL and Antarctica are slightly different on account of haze present over Delhi at the time and also because of vast temperature difference at the two places.

Angstrom's wavelength exponent 'α' is related to aerosol size distribution. 'α' can be calculated from extinction coefficients for any pair of filters :

$$\alpha = (\mathrm{In}\ \ Tm\lambda_1/Tm\lambda_2)\ \ /\ \ \mathrm{In}\ \ \lambda_2/\lambda_1 \qquad \ldots\ (6)$$

27 sunny days for sunphotometric measurements were available during summer of XI Indian expedition to Antarctica. The measurements have been used to calculate extinction coefficients Tmλ for all the four wavelengths. Six possible 'α' values havebeen calculated at different times of day for different values of m.The general trend In 'α' values has been found as:

$$\alpha 12 > \alpha 13 > \alpha 14 > \alpha 23 > \alpha 24 > \alpha 34$$

Diurnal variations of Tmλ vs local time have been plotted for a number of days and shown in Fig 2. The minimum and maximum values of Tmλ are found as:

Wavelength (nm)	Min. Tm λ	Max.Tm λ
368	0.2883	1.06
500	0.1984	0.9407
675	0.1062	1.03
778	0.1544	1.06

In contrast, during the VI expedition, Tm 368 values varied from 0.04 to 0.16 and for higher wavelengths the atmosphere was clear over Antarctica.

(b) UV - B Sunphotometer measurements were taken for 23 sunny days at Maitri, Antarctica. UV - B energies were calculated from the output in millivolts by multiplying by calibration factors. Calculations were made for estimation of O_3 using the modified expression:

$$I\lambda = Io\lambda\, e^{-(Tm\lambda + TR\lambda + Bx)m} \qquad \ldots(7)$$

which gives

$$x = I/B\lambda\ (1/m\ \mathrm{in}\ \ Io\lambda/I\lambda\ - Tm\lambda - T_R\lambda) \qquad \ldots \qquad (8)$$

Here.

Iλ = measured energies

Ioλ = energies at the top of atmosphere
$60.74 \times 10^6 w/cm^2$at310nm
(Ref. Table B - 5. The Stratosphere,1981)

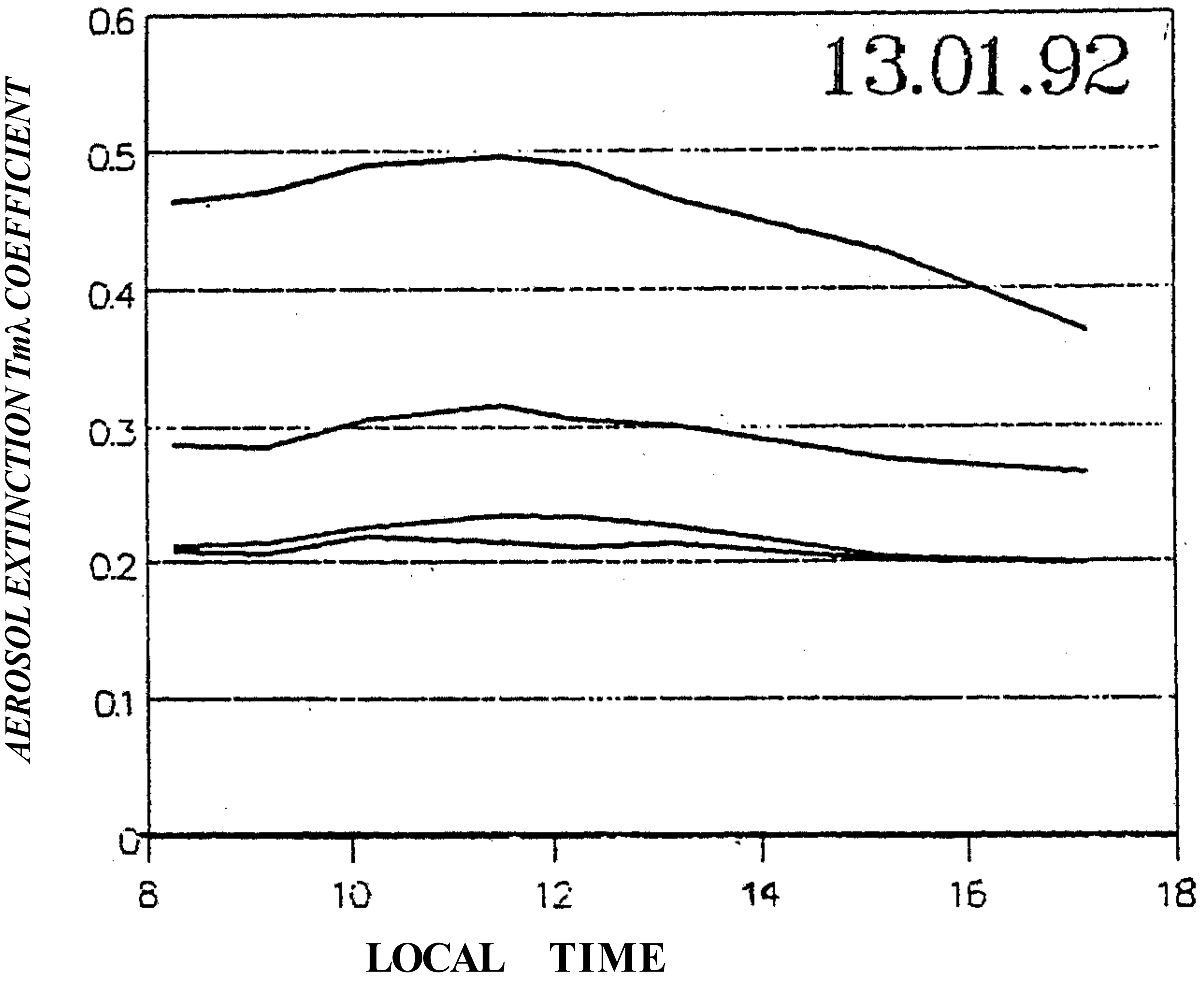

Fig 2 : Diurnal variation of Tmλ at Maitri, Antarctica.

B = 3.82 (M.C.Sharma et al.,1986)

TR310= 1.0614

h = 30° (Required for calculation of m)

x = total ozone values

Tm 310 can be calculated using equation (6) and Tm 368 values.

The results are shown as follows (Table 1)

Diurnal variations and seasonal variations are shown in Figs. 3 & 4.

(c) Spectroradiometric measurements were recorded manually because of the failure of the computer part. The intensity of solar irradiance at a particular wavelength is indicated in terms of voltage at the screen. Then, as per instrument literature :

I = K(10-(v+5)-10-11)

where

V = output at the screen of electronic unit

Kλ = calibration constants as follow:

Table I

Date	Time (hrs)	Tm368	Tm310	I310	X	
					(x 10^{-8})	(atm-cm)
30.1.92	1451	0.3811	1.634	0.6398	13.1	0.3582
31.1.92	1500	0.3781	1.679	0.5043	15.8	0.3692
01.2.92	0805	0.4505	2.020	0.6370	223	0.2890
03.2.92	1400	0.4679	2.280	0.6918	16.0	0.3187
05.2.92	1415	0.4544	1.995	0.6398	638	0.4523
07.2.92	1415	0.4490	2092	0.6428	11.1	0.3792
08.2.92	1400	0.3942	1.922	0.5481	143	03709
12.2.92	0905	0.4343	1.553	0.5668	*15.3*	0.3571

λnm	Kλ
280	2.450 X10^3
285	2.396 X 10^3
290	2.354 x 10^3
295	2.365 x 10^3
300	2.308 x10^3
305	2.470 x10^3
310	2.712 x10^3
315	2.951 x10^3
320	3.999 x 10^3
368	3.305 x10^3

Calculations for all the Iλ values have been made. Data forλ = 310 nm have been used for estimation of O3 as in the previous case. Results are shown in Table II.Ozone values in February'92 are normal but January'92 values are quite low (to be explained).

(d) Infrared sunphotometric observations were recorded on sunny days to study qualitative and quantitative presence of H2O, CO2, O3, CO, CH4,N2O etc. in the atmosphere. A typical run is shown in Fig 5.

As indicated, the water vapour absorption bands and CO$_2$ absorption bands dominate the spectrum in 2.5 to 4.5 pm range. In this range the absorptions of CO2, H20f CH4, N2O overlap each other. 2.7 μm is a moderately strong absorption band of H$_2$0. If we observe the spectra at New Delhi, it shows

Table II

Day Number	O3 (=310)
4	0.140(Atm-cm)
5	0.104
6	0.113
7	0.132
8	0.123
9	0.118
10	0.113
11	0.156
12	0.124
13	0.121
14	0.127
17	0.123
20	0.130
24	0.108
31	0.324
33	0.341
34	0.382
35	0.373
36	0.355
37	0.344
38	0.330
39	0.321
43	0.321

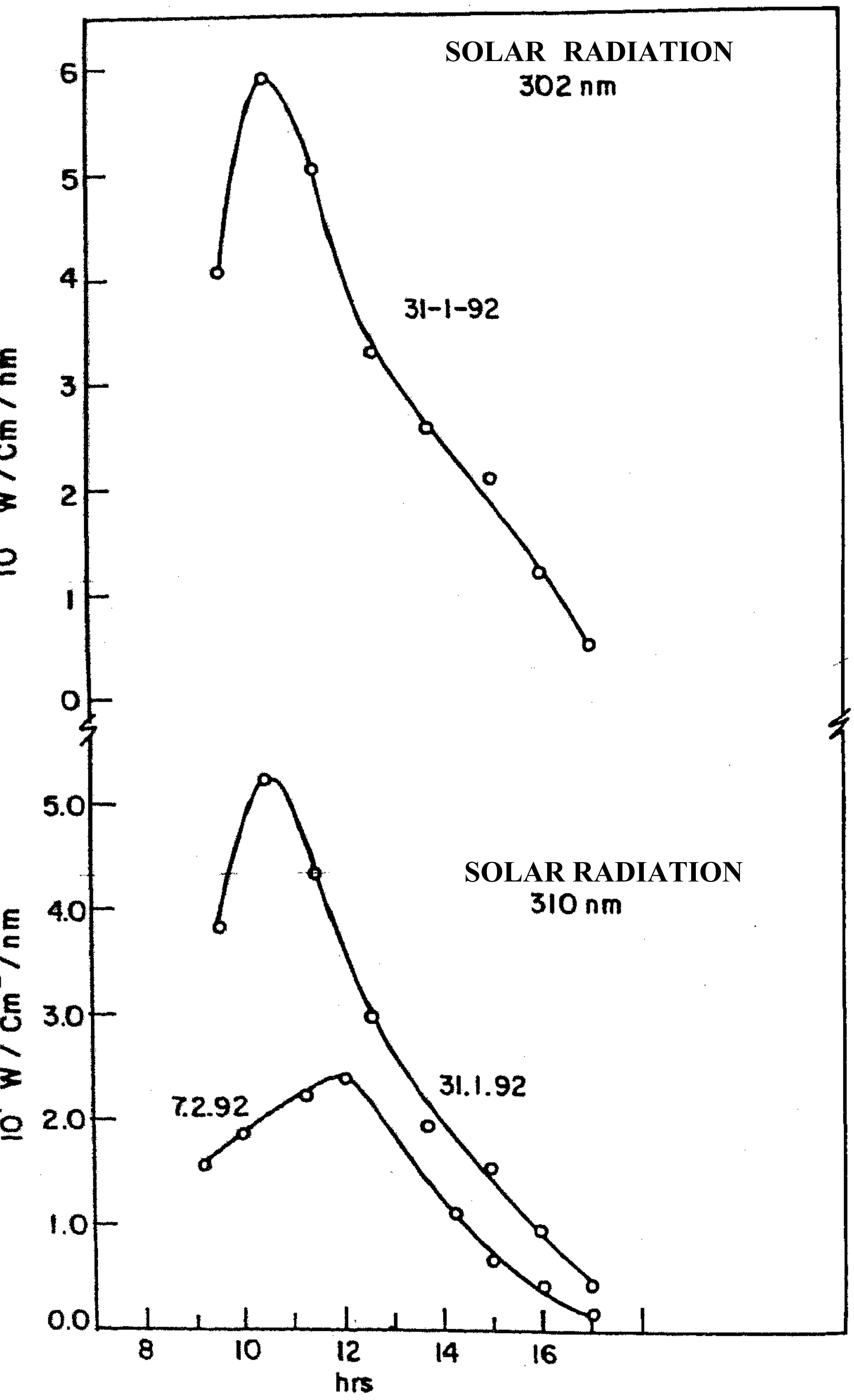

Fig 3 : Diurnal variation of solar irradiance at Maitri, Antarctica.

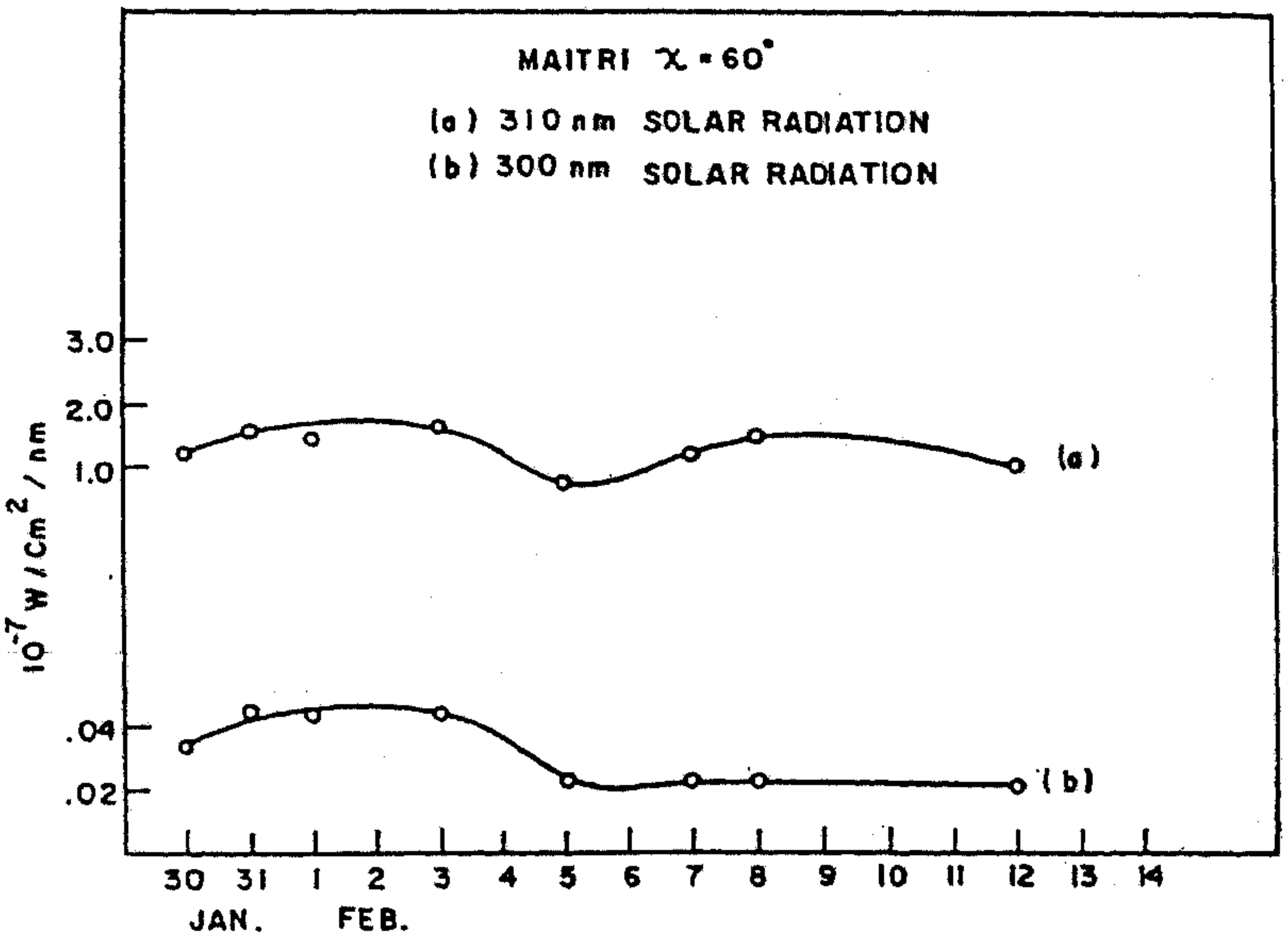

Fig 4 : Seasonal variation of solar irradiance at Maitri, Antarctica during austral summer of 1991-92.

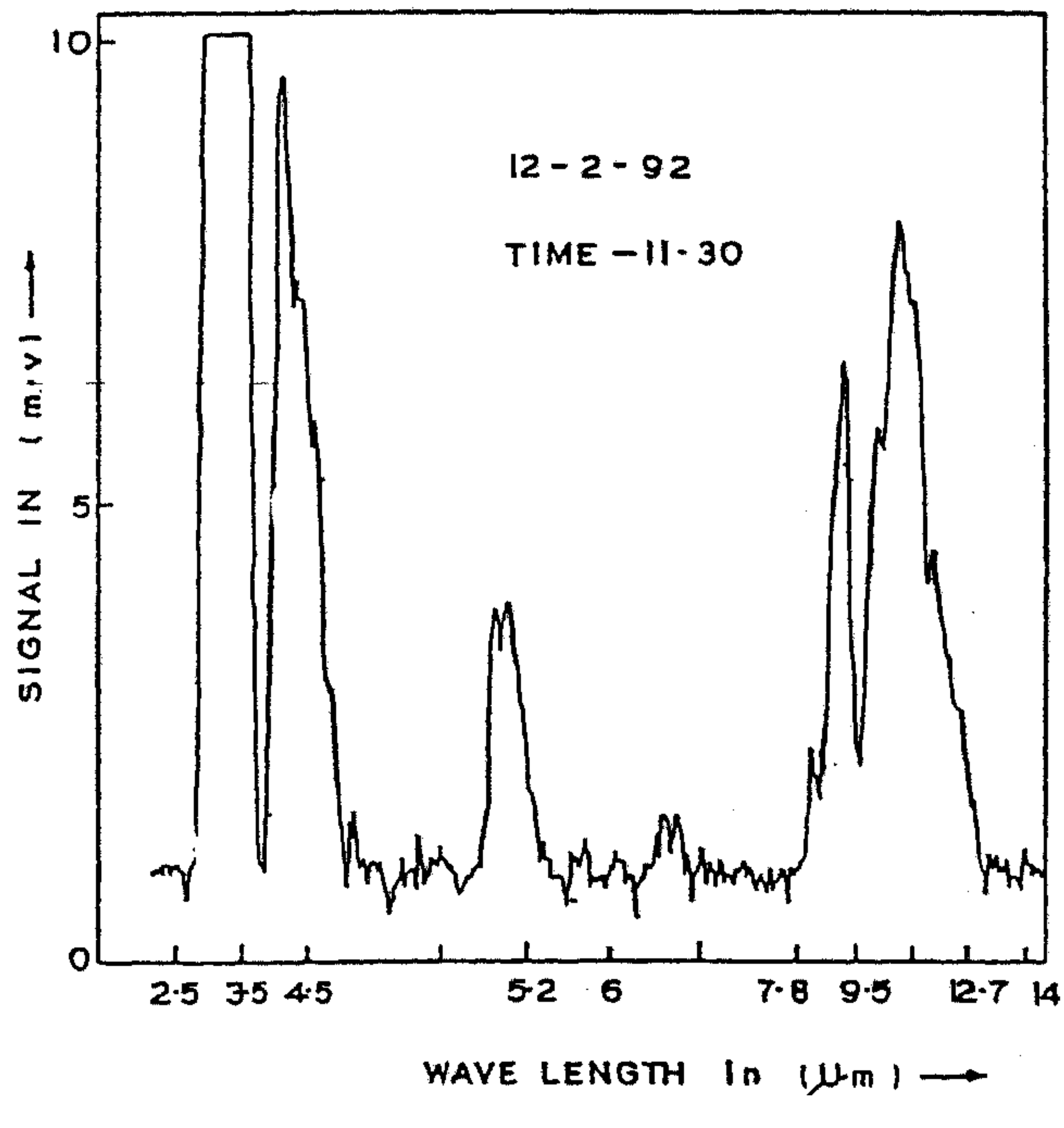

Fig 5: Infrared absorption (2.5 - 14.5 μm) spectra recorded at Antarctica.

signature of water vapour absorption but the absorption signature of 2.7μm is *absent in Antarctica* which shows low water vapour content of Antarctic atmosphere.

Also in Fig 5, 9,6μm ozone band is clearly seen. While comparing with New Delhi record, it shows more optical depth of ozone at Antarctica. This supports the early observations that at poles ozone concentration is more than at lower latitudes.

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The Stratosphere(1981), theory and measurments Table B5.