Fourteenth Indian Expedition to Antarctica, Scientific Report, 1998
Department of Ocean Development, Technical Publication No. 12, pp 15-23

Observation of Ozone Over Antarctica during 1995 Using Ground-based mm-wave Radiospectrometry

V.C. NAGAR[1] and R.S. ARORA

Radio and Atmospheric Science Division
National Physical Laboratory
New Delhi-110012, India

Abstract

During the year 1995 a ground-based millimetre-wave radiometer system was operated at the Indian Station (Maitri) Antarctica from February to December for study of polar stratospheric ozone. The observations were made at 101.7 GHz strong rotational transition line of ozone. The monthly spectra obtained during this period are presented here. A diminished spectral intensity is observed during the period Sept-Oct when ozone in the stratosphere undergoes rapid seasonal variations.

1. Introduction

Stratospheric ozone is known, to be vital to the earth's biosphere since it prevents lethal solar ultraviolet radiations from reaching to the surface of earth and hence makes life, as we know it, possible on earth. Ozone also plays a key role in governing the atmospheric thermal structure by absorbing solar radiations and exchanging long-wave radiations with surface-troposphere systems. Furthermore, variations of ozone are closely related to atmospheric circulation and chemistry, which makes it a key chemical component in stratospheric research. The atmospheric ozone layer is quite sparse and has a maximum fractional concentration of ~10 parts per million by volume (ppmv) in stratosphere. The total column content of ozone if compressed at STP gives a layer of about 3 millimetres in thickness (300 Dobson units).

Polar stratospheric ozone is particularly interesting for several reasons. It undergoes rapid seasonal variations called "ozone hole" during spring over Antarctica. During this period 50% or more ozone is destroyed by some chemicals which are now believed to be anthropogenic in origin. It has also been noted that ozone hole contributes to a general world-wide decrease in O3

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[1] *Present Address:* Physics Department, State University of New York, Stony Brook, NY 11794, USA

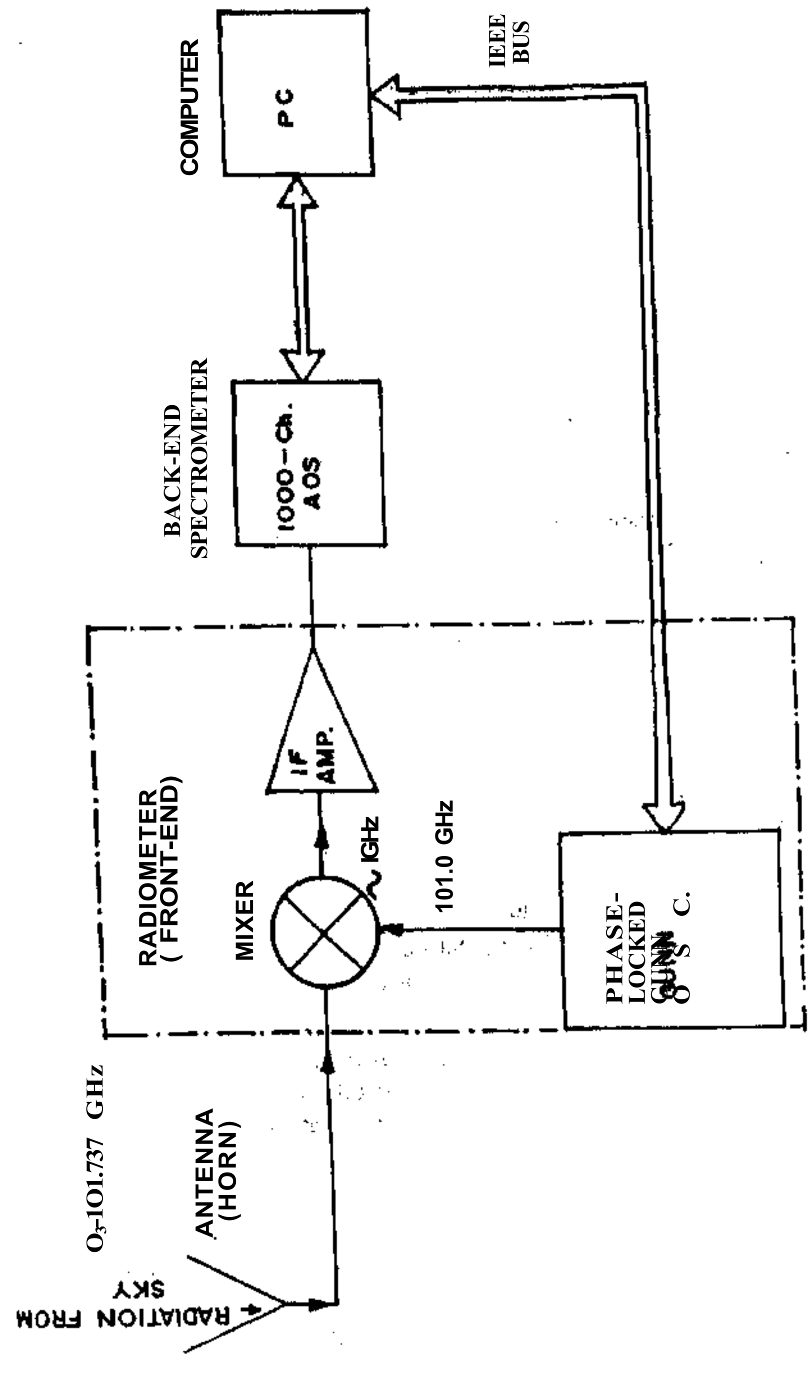

Fig.1: Simplified block diagram of the millimetre-wave ozone radiospectrometer

[1] The polar stratosphere has thus been proved to be an important region in studying the middle atmosphere with respect to climate and global change

Polar stratospheric O3, especially at Antarctica has been studied by a variety of techniques, including *in situ,* ground-based and satellite borne, for over a decade now since the discovery of "ozone hole" by Farman *et al*, 1985 [2] These observations together with simulation studies based on theoretical models have contributed significantly to our understanding of ozone's behaviour a polar stratosphere However, most polar observational studies are done on a short time duration and few attempts have been made to study the vertical distribution of Antarctic ozone over an annual cycle

During the course of present study a ground-based millimetre-wave radrospectrometer was operated year-round 1995 for observation of atmospheric ozone and atmospheric opacity at the Indian Research Station (Maitri) at Antarctica

2.101.7 GHz Radiometer System

A simplified block diagram of ozone radiospectrometer is shown in Fig 1 The incoming ozone signal at 101 737 GHz (corresponding to $4_{0},4 - 41,_{3}$ transition) is received by a 6" lens corrected horn antenna and passed on to a low noise mm-wave balanced mixer for frequency down-conversion In order to preserve the exact pressure broadened line shape of the ozone signal, this down conversion is accomplished through a highly stable 101 GH / phase-locked Gunn oscillator which is used as the pump source The frequency stability of the phase-locked Gunn oscillator was typically two parts per million per day The 500-1000 MHz intermediate frequency (IF) signal thus produced is amplified in a low noise high gain amplifier and passed on to the acousto-optic spectrometer(AOS) A back-end computer, which is interfaced with AOS, then receives and stores the digitised signals for further processing Details of the instrument design can be found in [3]

3. Calibration and Observation

Calibration of the system was done by measuring the response of the system to known thermal noise input signals This process derives the system noise temperature and also provides a relation between the power received at the input and the measured output voltage For the purpose of this calibration a millimetre wave blackbody "Eccosorb" (carbon loaded foam) was kept feeling the beam of the antenna at two known constant temperatures These two reference temperatures were chosen to be the room temperature and the liquid Nitrogen boiling point temperature (77 K) The load was roughened by a quarter wavelength at the observing frequency to avoid the development of standing waves between the instrument and the load. The output power levels were determined and their ratio was calculated. If this ratio be ' R' then the system temperature can be calculated using the following formula [4,5]:

$$T_{sys} = \frac{T_{amb}-T_{cold}}{R-1} - T_{cold} \qquad ...(1)$$

where

$Tamb$ = ambient or room temperature

$T\ cold$ = liquid nitrogen temperature

The system temperature (DSB) thus evaluated gives a value of 1300 K for our system.

The instrument was installed at the Indian research station Maitri (70°45'S, 11°45'E) at Antarctica in February 1995. Since the proper working of the instrument critically depends on the ambient temperature, the entire system was placed inside a thermally insulated hut in which an ambient temperature of 25±2°C was constantly maintained by means of three hot air blowers. The horn antenna was made to point at the sky from inside the hut through a 1' x 2' teflon window whose absorption was found to be negligible at mm-wavelengths. An elevation angle of about 23 ° was selected as a compromise between maximizing the intensity of the received ozone signal which requires lower elevation angles and minimizing ground radiation pick-ups requiring high elevation angles.

The observations were carried out at two local oscillator frequencies: one when the output band was centred at the main ozone line (ON-frequency) and the other about 80 MHz away (OFF-frequency). The best switching rate was also empirically found by having different time periods for data integration. It was found that about 100 scans from the AOS at ON-frequency and subsequent 100 scans at OFF-frequency could be integrated in a block without any gain variation problem. This operation also helps in removing the instrumental effects due to radiometer gain variations during the course of observation. The on-line and off-line data were stored separately in the hard disk of the computer and accumulated in 30 minute blocks to improve the signal-to-noise ratio. In order to extract the ozone line signal out of the system noise (consisting mainly of Johnson noise and shot noise from radiometer electronic components as well as contributions due to tropospheric emission) following arithmetic operation was performed in the computer:

$$\frac{Pon - Poff}{Poff} \qquad ...(2)$$

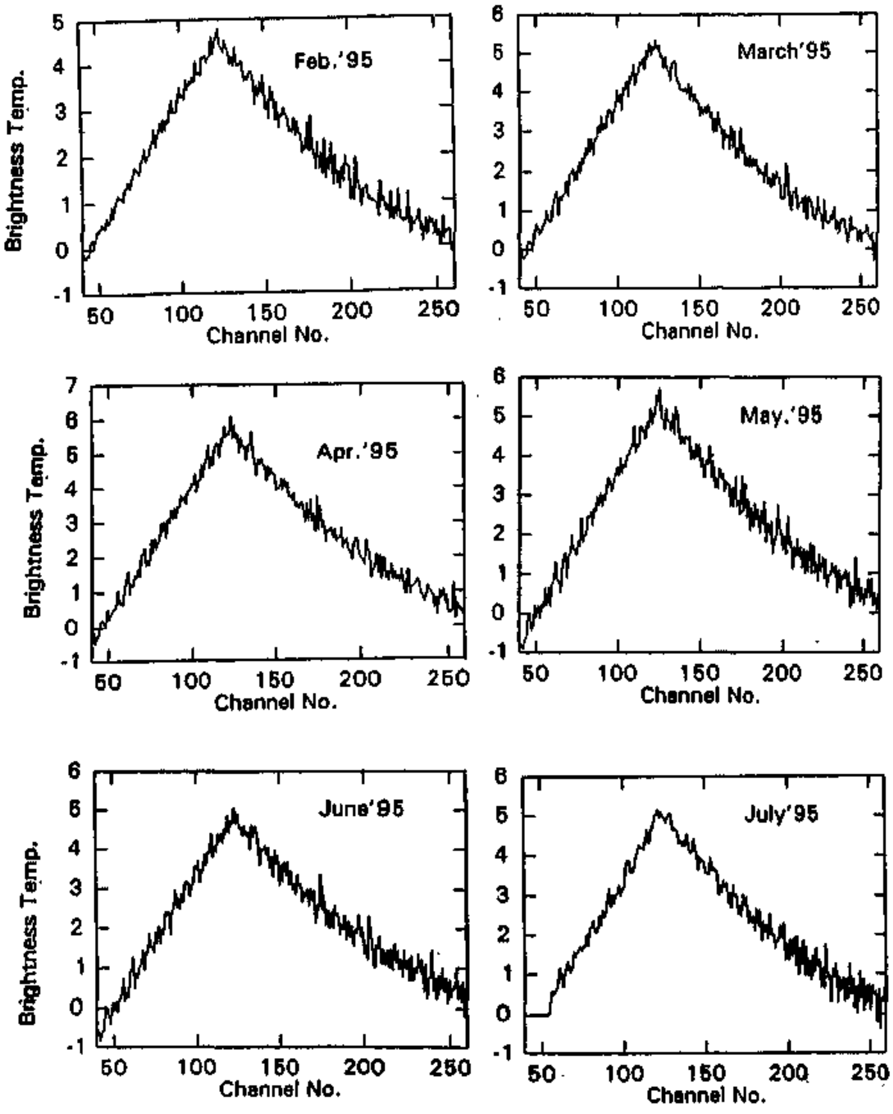

Fig. 2—(Contd.)

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Fig. 2—*(Contd.)*

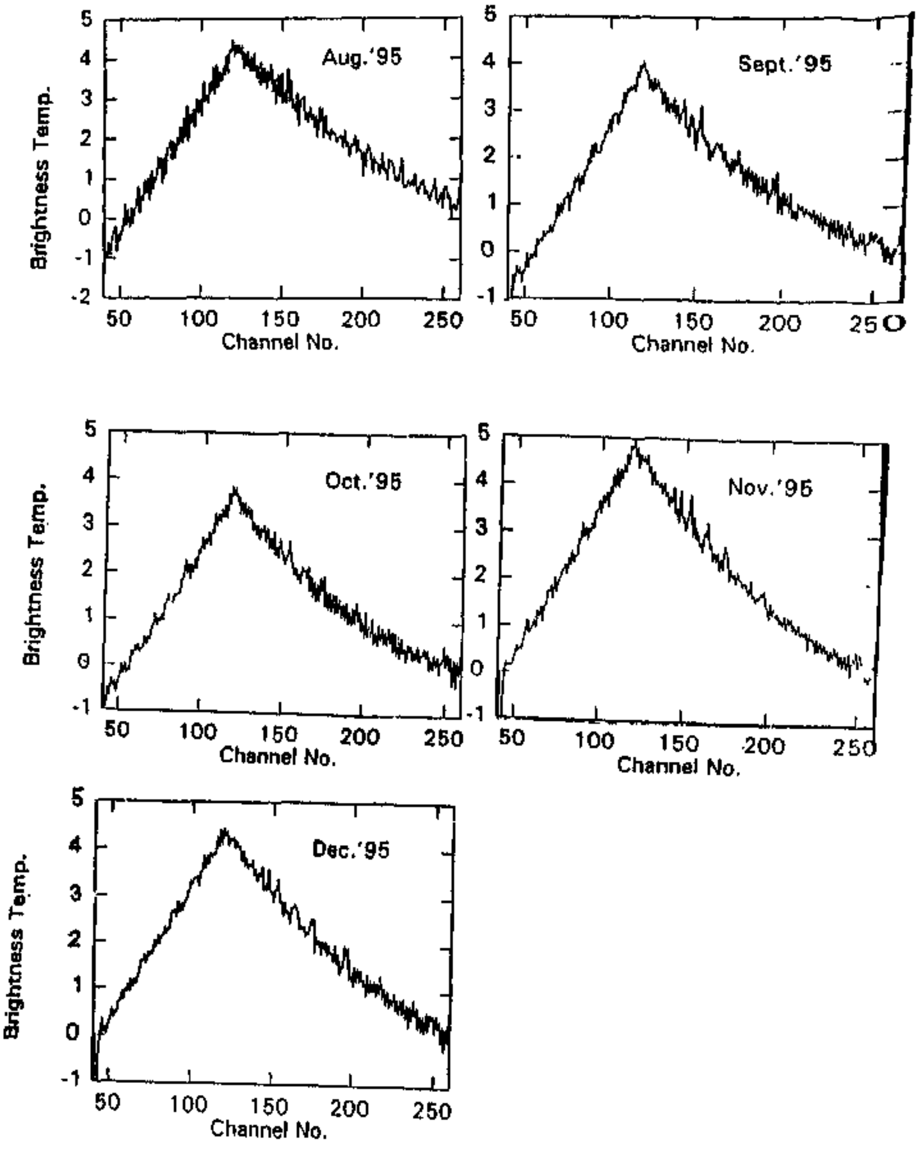

Fig. 2: Ozone line spectra at 101.737 GHz integrated for different months of year 1995, Maitri, Antarctica

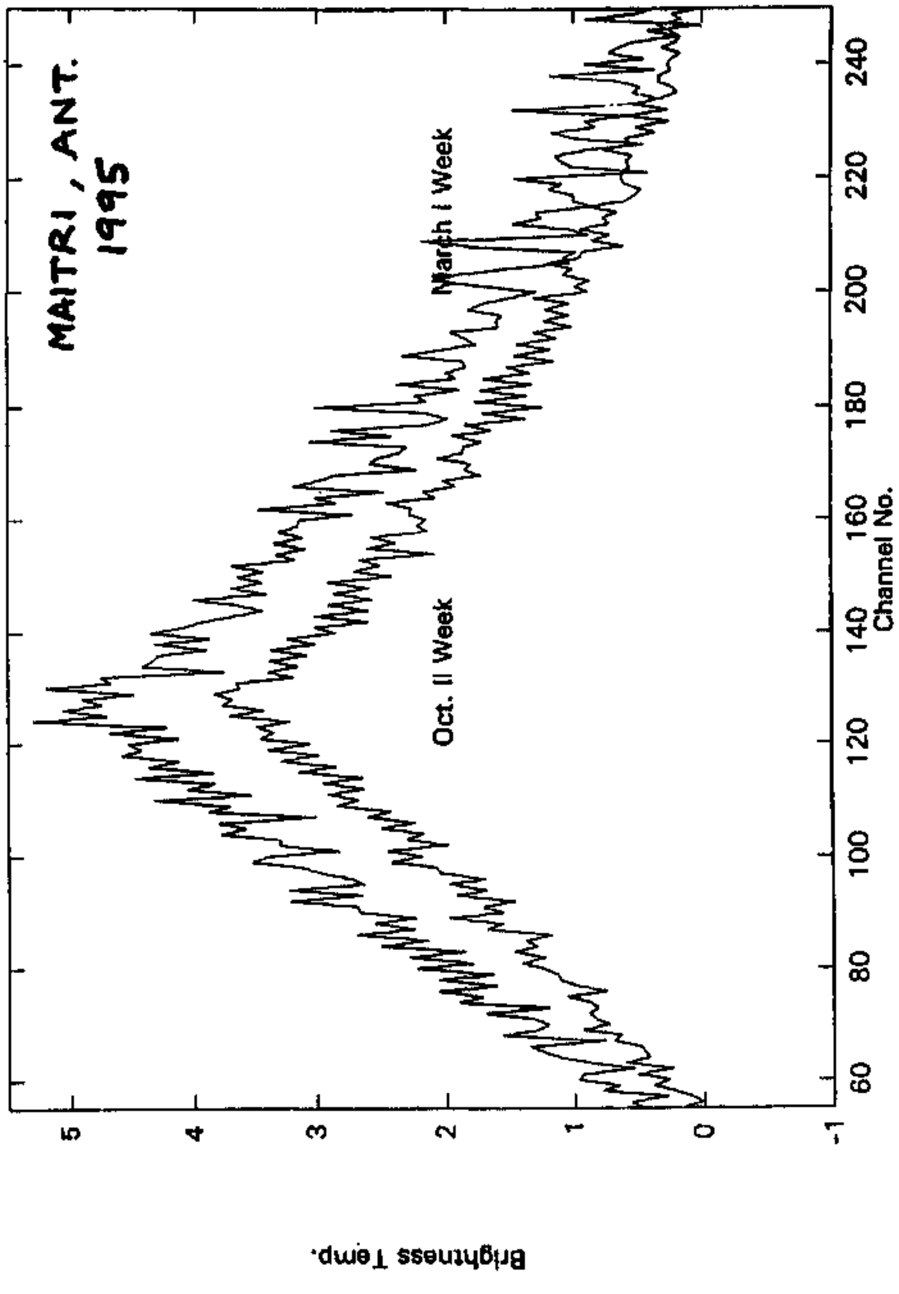

Fig.3: Comparison of two weekly spectra taken from March and October observations

where

P_{on} = Power received by the radiometer at on-line frequency

$Poff$ = Power received by the radiometer at off-line frequency

This operation helps inremoving the instrumental effects due to radiometer gain variations during the course of observations. In addition, a second order polynomial baseline had to be subtracted from the data to remove the effect of varying frequency response of the radiometer at the on-line and off-line frequencies. This data is then corrected for the effect of tropospheric absorption which is determined separately by comparing the radiometer output from the sky against that obtained by placing a microwave absorber in front of the horn antenna. Typical values of tropospheric absorption were between 0.2 to 0.5 dB. In addition to the usual system noise some instrumental artefacts due to the non linearities of the system are also seen, which set an upper limit to the signal to noise ratio achievable in our system. The asymmetry of the observed line spectrum is a consequence of the frequency switched mode of operation. During every observation period the total power output of the system was separately monitored on a panel meter and the data were rejected if the output changed abruptly. This change was mainly caused by erratic receiver performance. This occurred when the phase lock of the 101 GHz Gunn oscillator system got disturbed.

4. Monthly Ozone Spectra

The ozone spectra integrated for different months of year 1995 are shown in Fig.2. Each channel represents 0.5 MHz frequency width. As can be seen from here a change of about 1 Kelvin in brightness temperature is obtained during October compared to March spectra. This shows a definite decrease in ozone during spring season. This change is more clearly shown up in Fig.3 where weekly data is compared from these two months. A quantitative change can only be obtained after proper analysis of data. This, however, is found to be difficult due to poor signal to noise ratio on integrated spectra and limited bandwidth constraint. Some model fitting techniques [6] were tried in a least square sense but they were not found to be working during crucial "hole" period when a-priori information about profile shape is unreliable.

Acknowledgements

This project was funded by the Deptt. of Ocean Development (DOD), Govt. of India and we gratefully acknowledge the help and support of various officials of this Department, especially, Prof. V.K. Gour, former Secretary, DOD.

We thank Dr S.D. Sharma, Leader 14th IAE, and all the members of 12th wintering-over team for providing help and cooperation for successful running of instrument at Antarctica.

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