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Millimeter-Wave Ozone Radiospectrometer Experiment at Maitri, Antarctica

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Abstract

Ground based millimeter-wave observations of atmospheric ozone at the Indian station Maitri in Antarctica are described. They involve observation of strong emission line of ozone at 101.737 GHz and inversion of the observed line data to obtain ozone height distribution. The instrument was successfully installed during the 13th Indian Antarctic Expedition and preliminary ozone observations carried out during Jan-Feb, 1994.

Introduction

Ozone, a trace constituent of our atmosphere, is found in various abundances from ground level to the upper reaches of the mesosphere with a peak in the stratosphere. Though a minor constituent, it's importance lies in the fact that it absorbs the harmful part of the solar ultraviolet radiation, which would otherwise reach the surface of earth and harm biological life. The discovery by the British Antarctica Survey team at Halley Bay of the so called Ozone hole in Antarctica [1] and the suspected decrease of total global ozone content over the last two decades has intensified ozone research around the world. However, the exact mechanism of ozone depletion is still not fully understood. It is, therefore, important to understand implications of the Antarctic ozone hole for global stratospheric ozone.

Ozone has been regularly monitored for the past several decades by a global network of Dobson -spectrophotometers which measure the total ozone content of the atmosphere by monitoring the absorption of solar ultraviolet radiation at selected wavelengths. Insitu measurements of ozone have also been carried out by ozonesondes placed on rockets and balloons. More recently, ozone has been monitored on a global basis by means of total ozone mapping spectrometers (TOMS) as well as solar back-scatter ultraviolet spectrometers (SBUV) carried on satellites. Most of these methods, however, require the sun as the background source of radiation and consequently are limited to only day time observations in good weather conditions. It is in this context that the mm-wave technique of ozone measurement offers several unique advantages.

The millimeter (mm) wave technique involves observation of isolated emission lines of ozone which fall in the mm-wave band of the electromagnetic spectrum and inverting the observed line data to obtain ozone height distribution [2] . Since this is an emission measurement ozone can be observed continuously during both day and night, a feature most suited to Antarctic observations during polar nights. Moreover, mm-waves are least affected by clouds, dust or aerosols giving it an all weather capability. Most importantly, absolute calibration of intensity of the received mm-wave signal can be carried out by means of microwave absorbers at known temperatures. This minimizes the possibility of calibration error caused by instrumental drift over a long period of time . We report here on the development of a mm-wave ozone radiospectrometer which was successfully tested at Antarctica during Jan.-Feb., 1994 as part of the 13th Indian Antarctic Expedition.

System Description

A simplified block diagram of ozone radiospectrometer is shown in Fig. 1. The incoming ozone signal at 101.737 GHz (corresponding to 40,4 ~» $4_{1,3}$ 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 Ghz phase-locked Gunn oscillator which is used as the pump source. The 500-1000 MHz intermediate frequency (IF) signal thus produced is amplified in a low- noise high gain amplifier and passed on to the back-end spectrometer.

The back-end spectrometer, which produces the power spectrum of the input signal is a 500 MHz bandwidth, 1000-channel acoustic optic device. The IF signal from the front-end radiometer is coupled to a Bragg cell inside the spectrometer through a piezoelectric transducer. This, in turn, produces ultrasonic waves in the cell which is then used as a traveling wave grating to deflect a laser beam of light. The angle of deflection of this laser beam is proportional to the frequency of incoming signal while its intensity is proportional to its input power. Thus, the incoming power spectrum is effectively transformed into a one- dimensional spatial distribution of light, which is then sampled by a linear 1024 element charge coupled device (CCD).

The output of the CCD array is digitized and fed into a 80386 based personal computer (pc) which stores the data on it's hard disk. The PC also serves as the system controller for frequency switching of the phase locked

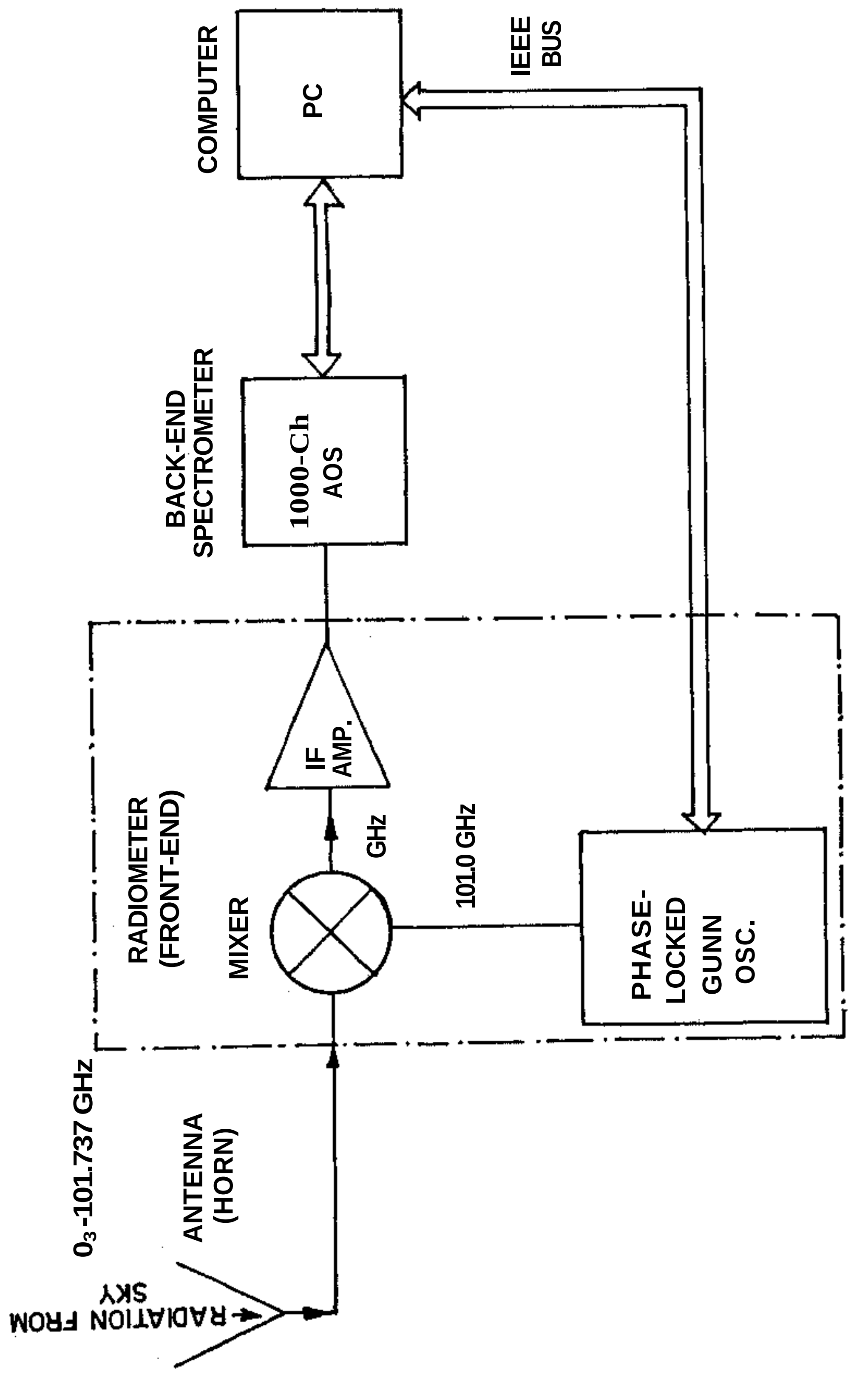

Fig 1: Simplified block diagram of the millimeter- wave ozone radiospectrometer

Gunn oscillator as well as for all other data acquisition and calibration sequences required during observations. A photograph of the system installed at the Indian Research Station Maitri in Antarctica is shown in Fig.2.

The system is calibrated by showing microwave absorbing loads at two known temperatures, i.e., room temperature and liquid nitrogen temperature which are placed in front of the horn antenna during the calibration sequence. The system noise temperature, determined at Antarctica just after the installation of Jan. 1994, gave a value of about 1350 KDSB (double side band).

Ozone Observations at Antarctica

The instrument was installed at the Indian Station Maitri (70°45'S, 11°45'E) in Jan. 1994. 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° was constantly maintained by means of two 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 taken into account by showing calibration loads from outside the teflon window. An elevation angle of about 30° was selected as the best compromise between maximizing the intensity of the received ozone signal which requires lower elevation angles and minimizing ground scatter pick-up requiring high elevation angles.

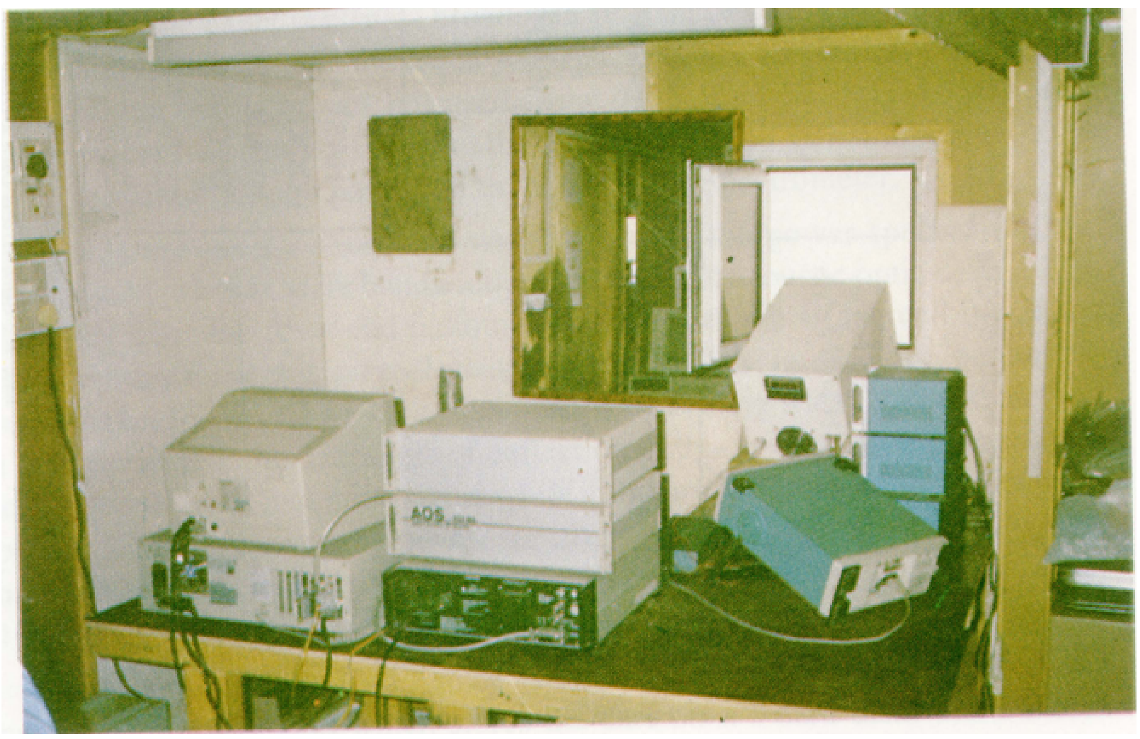

Fig. 2: Photograph of the millimeter- wave system installed at Maitri, Antarctica

All observations were made in the frequency switched mode.The frequency of the mm-wave radiometer was alternately switched between the ozone on-line frequency (101.737 GHz) and an off-line frequency about 75 MHz away. This was done by switching the frequency of the phase.locked Gunn oscillator every 6 seconds under computer control. 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), the following arithmetic operation is performed in the computer for each 30 minute block of data.

$$\text{Output} \quad \frac{P_{on} - P_{off}}{P_{off}} \qquad (1)$$

where

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

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

This operation also helps in removing the instrumental effects due to radiometer gain variations during the course of observation. 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. Eqn. (1) has to be multiplied by the system noise temperature to obtain the observed line strength of ozone. This is then corrected for the effect of tropospheric absorption which is determined separately by placing a microwave absorber in front of the horn antenna. Average ozone line signal obtained through such an observation procedure for the month of Jan. 1994 is shown in Fig.(3). In addition to the usual system noise, some instrumental artifacts are also seen, whiph 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.

Retrieval of Ozone Height Profiles

Ozone line was observed at Antarctica for a total of 21 days in the months of January & February 1994 and the power spectra stored in the hard disk of the computer as discussed in the previous section. In order to obtain the height profile of Ozone from these spectral measurements, we need to model the ozone distribution and derive a theoretical ozone line spectrum using radiative transfer. This is relatively simple at mm-wavelengths since we are in the Rayleigh-Jeans limit where all powers can be expressed in terms of brightness temperatures. This leads to simple additive terms to obtain total radiate

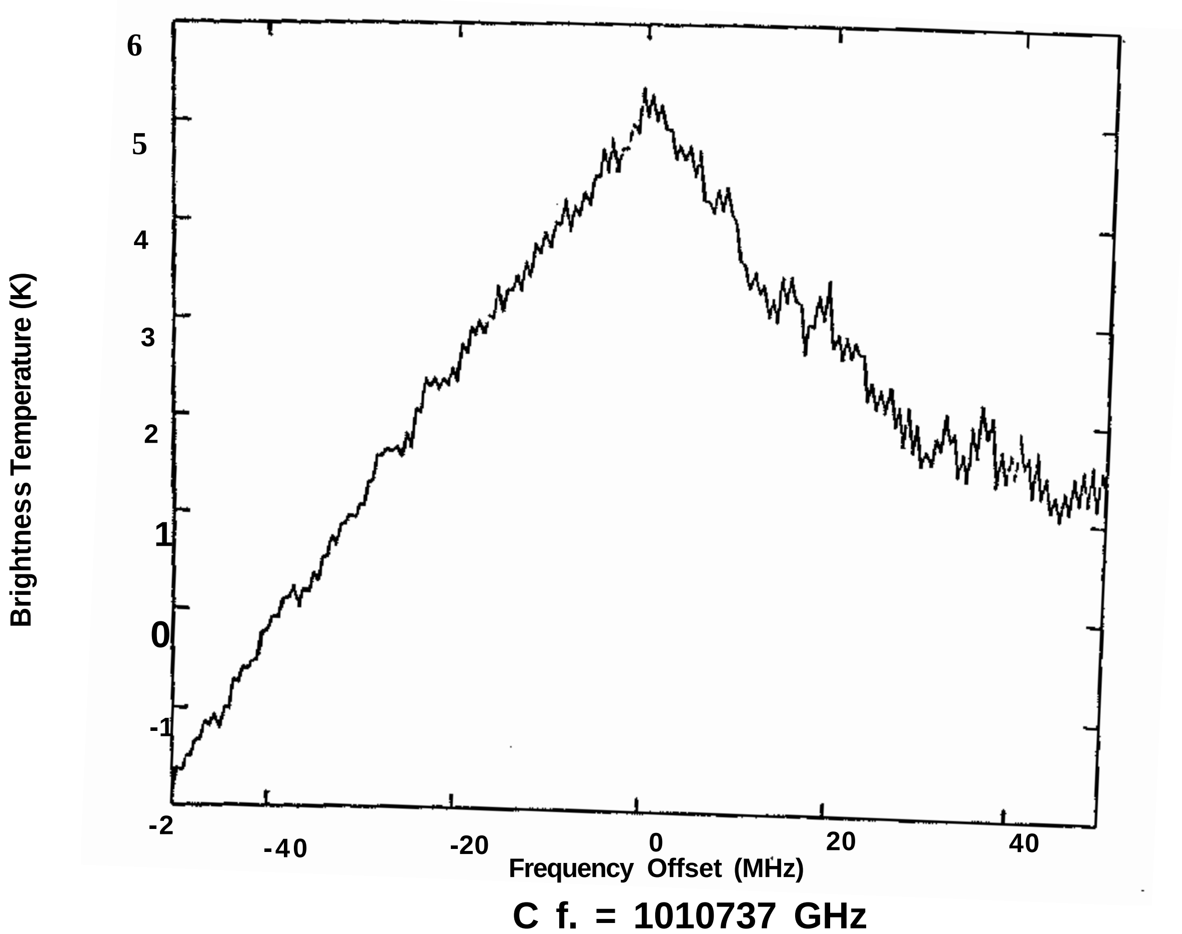

Fig. 3: Average Ozone line spectrum at 101.737 GHz observed at Maitri, Antarctica in Jan. 1994. This spectrum is obtained by combining data taken over 15 days for a total integration time of about 4 hours

from ozone molecules which are assumed to be in local thermodynamic equilibrium (LTE). Moreover, mm-wave ozone lines are mainly pressure - broadened, at least up to a height of 75 km, which further simplifies the radiative transfer.

Although there are several ways in which height profile can be retrieved from ozone spectral line data, we adopt the approach outlined in Vivekanand & Arora [3] for it's simplicity. In this approach, ozone height distribution is modeled as:

$$D(h) = 4Dmax \frac{\exp(r(h-hmax))}{[1+\exp(r(h-hmax))]2} \quad (2)$$

Where D(max) is the peak ozone density in molecules per cubic centimeter, h(max) is the altitude of the peak density in Kilometers and r is a shape factor in units of $(\text{Kilometer})^{-1}$. With this model, we calculate the ozone absorption coefficient k(v,h) using the following formula

$$k(v,h) \quad \frac{1.7x10\text{-}24D(h)2vf(v,h)exp[\sim 25.3/T(h)]}{T(h)5/2} \quad Km\text{-}1 \tag{3}$$

where T(h) is the temperature height profile and f(v.h) is the line shape function of ozone at various heights. A theoretical ozone line spectrum is then obtained using the following Eqn.

$$T(B)(v) = \int_0^{\infty} k(v,h)e^{-\int_0^h k(v,h')dh'}T(h)dh \tag{4}$$

A computer algorithm with necessary auxiliary data like temperature and pressure as a function of height and other line parameters for the particular ozone line is used for the purpose. The theoretical ozone line spectrum thus obtained is compared with the observed data for best fit in a least square sense. Ozone height profile using such a procedure for the observations of Jan. 1994 is shown in Fig.4. Plotted on the same figure is the balloon ozone sonde data

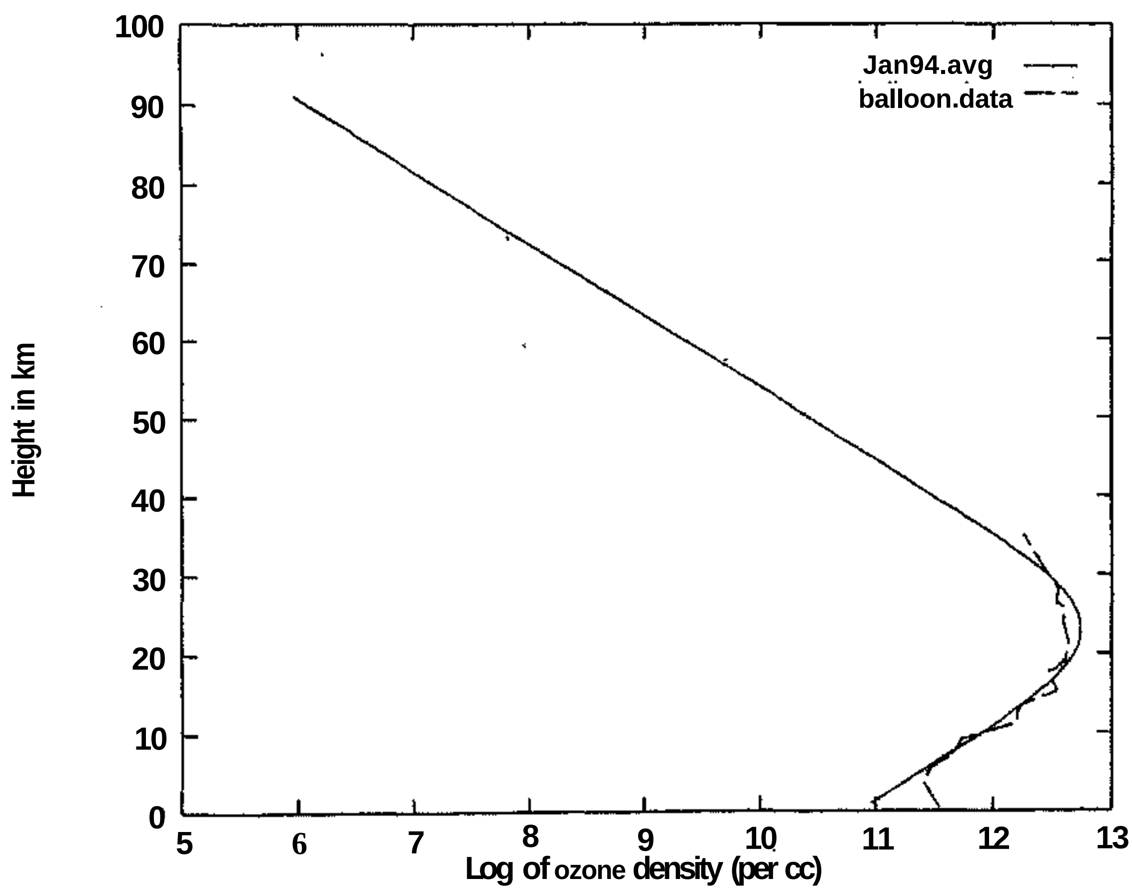

Fig. 4: Ozone height profiles obtained by the mm- wave technique and balloon ozonesonde at Maitri, Antarctica in Jan. 1994. The millimeter-wave ozone height profile is obtained by inverting the average line spectrum shown in Fig. 3

also taken in January by the India Meteorological Department (IMD) [4]. There seems to be good agreement in the overlapping height range for which the balloon data is available.

Concluding Remarks

We have successfully used a ground-based mm-wave technique for preliminary ozone observations at Antarctica. It was found that the observations could be continued even on cloudy days and during blizzards when most other techniques were rendered ineffective. The accuracy of the ozone height profile obtained through this technique can, however, be determined by a long-term comparison with other techniques, e.g., balloon ozone sonde, currently being used in Antarctica.

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