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Laser heterodyne system at Maitri, Antarctica

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Abstract

The ozone depletion in general and ozone hole phenomenon over Antarctica during spring in particular has generated a surge of interest in the measurement of ozone using various techniques. A High-Tech Laser Heterodyne System using a 1 GHz Acousto-optic spectrometer as back end has been designed and developed at National Physical Laboratory, New Delhi to monitor ozone and other trace species in the atmosphere. The Laser Heterodyne System has been successfully operated at Maitri (70°46'S, 11°44'E) an Indian Antarctic station during 1996-98 Lo obtain ozone line spectra at 1043.1775 cm with an ultra high spectral resolution. The line spectra thus obtained with high spectral resolution in trun has been used to get vertical profiles of ozone in the atmosphere using inversion technique developed at NPL for Antarctic conditions. A liquid nitrogen plant was also installed at Maitri. In the present communication the salient feature of the Laser Heterodyne System, Acousto-optic spectrometer, liquid nitrogen plant and results obtained are discussed in detail.

1. Introduction

The study of minor constituents in the atmosphere is of vital interest to understand the structure of troposhere and stratosphere. The evidence of catalytic destruction of ozone by NOx and CIOx in early seventies Johnstkon [1971] and reporting of "ozone hole" Farman et al [1985] at Antarctica in spring time has generataed an unprecedented surge of interest in the measurement of ozone using various techniques. A tunable $C0_2$ laser heterodyne system has been designed, developed and set up at NPL, New Delhi, Jain et al [1988] to monitor various trace species in the atmosphere.

The laser heterodyne system with one GH acousto-optic spectrometer (AOS) as backend, was also set up at Maitri, an Indian Antarctic station (70° 46S 11° 44'E) during 1993-94 and 1994-95 Antarctic summer to obtain ozone profiles and is first of its kind over Antarctic region. However the system was brought back that time due to non-availability of liquid nitrogen during winter. Again in the sixteenth expedition the system has been set-up al Maitri and made operational in summer as well as winter. The liquid nitrogen plant which was brought during 1993-94 Indian Scientific Antarctic Expedition for producing liquid nitrogen for the laser heterodyne system was also made operational, In the present communication the salient features of laser heterodyne system. Acousto-Optic Spectrometer, liquid nitrogen plant and results obtained are discussed.

2. Laser Heterodyne System (LHS)

Infrared laser heterodyne spectroscopy provides a powerful tool for identification of week molecular and atomic species Menzies [1976], The advantages of the laser heterodyne system over other techniques are its ultra high spectral resolutions, high spatial resolution, high quantum detection efficiency and very good signal to noise ratio. The high resolution makes the system very selective as the interference problem due to overlapping lines or bands are minimized and the lines can be resolved completely. The block diagram of the system is depicted in Fig. 1. The CO, laser used as a local oscillator is tuned on a line corresponding to the absorption line of the minor constituent of interest. The chopped solar radiation and CO, laser beam are coaligned and focused on the high speed liquid nitrogen cooled Hg Cd Te detector. The detected IF signal is further amplified in low noise wide band (5-1200 MHz) RF amplifiers.

3. Principles of Operation of Laser Heterodyne System

The laser heterodyne system is a passive technique in which CO, laser (local oscillator) or semiconductor tunable diode laser is tuned on or near the absorption line of the constituent of interest say ozone and is mixed with a chopped solar radiation. The two signals are focused on very high speed (1000 MHz) liquid nitrogen cooled Hg Cd Te detector. The beat signal thus obtained is amplified in a wide band RF amplifier (5-1000 MHz). This beat signal is fed to a HI_TECH I GHz acousto-optic sectrometer to record the frequency power spectra (line profile) by PC based data acquistition. The signals on the various channels is synchronously detected.

The pressure broadened (Lorenlz broadening) absorption line width varies with altitude which is being exploited to get height profiles. The absorption at line centre is strongly influenced by the upper altitude molecules while absorption a filter channels in the wing of the line will be mainly influenced by the lower altitude ones. Thus the measurement of total absorption at several frequencies (channels) in the wing of the line spread over 50 to 1000 MHz will provide informaiton about the concentration at various altitudes. Since spectral line profiles thus obtained contain information on the regions of their formation, the composition profiles can be obtained by analysis of individual spectral lines measured at ultra high spectral resolution through inverse solution of radiative transfer equation.

4. Acousto-Optic Spectrometer (AOS)

Acousto-Optical technique for power spectral measurement have been exploited for a variety of signal analysis applications Turpin [1981] and Gorden [1966]. The Bragg cell converts RF signal to ultrasonic traveling waves modulaating the optical index of the cell. The cell is illuminated across its aperture by a laser beam. A fraction of light is diffracted by acoustic waves, the angle of diffraction array is proportional to the power of the input RF signal. The intensity distribution can be detected by linear array of photo-detectors tecors which in turn represent the required RF power spectrum. An AOS with one GHz bandwidth was designed and developed at NPL, New Delhi as depicted in Fig 1. The block diagram of the AOS is shown in Fig2. The acousto-optic spectrometer consists of 1 GHz Bragg cell (Li Nb 03), diode laser at 784 nra, Fourier lens, 1050 pixel CCD array and PC based data acquisition system.

5. Liquid nitrogen plant: Operation and Problems

The liquid nitrogen is a must for cooling the Hg Cd Te detector of our laser heterodyne system. We also brought liquid nitrogen plant to install during the 1993-94 ISAE. but due to various logistic problems it was not made operational during last three expeditons. The capacity of the plant is 1 liter of liquid nitrogen per hour. The principle of production of liquid nitorgen is briefly described below :

The vacuum swing absorption (VSA) for separating nirogen from air functions on the principle that certain molecular sieves will absorb nitrogen from a stream of air and permit oxygen to pass through. The nitrogen is then desorbed from the sieve by evacuating the sieve vessel. The excess nitrogen is used to purge the molecular sieve of any residual oxygen to ensure a high quality nitrogen product. The carbon dioxide are removed form the air by conventional drier. The drier is continuously regenerated by heating and purging it with waste air form the process. The cycle timing is provided by two cam timers that actuates the solenoid valves and regenerative drier heaters in the correct sequence. The refrigerator is mounted on top of the dewar. The VSA nitrogen generator thus supplies dry nitrogen gas to the dewar. The cold end of the refrigerator cools the dry gas in the dewar. The VSA nitrogen generator thus supplies dry nitrogen gas to the dewar. The cold end of the refrigerator cools the dry gas in the dewar where it condenses. The refrigeration capacity is 100 watt at 77K for 50 Hz operation. The expander cable connected to a helium compressor furnishes the electricity to power the valve motor. The two compressors (master and slave). the expnader and VSA all are interlocked. The compressors are cooled by running continuous water using a water pump. This type of plant is especially important to use in areas like Antarctica where liquid nitrogen is not commercialy available. The system can provide 1 liter per hour of liquid nitrogen on continuous basis. The only utilities required are cooling water for helium compressors and electricity. THE PLANT WAS FINALLY OPERATIONAL ON FEBRUARY 5, 1997. The first drop of liquid trickled out of the plant in the early hours i.e.0005 hrs on February 5,1997 after continuous run of eight hours which is the minimum time required hrs to cool down the dewar. This was very exciting moment to see the production of liquid nitrogen for the first time at Maitri A large number of team members showed keen interest during the installation of the plant as we faced lot of problems before regular operation. Once operational, the plant was run as and when weather was bad as on cloudless days regular observations using laser heterodyne system were not in progress. In ten runs nearly 75 liters of liquid nitrogen was produced which is enough for the period March-April, 1997 observation.

The plant was again operated during August 1997. However due to power cut most of the time during winter resulted in freezing of water in water circulating coil of compressrs which in turn damaged the coil. When switched on the plant on august 12, 1997, water started spraying and oozing from all around the compressors, two trays were put under the compressors to collet oozing water and another motor was used to pump this water back to the tank. Any how plant was made operational in winter and after non stop running for seventy two hours sixty liters of liquid nitrogen was produced which was sufficient for two months of LHS observation, during the operation severe blizzard was going on but with the help of all scientific members the target was achieved. Next operation of the plant was done in November. This time weather was good, our last operation was on 16th Jan. 98; this operation was to make next wintering member expert in plant operation and it was continued for three days.

6. Laboratory Set - up

The laboratory set up started on 10-1-97 with of all the individual instruments arrival and unpacking of all the equipments. Within next four days the system was aligned using He Ne Laser beam. The laser heterodyne signal was obtained by beating of Co, laser and solar radiation using heliostat which was already installed and its tracking was tested . Due to want of proper earthing we have to wait for the measurent for few days. The earth to neutral voltage was nearly 100 to 165 volts which was very dangerous for our very sensitive instruments. Thus we lost four wonderful blue sky cloudless days which are very crucial for experiments like ours which totally depend on availability of sunny days and finally on January 18, 1997 proper electical earthing was provided (E-N voltage around 6 volts) The trial ovservations on ozone line profiles were obtained on 19-1-97. The weather was not worth ovservations for next few days and regular observations started form January 25, 1997, on all blue sky cloudless days. The data collection being continued on all clear blue sky days. The summer camp was formally closed down on February 26, 1997.

The CO_2 laser was tuned on P(24) line which is very near to the ozone absorption line 1043. 1775 cm-1. The line parameters for this line were computed using HITRAN data base. The spectra obtained on this line were in turn used to get vertical profiles of ozone using inversion technique (28,32,33). The typical ozone profile obtained on Feb.8, 1997, Oct 14, 1997 and Feb 6,1998 are, in Fig. 3, 4 and 5.

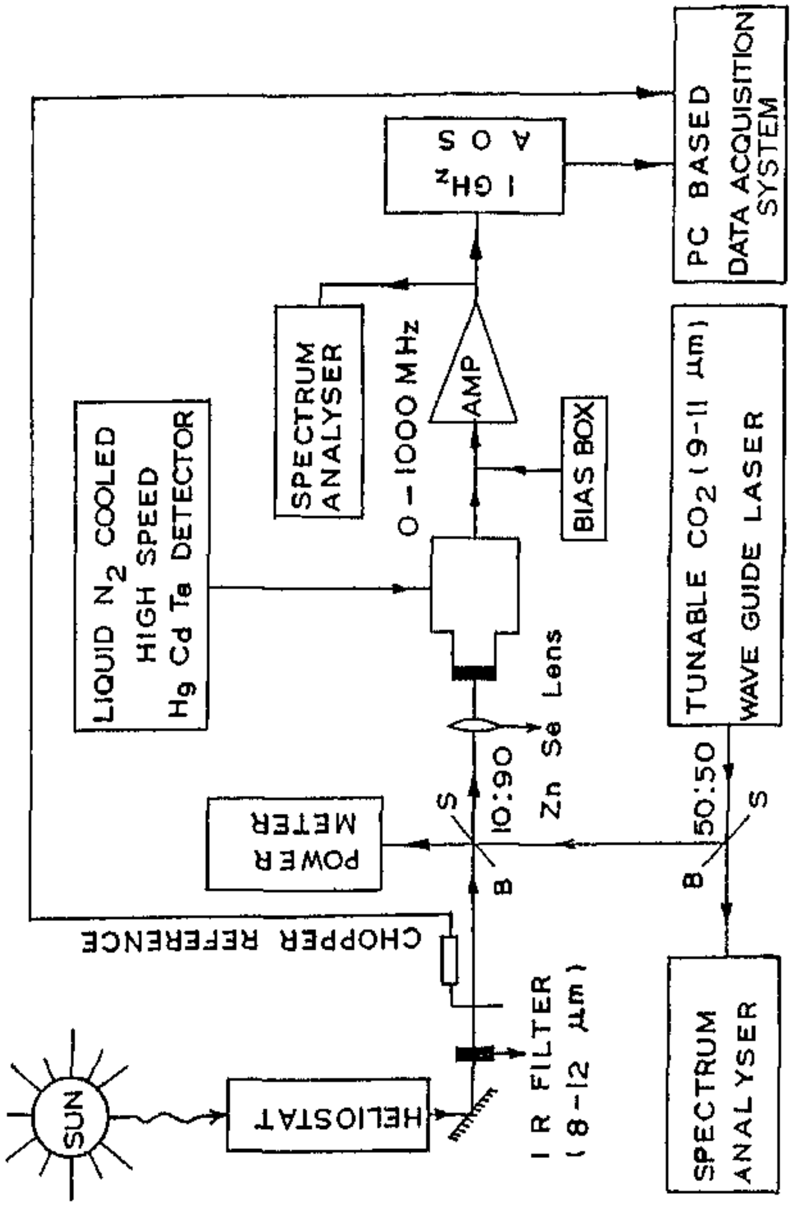

Fig. 1: Block diagram of laser heterodyne system

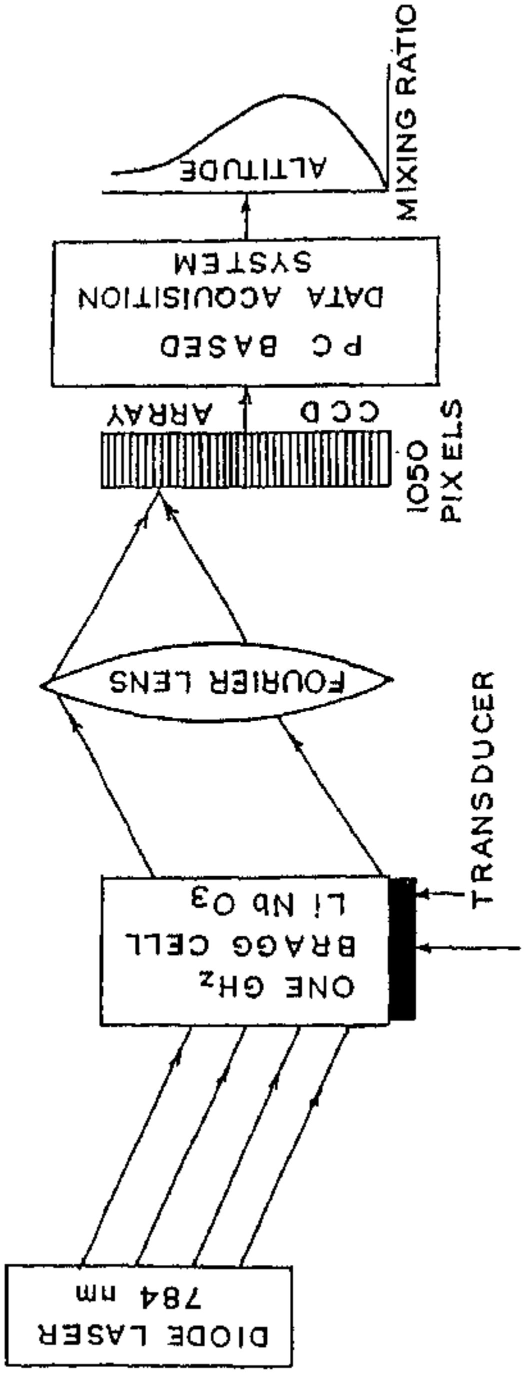

Fig. 2: Block diagram of 1GHz acousto-optic spectrometer for laser heterodyne system

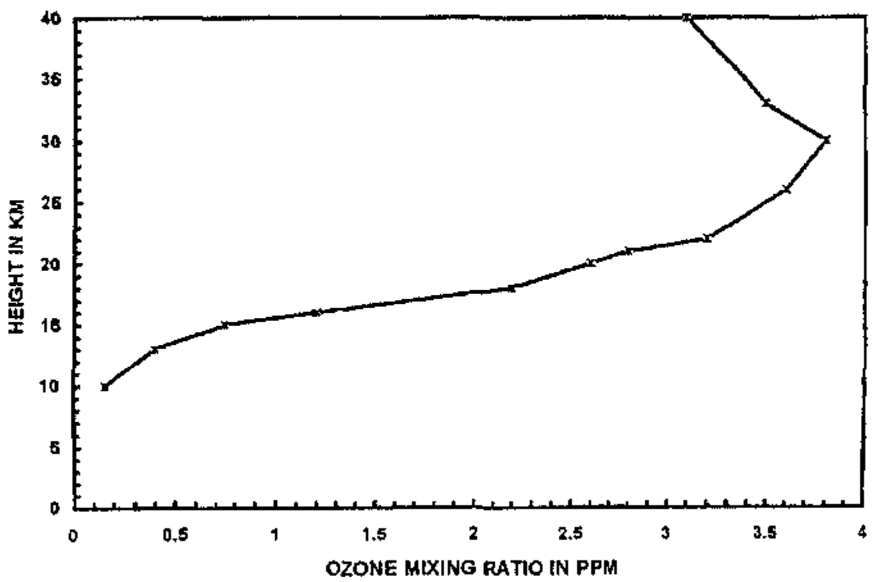

Fig. 3 : Ozone Profile at Maitri, Antarctica on Feb 8, 1997

7. Inversion Technique

The composition profile or temperature profile can be obtained by analysis of individual spectral line measured at ultra high resolution through inverse solution of radiative transfer equation Kaplan (1959). A software program has been developed and tested to obtain the height profiles for ozone using inversion technique, Jain (1987). It is found that the retrieved profiles match well with the model profiles and are independent of initial guess., Jain (1987). The inversion technique was also tested using actual profiles during normal and ozone hole conditions and it is found that the retrieved profiles compare well with the original profiles. Different height zones have been considered for Lorentz and Voigt line profiles depending on the constituent of interest. The various line parameters were computed using AFGL HITRAN data base, Rothman et. al.[1986]. The careful selection of absorption line is made to get sharp contribution functions and hence the good height resolution. The contribution functions which depend on absorption coeffcient have a property of reaching maximum peak at different values of height for different values of frequencies. The computations are made for line center and in the wing of the line. The inversion technique developed for ozone height profile has been dicussed in detail by Jain [1987].

8. Results & Discussions

The laser heterodyne system has thus demonstrated successfully its capability to monitor ozone height profiles in the atmosphere in the harsh environmental conditions like that of Antrarctica during both normal and ozone hole period. The ozone was Found to be depleted during ozone hole period from 3 percent to 68 percent in the height range 13 to 40 km. However the system has some limitations as it can be operated only when clear sky and sunny days. Also it needs liquid nitrogen for cooling the detector and therefore generation of liquid nitrogen is a must which is a very difficult task at Antarctica. The efforts are on to extend the facility to monitor other constituents to understand the complex interaction between atmospheric dynamics, chemistry and radiation budget which in turn requires a large data base on regular basis at tropical as well as at Antarctic latitudes. In order to extend the wavelength coverage of the $C0_2$ laser the other carbon isotopes such as C^{14} or C^{13} are to be used which in turn needs some R and D work.

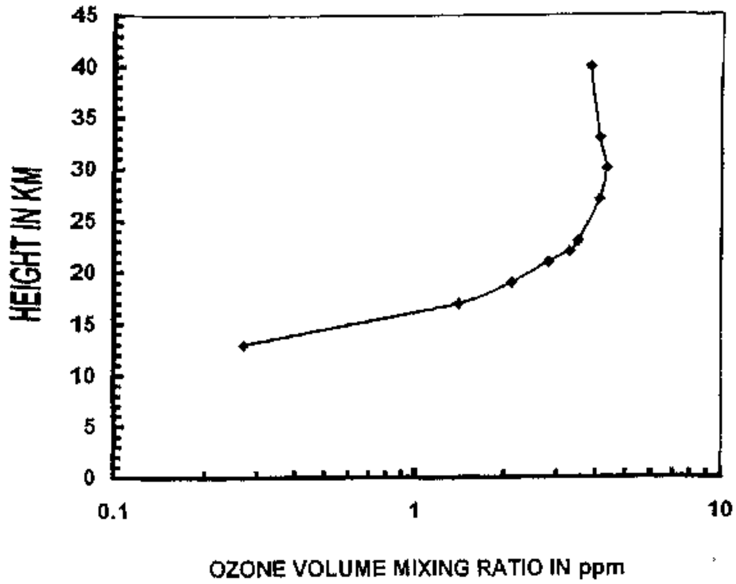

Fig. 5 : Vertical profile of ozone at maitri on feb 6, 1998

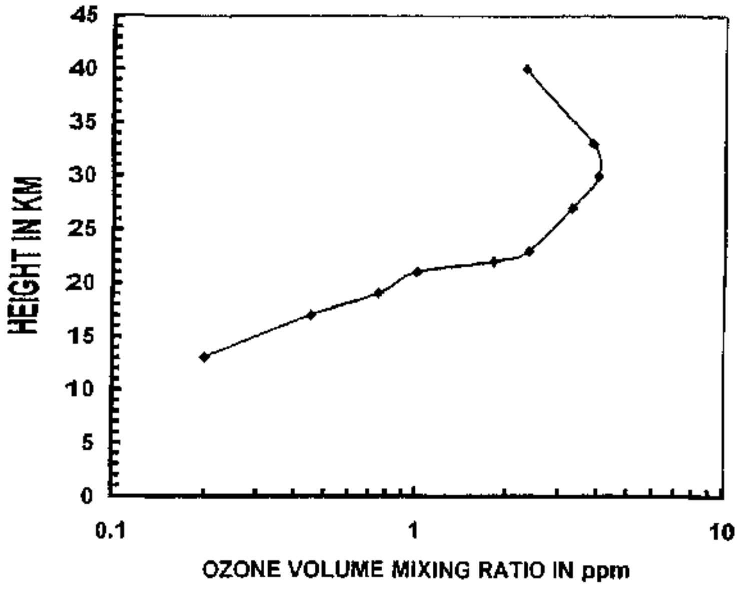

Fig. 4 : Vertical profile of ozone at maitri on oct 14, 1997

7. *Problems and Recommendations*

a. For the safety of the sensitive and expensive instruments like ours the perfect electrical earthing is a must and expert opinion may be sought for the same keeping in view the special Antarctic conditions (perma frost, low humidity etc) or fully floating voltage supply can be implemented or any other solution after expertise.
b. Very strong VHF interference at 124 MHz was creating problems for our measurements throughout the year. This was due interference at 124 MHz used for communication.
c. During the VHF communication high voltage fluctuations are observed and it is suggested that separate generators should be used for experimental work and HF transmission and it may be needed to stop HF broadcast during observing time.
d. Power changing at odd times like 1100 or 1200 Hrs is also a serious problem for LHS. Laser takes about one and half hour to stabilize and if in the mean time power changes our observations delayed for another two hours. Finally we loose noon period which gives the best result.
e. Electrostatic charge is an another problem and one have to get discharge himself before touching any sensitive instrument.

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