Tenth Indian Expedition to Antarctica, Scientific Report, 1995
Department of Ocean Development, Technical Publication No. 8, pp. 35-41

Boundary Layer Studies by Acoustic Sounder at Indian Antarctic Station Maitri

A.K.HANJURA

National Physical Laboratory, New Delhi

Abstract

An acoustic sounder system designed and developed at NPL was installed at Maitri in austral summer of 1991. This instrument consists of a low' power audio frequency generator, transmitting tone burst vertically up in the air and receving the weak echo returning from atmospheric irregularities and recording them on facsimile recorder/ digital printer. Among the various types of structures observed by the acoustic sounder, were the echo patterns, representing ground based inversions and variable structures on the surface of the inversion layer, throwing light on the nature of planetary boundary layer.

Introduction

The Acoustic Sounder is a remote sensing tool to probe the atmosphere. It can give real time values of the structure parameters as can be obtained by meteorological tower and aircraft techniques. The system is capable of monitoring the structure turbulent boundary layer. It provides an inexpensive method to probe the complete dynamics which is represented in a simple picture form for various practical applications. Gilman et al, (1946) were the first to use the acoustic sounder in studies of signal fadings in the troposcatter trans-horizon microwave radio link over the 64 km distance between New York and New Jersey. A correlation between microwave radio fadings and the structure parameter obtained by the acoustic sounder was reported. During mid 60's, Mc Allister (1968) re-discovered the potential use of the acoustic scattered intensity from the atmosphere due to fluctuations in the wind velocity and temperature. He obtained a very clear picture of inversion including the presence of gravity waves and he found the scattering of the sound waves due to temperature discontinuities or inhomogeneities.

In the lower atmosphere, the atmospheric boundary layer and planetary boundary layer are the most dynamic regions due to the interactive process between ground, ice, water and air. In this region the exchange of heat momentum, moisture and radiation takes place due to various dynamic processes including the cooling and warming of the earth surface. The South Pole is substantially colder than the North.

The continental ice reflects more than 80% of incoming solar radiation back to space. The driving force of the atmospheric circulation is the difference between the temperature near the equator and the poles. Winds are also strong in the southern hemisphere. Winds are dominated by negative thermal wind brought about by the intense radiational cooling of the ice slopes. The cooling of the air causes a thermal inversion resulting in a favourable pressure gradient for the down slope wind component. Similarly the planetary boundary layer is characterised by a high degree of turbulence under various conditions and is an important parameter which needs to be studied over Antarctica. For this reason one Acoustic Sounder was installed at Indian Antarctic Station, Maitri, in the Schirmacher Oasis in January 1991 during the 10th expedition.

Theory of Operation

The sound velocity in the lowest part of the atmosphere is 330 m/s. Even the mildest variation in temperature, humidity and wind velocity of the medium will cause a major change in terms of refractive index for the sound waves while electromagnetic waves and optical waves suffer a neglegible interaction. Refractive index (n) is a function of temperature, pressure and humidity of the atmospheric air (Bean & Dutton, 1968 & Stilke, 1973). The scattering power of the waves depends on $(An/n)^2$ which makes the scattering of sound waves million times greater than the electromagnetic waves for the same temperature inhomogenities. This property of sound waves offers an unique opportunity to pick up measurable scattered power while transmitting a low power pulse of nearly 100W. The backscattered power per unit volume, per unit incident flux, per unit solid angle (9) from the initial direction of propogation is given by

$$\sigma(\theta) = 0.03K^{1/3} . \cos^2(\theta) [C_v^2/C^2 . \cos^2(\theta/2 + 0.13C_T^2/T^2] . [\sin(\theta/2)]^{-11/3}$$

where $K=2c/\pi$ and C_T^2 and C_v^2 are known as temperature structure and velocity structure constants defined as

$$C_T^2 = r^{-2/3} \mid \overline{T(x) - T(x+r)} \mid^2$$

and

$$C_v^2 = r^{-2/3} \mid \overline{v(x) - v(x+r)} \mid^2$$

where 'r' is the separation vector such that temperature has been measured at location x and (x+r). Similarly, instantaneous wind speed at a point x to the direction of other point (x+r). C_v and CT are the root mean square differences in longitudinal velocity and temperature for the two points separated by a unit distance. So scattered power varies relatively with the wave length. There is no scattered power atθ = 90°. If we put 0 = 180°, the above equation becomes

$$\sigma(\theta) = 0.0039\, K^{1/3}.\, C^2T/T^2$$

where K is the wave number of the acoustic wave and T is the absolute temperature within the scattering volume.

For the monostatic acoustic sounder i.e. system using a common transmitter and receiver antenna, the received power from a distance R can be written as

$$P_r = C.T.\sigma\,(m°).A.L.P_t\ /2R^2$$

where P_t is the transmitted power;

τ is the pulse width;

A is the collecting area of the antenna;

C is the velocity of sound;

R is the probing range of target height

and L is the attenuation factor which takes into account the transducer efficiencies at the atmospheric absorption along the double path.

Replacing $\sigma(\theta)$ when $\theta = 180°$, the above equation can be written as

$$P_r = 0.0039\ .Pr.C.T/2.\ A/R^2\ .\ C^2T/TL\ .\ K^{1/3}\ .\ L$$

Except C_T^2, R and L, all others are known parameters and considering them a constant, the above equation can be written as

$$P_r = K^1\ .C^2T/R^2.L$$

This shows that the receiver power is directly proportional to the thermal structure parameter for any one range at any one time. So it can be used to estimate C_T^2. The refractive index parameter C_n^2 can be derived from the thermal structure

$$C_n^2 = 77.6x10^{-6}.1/T^2 \cdot P/CT^2$$

Where P is the atmospheric pressure and T is the temperature.

This refractive index is very important in studying the phenomenon of radio waves.

Installation of the Acoustic Sounder at Maitri

The acoustic sounder was installed at Maitri in January 1991 during the 10th Indian Antarctic Expedition. The system has been designed and developed at the National Physical Laboratory.

In this system, a low power (50W acoustic) audio frequency (2000 Hz) tone burst is transmitted vertically up in the air and the weak echo returning from atmospheric irregularities are recorded on facsimile recorder.

During January 1992, the system was modified with the installation of a digital processing unit and its interfaces including data storage unit. Now the system is capable of storing the back scattered energy either in an EGA monitor and digital printer or facsimile recorder. With this digital data, quantitative analysis of the structure parameter are possible now. A schematic representation of the system is shown in Fig. 1.

The antenna system is the most crucial and major part of the system. The antenna is a parabolic dish made of fibre glass. A transducer with a conical horn has been fitted at the focus of the dish. The same transducer has been used for transmitting and receiving. The transducer is very sensitive to audio noise. Before installation of the antenna system, noise level was measured at the installation site. To improve the sensitivity and for noise reduction, an acoustic shield was installed surrounding the dish antenna. The acoustic shield is an important part of the system because it has to be in the field to bear the stress of the Antarctic winds. The shield is a cylindrical structure whose outer diameter is 2,3 m at the base and 2.4 m at the top. Its height is 2.5 m. Acoustic absorbing foam has been used on the inside wall of the shield to avoid the reflection of the sound wave and minimise the noise. After the installation of the antenna system, the pre-amplifier was kept in a temperature controlled enclosure near the antenna. Various teflon cables were laid connecting the antenna to the processor unit. The processor unit consists of transmitting and other process-

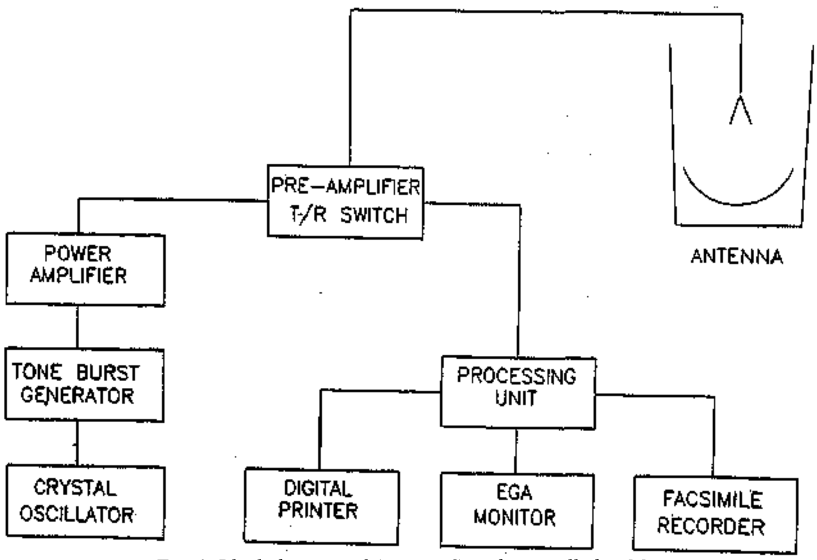

Fig. 1. Block diagram of Acoustic Sounder installed at Maitri.

ing circuits. After calibration, the system became fully operational in January 1991 and has been in use since then.

Observation

The acoustic sounder data has been recorded on facsimile recorder during the period January to December 1991. Besides that, other meteorological surface data has been collected during the above period by the automatic weather station. All these data are valuable for a partial qualitative assessment of the boundary layer phenomena of the Antarctic continent.

Various types of structures have been observed by the acoustic sounder at Maitri. Special features indicated by the echo intensity, obtained from facsimile recorder of the acoustic sounder, are shown in Figs.2-6.

Echo patterns representing ground based inversion and variable structures on the surface of the inversion layer have been observed. Radiative cooling of the earth surface is the cause of the ground based inversion layer. Stratified layer observed in the echo denotes turbulent interface between two stable layers and this variation provides information in the thermally inducted changes occuring in the atmospheric boundary layer. Unstable spike observed over the ground based inversion layer structure represents a region of wind powered turbulent mixing or gusting winds

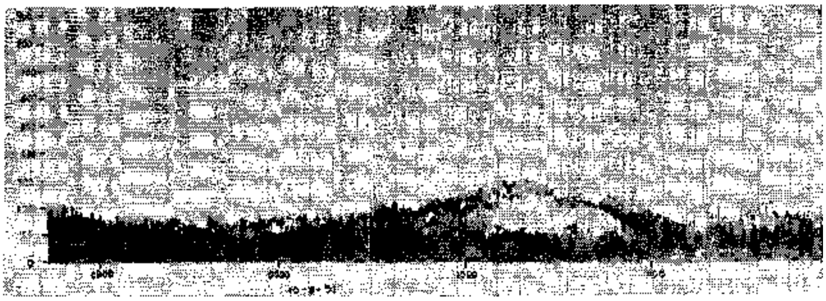

Fig. 2. Ground based inversion wan stratified layer.

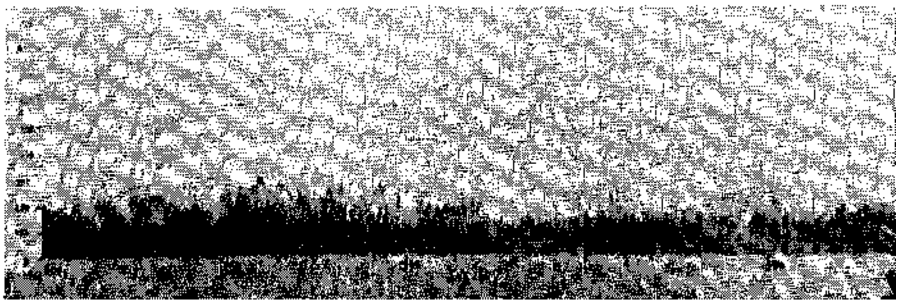

Fig. 3. Ground based inversion with unstable spike.

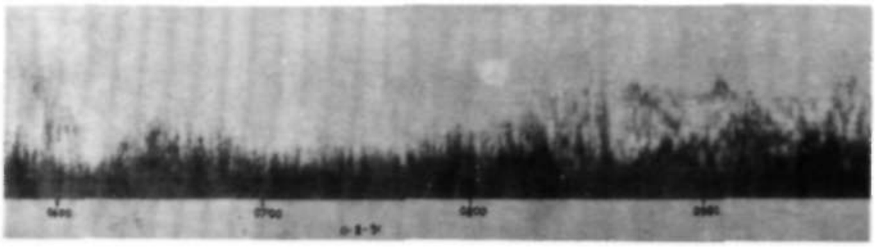

Fig. 4. Ground based inversion layer with thermal echo and wavy spike.

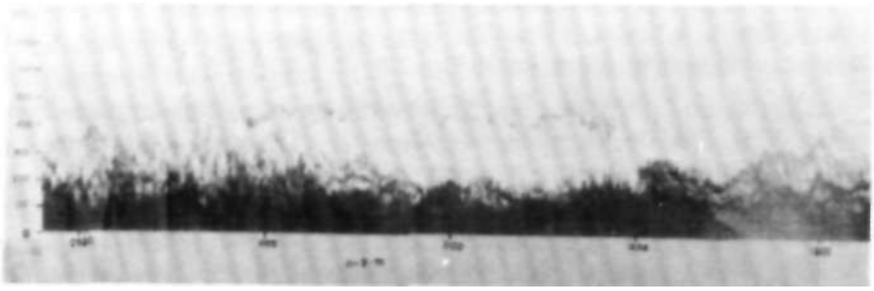

Fig. 5. Undulating inversion with undulated layer.

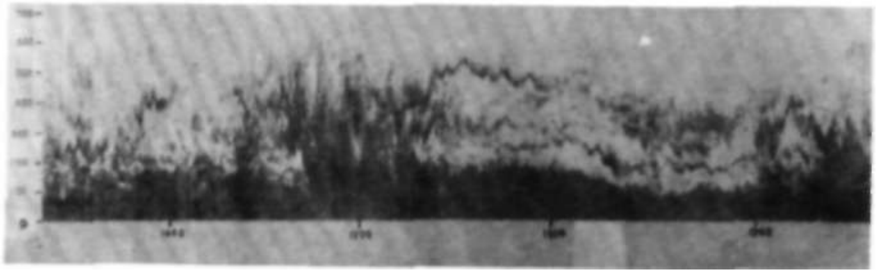

Fig. 6. Stratified inversion layer with cold front.

sudden jumps may take place. The temperature jump can be both, a positive or hot front, as well as a negative or cold front. Hot front lifts a lot of dust from the ground and increases the temperature by 2 to 5°C. Cold fronts normally lead to the formation of ground based inversion layers due to influx of cold air mass.

Conclusion

The acoustic sounder is a cost effective technique and when operated continuously can yield valuable information about the height, stratification and turbulent strength of the inversion boundary layer. All these data are also useful for UHF, VHF and microwave communication links. The latest modification in the instrumental digital recording will be more helpful in precise assessment of information about the atmospheric boundary layer. To understand the dynamic nature of the atmosphere, a Doppler SODAR will be essential in Antarctica. To understand the complete boundary layer phenomenon of this continent, at least three acoustic sounders have to operate simultaneously at three different points.

Acknowledgements

I wish to thank Army team members who installed the system inspire of bad weather. I also thank all the wintering members who helped in clearing snow from the antenna shield every now and then. Thanks are due to K.U.Nair and R.PJoshi who helped in data collection.

References

Bean, B.R. and Dutton, E.J. (1968): Radio Meteorology, Dover Publication; New York.

Gilman, G.N., Coxhead, H.B. and Willis, F.H. (1946): Reflection of sound signals in the troposphere. *J acoust Soc Am* 18,274.

Mc Allister, L.G,(1968): Acoustic sounding of lower troposphere. *J Atmos terrestr phys.* 30,1439.

Stilke, G. (1973): Occurrence and features of ducted modes of internal gravity waves over western Europe and their influence on microwave propagation. *Boundary Layer Meteorol,* 4,493.