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Echo Sounding of the Lower Atmosphere: Preliminary Studies

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An echosonde system at 2.4 kHz has been developed and installed at the Punjabi University, Patiala. Preliminary results along with geomorphological and climatic conditions in the regions around Patiala are presented. The echograms show domination of inversions in winter and fronts in summer.

1. Introduction

The lower part of the earth's atmosphere plays a crucial role in major areas of human endeavour such as communication[1-4], aviation[5-7], air pollution[8-11], etc. Any detailed study of these areas requires a complete information about the structure of the atmosphere and its variation with time. With this objective in view, various techniques have been developed and Echosonde (Sodar) has come to be an important tool in studying the lower atmospheric structure in space and time.

The tropospheric propagation of radio waves involves an understanding of the morphology and dynamics of the atmospheric boundary layer, and the echosonde is a simple system for such studies. To understand the cause of signal fading in the tropospheric (transhorizon) radio propagation during the World War II, Gilman *et al.*[12] developed an acoustic radar as early as in 1946 at a frequency of 4 kHz using the scattering of sound waves by the temperature fluctuations and named it as SODAR (sound detection and ranging) analogous to radar. Scattered sound signals especially from low level inversions (below 100 m) showed a correlation between radio signal fading and inversions. McAllister[13] followed it by an improved system at a lower frequency of 1 kHz, using a simple monostatic arrangement with a facsimile recording. The use of a facsimile recorder most probably evolved from the sonar and hence revolutionized the use of the scattered echo to understand the various aspects of the atmospheric structure and the motions as it could display the back scattered signal as a function of both altitude and time. Thus McAllister[14] could effectively demonstrate the display of various atmospheric structures such as thermal plumes, inversions along with their growth and decay, and breaking waves up to a height of several hundred metres. Little[15] obtained the quantitative estimates of the back-scattered signal strength and verified them with comprehensive observations. The strength of scattering due to interaction with turbulence for the acoustic wave exceeds the strength for electromagnetic waves by a factor of 10^6. Little further suggested that the ecohosonde can also be used to measure wind speed (using Doppler effect), humidity profiles, the spectra of temperature and wind fluctuations in addition to the thermal structure of the atmosphere. It is followed by a decade of a very high activity of building up acoustic sounding system largely at the Wave Propagation Laboratory (WPL), Boulder, but somewhat at other places also around the globe. The echosonde technique improved as new systems such as bistatic, three element and Doppler systems were developed. These systems, in combination with CW and HF radars including WPL's 300-m tower (the Boulder low level intercomparison experiment, Phoenix[16]) for the comparison of various atmospheric parameters to understand the behaviour of boundary layer, produced extremely rewarding results in the last decade.

Different workers have used different names for the acoustic sounder such as echometry[17], echosonde[18] and acdar[19]. This system which we prefer to call as the echosonde has become a powerful tool to continuously monitor the first one to two kilometres of the planetary boundary layer of the earth. A simple system can monitor temperature variations and wind speeds to a fairly good accuracy. However, combined with some other monitoring systems as described in WPL's intercomparison experiment it can be effectively used to aid in communication, aviation, particularly landing and take-off, air pollution studies and in number of other applications including meteorology.

A monostatic echosonde at 2.4 kHz has been designed and constructed by the authors. It became operational in July 1980. On the basis of the echosonde monitoring, we are making various studies on (i) thermal plumes (ii) temperature inversions and (iii) small scale irregularities to be published separately.

In the same building where the echosonde is operated, we have the India Meteorological Department (IMD) radiosonde sounding twice a day and a full-fledged meteorological observatory including direct and diffuse solar radiation monitoring. This provides us with a unique opportunity to compare echosonde data with conventional meteorological data. We have also a limited capability to use the radiosonde as a tethered balloon for temperature comparisons.

2. Echosonde Equation

The scattered power per unit solid angle, per unit volume, per unit incident flux may be written as[20-22]

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

where θ is the angle between the scattered and the incident directions, C_v^2 and C_T^2 are the constants of the structure functions for velocity and temperature inhomogeneities and $k = 2\pi/\lambda$ is the wavenumber of the sound wave and T is the mean absolute temperature of the scattering volume. The scattered acoustic power depends weakly on the wavelength of the sound wave and both the velocity and temperature fluctuations contribute to scattering. Most of the power is scattered in the forward direction while no scattering takes place at right angles to the incident direction. It is important to note that the velocity fluctuations do not contribute to the power scattered in backward direction. For $\theta = 180°$, the above equation reduces to

$$\sigma(\theta) = 0.0039\, k^{1/3}\, C_T^2/T^2 \quad \ldots (2)$$

The received power P_r for the vertical sounding can be estimated from the usual radar equation[18]

$$P_r = \eta_t\, \eta_r\, P_t\, (C\tau/2)\, A_r\, (1/R^2)\, \sigma(\theta)\, L \quad \ldots (3)$$

where η_t and η_r are the transmitting and receiving efficiencies of the transducer, P_t is the transmitted power, c is the velocity of sound, τ is the pulse width, A_r is the receiving area of the antenna, R is the range of the scattering region while $\sigma(\theta)$ is given by Eq. (2) and L is the attenuation factor of sound due to the atmospheric absorption along the double path to and fro in the scattering region.

Based on Eqs. (2) and (3) the basic acoustic sounding system thus requires (Fig. 1) the following.

(i) A transmitting system to illuminate the turbulent region with a powerful acoustic flux

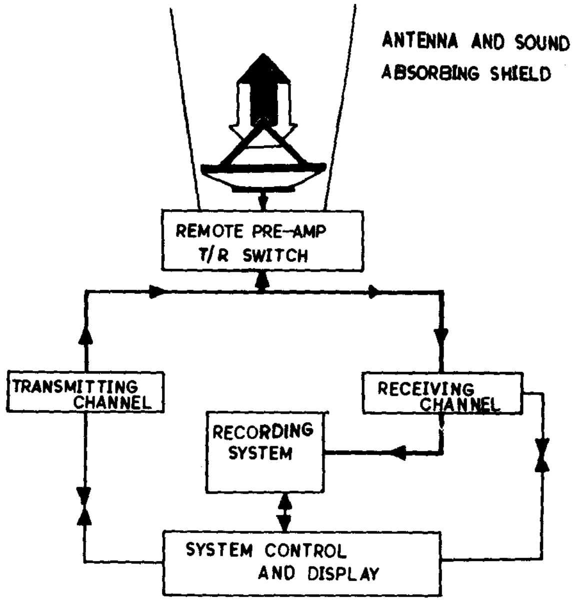

Fig. 1—Block diagram of a basic echosonde

(ii) Pre-amplifier with a T/R switch

(iii) Transmit/receive antenna enclosed in an acoustic shield

(iv) Sensitive receiving system

(v) Recording system to monitor the backscattered energy

(vi) System protector and display system

Based on these requirements the detailed design of monostatic echosonde has been developed and is in operation since July 1980.

3. Acoustic Sounding System

The system designed, developed and fabricated at Punjabi University, Patiala, is shown in Fig. 2. The transmitting system consists of a tunable oscillator (from 500 to 4000 Hz), a tone burst generator to produce the desired pulse length, a power amplifier and a 16-ohm acoustic transducer. The acoustic antenna system consists of an exponential horn attached to the transducer, which is placed at the focus of the parabolic reflector (six feet in diameter) made of fibre glass. To reduce the side-lobes the parabolic dish is placed inside a diverging octogonal-shaped absorbing cuff of mildsteel sheets pasted with a 10-cm thick rubber foam[23]. The absorbing cuff improves the S/N ratio by about 20 dB (Fig. 3). The height of the cuff is about 8 ft.

The preamplifier, the most important part of the receiver system, has a gain of 90 dB and a sensitivity of 0.05 microvolt at 2400 Hz. This is followed by a tunable narrow bandpass filter (bandwidth = 10 Hz) with a gain of 40 dB. The signal is then detected linearly or logarithmically, amplified and fed to the facsimile recorder. Alternatively, the signal can be range-compensated for the range-loss due to absorption in the intervening medium in the ramp amplifier and fed

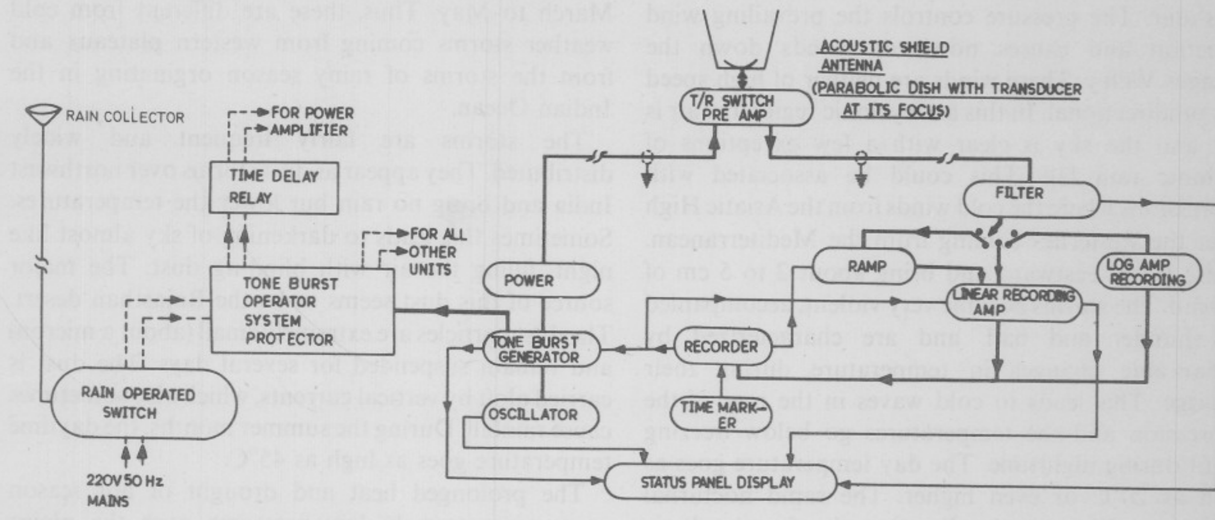

Fig. 2—Details of the Punjabi University, Patiala, echosonde system

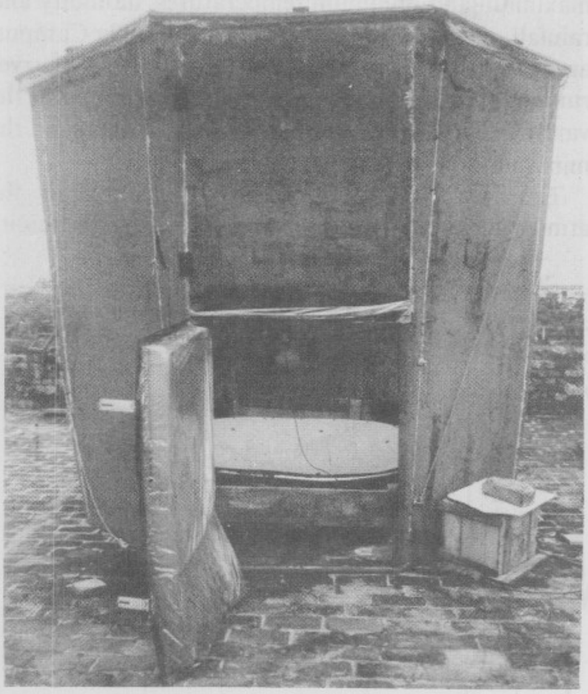

Fig. 3—Antenna and absorbing cuff

Table 1—Characteristics of Facsimile Recorder Designed and Developed at the Punjabi University

Weight	15 kg approximately
Size	44 × 41 × 25 in cm
Paper width	27.5 cm
Paper speed	6″, 12″ and 18″/hr
Paper sensitivity	1 V
Paper dynamic range	22 dB
Input impedance	220 Ω
Helix speed	30, 15 and 10 rpm
Probing range	340, 680 and 1020 m
Triggers	i. Photo-optical ii. Magnetic read relay
Power consumption	11 W
Operation duration	Non-stop

to the facsimile recorder. The facsimile recorder (Table 1) designed and developed indigenously, records the received signal on a voltage sensitive paper.

As the system runs round the clock unattended, a system protector switches off the system permanently, whenever there is a fault in the system. The time marker unit is being designed to ground the facsimile recorder input at intervals of 30 min or 1 hr.

4. Climatic Pattern of Patiala

The weather in Punjab is mostly dominated by temperature perturbations than humidity variability and hence the echosonde data can be unambiguously interpreted. To appreciate the utility of the echosonde studies in this area, a description of local climatic patterns is given below.

Patiala (30° 21′N; 76° 24′E) is situated in the gently sloping flat terrain in Punjab with a slope of 0.001, i.e. one metre for every kilometre towards southwest. Siwalik hills are in the northeast with the foot hills being about 50 km. Beyond the Siwalik range falls the Himalayan range. The semi-arid region starts at a distance of about 100 km in the southwest direction. Most of the land around Patiala is irrigated except a few patches of jungle here and there.

Climatic environment over these areas can be divided into mainly three seasons, i.e. the cold season from mid December towards the end of February, the hot season from March to mid June and wet season from mid June to mid December. In the cold season a high pressure system develops over Punjab and

Kashmir. The pressure controls the prevailing wind direction and causes northwest winds down the Ganges Valley. These winds are neither of high speed nor unidirectional. In this anticyclonic region the air is dry and the sky is clear with a few exceptions of cyclonic rain fall. This could be associated with depressions where the cold winds from the Asiatic High meet the westerlies coming from the Mediterranean. These travel eastward and bring about 2 to 5 cm of rainfall. The storms become very violent, accompanied by thunder and hail, and are characterized by remarkable changes in temperature during their passage. This leads to cold waves in the rear of the depression and the temperatures go below freezing point during nighttime. The day temperature goes as high as 20°C or even higher. The rapid nocturnal radiation of heat is the direct result of anticyclonic conditions.

The high pressure during cold season over Punjab gradually breaks down and disappears entirely by April and is replaced by low pressure. This can be regarded as a transition period between winter and summer monsoons, a time when local factors can have control over the planetary factors. It leads to feeble cyclonic air circulation, thereby generating local thunderstorms because of local changes of humidity and temperature with a progressive increase from March to May. Thus, these are different from cold weather storms coming from western plateaux and from the storms of rainy season orginating in the Indian Ocean.

The storms are fairly frequent and widely distributed. They appear as dust storms over northwest India and bring no rain but lower the temperatures. Sometimes this leads to darkening of sky almost like night, filling the air with blinding dust. The major source of this dust seems to be the Rajasthan desert. The dust particles are extremely small (about a micron) and remain suspended for several days. The dust is carried aloft by vertical currents; which also sometimes cause rainfall. During the summer months, the daytime temperature goes as high as 45°C.

The prolonged heat and drought of hot season generates extremely low pressures over the plains which leads to low-level westerly monsoon wind.

The variations of the meteorological parameters, i.e. maximum and minimum temperatures, humidity and rainfall over the Punjabi University, Patiala Campus, are shown in Fig. 4 for the year 1980. The thick curves running through the temperature graphs represent the variation of expected normal of the maximum and the minimum temperature variation.

Thus we have a fairly large variation in the atmospheric temperature, pressure and humidity

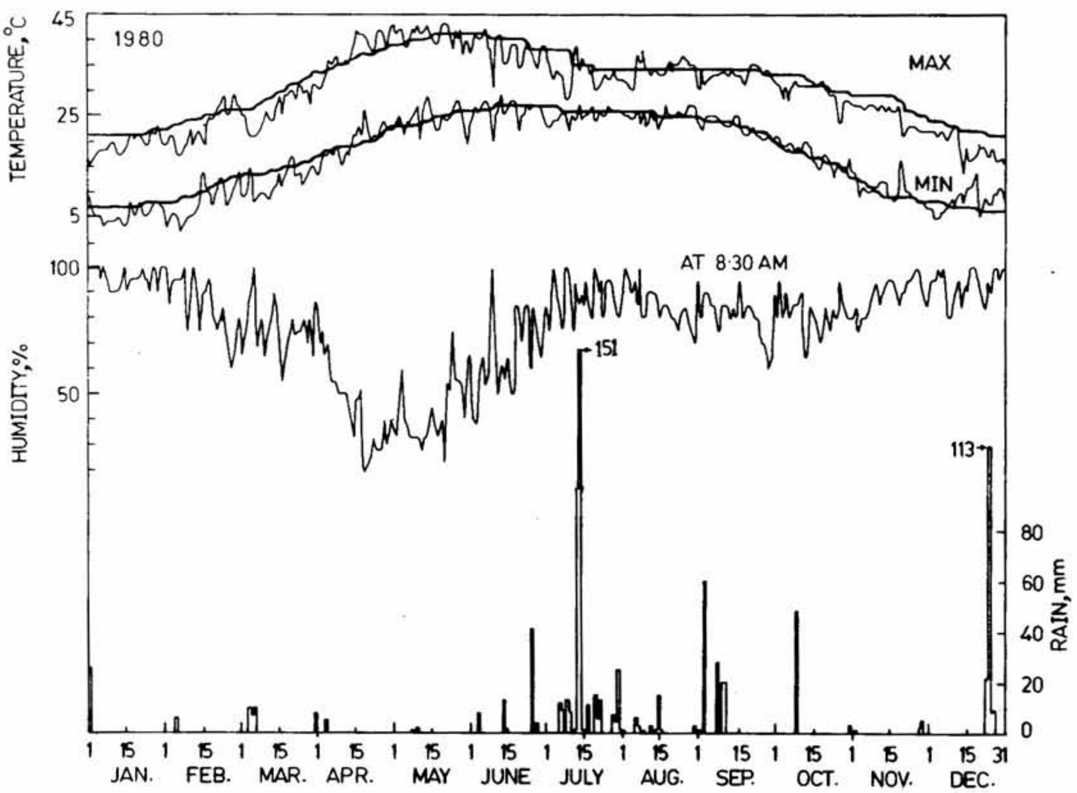

Fig. 4—Variation of meteorological parameter at the campus for the year 1980 (Along maximum and minimum temperature graphs thick curves show the IMD expected normal value)

along with the wind conditions thereby giving a natural opportunity to observe various kinds of the atmospheric structures on the facsimile recording of the echosonde. We are observing strong inversions, the effect of cold breeze on the atmosphere, the atmospheric stability, the gravity waves and a slow morning rise of the surface-based inversion during winter compared to all other seasons, while summer will show front movements and will give an opportunity to study the dust suspension. The monsoon season provides a clear-cut opportunity to study the effect of humidity, the passage of rain clouds for a short time and the thunderstorms on the echograms.

In recent times the irrigation by artificial means particularly the tubewells, spreads water over the cultivated land in these areas during the dry season, both during winter and summer. A part of it evaporates thereby causing local disturbances which include rains and more frequent cases of tornadoes. It is essentially modifying the climatic conditions in and around Patiala, and, for that matter, all over the whole northwestern region of Punjab, Haryana and part of the western Uttar Pradesh.

5. Observations

The echosonde has been in continuous operation since July 1980 and a number of phenomena have been recognized on the echograms. The main features which relate to the diurnal variation of the atmosphere are the surface-based temperature inversions (Fig. 5), the thermal plumes and the rising surface-based inversions (Fig. 6). These structures are also associated with several other features like small and large scale inhomogeneities and wave motions (Figs. 5 and 7), mechanically mixed structures (Fig. 8), weather fronts, etc.

The temperature inversions (Fig. 5) are formed at night as a result of the cooling of the earth's surface and grow in intensity and height with time, but they have a high variability due to the changing prevailing conditions in the atmosphere such as water vapour content, wind, etc.

With the sunrise, the earth gets heated up resulting in convection near the ground which pushes up the surface-based inversion formed at night. The phenomena starts an hour or so after sunrise (Fig. 6) and continues for 3-4 hr, before the rising layer gets completely mixed with the atmosphere at certain altitude. Subsequent to this the atmosphere becomes fully convective and the thermal plumes (Fig. 6) which continue for the whole day are observed. The maximum height of the plumes is around 1400 hrs which decreases with time and finally leaves the atmosphere in a homogeneous condition before the inversion forms after sunset.

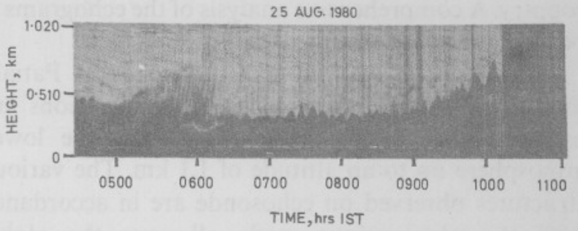

Fig. 5—Echogram showing surface-based temperature inversion

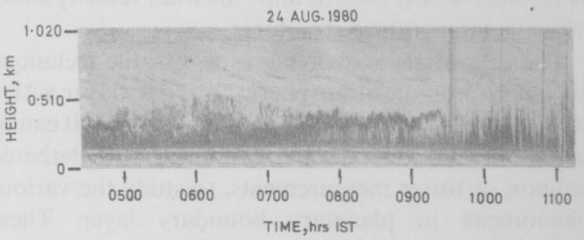

Fig. 6—Echogram showing surface-based inversion and thermal plumes

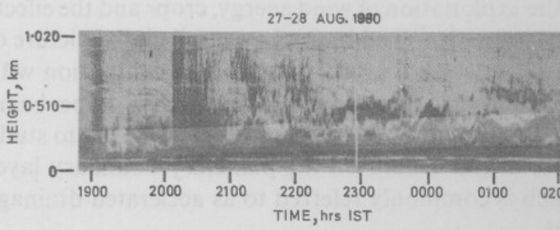

Fig. 7—Echogram showing wave motions

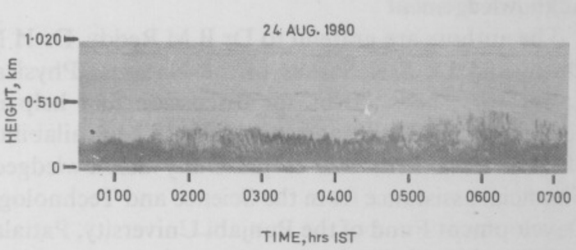

Fig. 8—Echogram showing mechanically mixed structure

The irregularities and the wave motions are seen basically during night (Figs. 5 and 7). But the mechanical mixed structure due to strong surface wind and vertical wind movement is also seen sometimes during night (Fig. 8).

6. Conclusions

From the geomorphology and the meteorological conditions prevailing over Patiala and the echogram observations made so far it is observed that the inversions dominate the winter and the fronts dominate the summer. The winter rain caused by western disturbances and the pre-rain turbulence offer interesting echosonde studies in this part of the country. A comprehensive analysis of the echograms is beyond the scope of this paper.

The successful operation of echosonde at Patiala indicates that the various design considerations are optimum and it is capable of probing the lower atmosphere up to an altitude of 1.1 km. The various structures observed on echosonde are in accordance with the observations made all over the globe. Attempts are being made now to develop the Doppler echosonde facility to determine the wind velocity along with the temperature structures.

The echosonde is evolving as a versatile technique for monitoring the atmospheric boundary layer with a resolution of 10 to 30 m on a continuous basis. It can be potentially exploited, when combined with tethered balloon or tower measurements, to study the various phenomena in planetary boundary layer. These phenomena are important in other areas such as communications and air-pollution. Similarly these studies have great potential in relatively new areas such as the exploitation of wind energy, crops and the effects of pests on them and lastly the overall global picture of the planetary boundary layer and its connection with the mesoscale phenomena. The terrain slope being 0.001 in this study, this technique can be used to study effect of the terrain on the planetary boundary layer which is commonly referred to as acclerated drainage flow.

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