Studies Different Structure of Atmospheric Boundary Layer Using Monostatic SODAR

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Abstract The Atmospheric Boundary Layer (ABL) was continuously monitored using Monostatic SODAR, which was conducted at CSIR-NPL, New Delhi. In this paper, an effort has been made to review the studies in the field of the structure of ABL using SODAR echograms in Delhi during a special observation period of the experiment. The change in weather conditions has found to have definite marks on the SODAR observed the structure of ABL. In particular, it has been seen that dot echoes and spiky top layered structures are different typical structures of the different seasons, which are associated with temperature, wind speed, and relative humidity. Also, the knowledge of these structures is great to use in air pollutant studies and dispersion models.

Keywords SODAR · Atmospheric boundary layer · Different ABL structure

1 Introduction

This paper represents the processes governing the different types of structure in the Atmospheric Boundary Layer (ABL) and discusses relevant uses of Sonic Detection And Ranging (SODAR) information in the field of ABL. It is written from the practical point view of a meteorologist involved in consulting and advisory work for industry and government agencies, rather than from SODAR researcher.

Factors that govern the dilution, rise, and spread of pollutants include wind speed and direction, turbulence, temperature lapse rate, and ABL [1, 2]. As a result, to understand local pollutants transfer and dispersion over an area, researchers should know the ABL, the different types of structure of ABL. During recent years, the capacity of SODAR to map the different types of ABL structure is increased. The knowledge of these structures is of great use in air pollutant studies [2, 3]. SODAR

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is a comparatively cost-effective continuously operating remote sensing technique, and can be thus usefully employed to deal with hazardous situations of air pollution [4].

1.1 Acoustic Wave in the Atmosphere

When the flexible diaphragm of a speaker moves, it creates small pressure fluctuations traveling outward from the speaker [3]. These pressure fluctuations are sound waves. The speed, c, at which these waves travel can be expected to depend on the mechanical properties p_{atm} (atmospheric pressure) and ρ (air density) [3]. Therefore

$$c \propto \sqrt{\frac{p_{\text{atm}}}{\rho}}$$

and, as already noted, the temperature and density are inversely related to each other at constant pressure through the gas equation

$$p_{\text{atm}} = \rho R_d T$$

where $R_d = 287\ \text{J kg}^{-1}\ \text{K}^{-1}$. This means that

$$c \propto \sqrt{T}$$

Allowing for T being the temperature in K, and that the speed of sound at 0 °C is 332 m s^{-1}, therefore

$$c(T) = 332(1 + 0.00166\Delta T)\ \text{ms}^{-1}$$

where ΔT is the temperature in °C. For air containing water vapor, the air density is the sum of the dry air density, ρ_d, and the water vapor density, ρ_v, or

$$\rho = \rho_d + \rho_v = \frac{p_{\text{atm}} - p_v}{R_d T} + \frac{p_v}{\left(R_d/\varepsilon\right) T}$$

where $\varepsilon = 0.622$ is the ratio of the molecular weight of water to molecular weight of air, and individual gas equations have been used for dry air and for water vapor. A simpler expression is obtained in terms of the water vapor mixing ratio, $w = \varepsilon p_v/(p_{\text{atm}} - p_v)$, which is the mass of water vapor divided by the mass of dry air per unit volume. The adiabatic sound speed is

$$c = \sqrt{\frac{\gamma RT}{M}}$$

where $R = 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$ is a universal gas constant, γ is the ratio of specific heats for the gas, and M is the average molecular weight. This sound speed does not allow for the effect of air motion (i.e., wind) in changing the speed along the direction of propagation.

1.2 Reflection and Refraction

At the point, when an acoustic signal meets an interface where the signal speed changes, some signals are reflected and some proceeds over the crossing point thus far with an alteration in direction [3]. This has been pictured using the Huygens rule, which expresses that each point on a signal goes about as a point source of spherical wavelets, and taking the unrelated twist to the wavelets before long gives the position of the proliferated signal. Generally, acoustic signal traveling through the air, there has no separate interface but rather a continuous change in acoustic signal speed due to a temperature gradient or wind shear [2].

On account of acoustic travel-time tomography where the stimulating way is a pair of meters on the ground, ground reflections has been a major supposed. In this case, the reflection from the ground has combined with the direct line-of-sight signal, causing much-reduced signal amplitude [2, 3]. For this reason, continuous encoded-signal systems have experienced difficulties, therefore short pulses are used. The acoustic signal speed increases by 0.17% for every degree rise in air temperature [3].

2 Data and SODAR

SODAR is an all-around perceived acoustic remote-detecting method [2, 4] that ceaselessly screens ABL warm structures up to statures in the scope of 340–3400 m. ABL height has been measured utilizing monostatic SODAR, which was designed at Council of Scientific and Industrial Research (CSIR)—National Physical Laboratory (NPL) and worked at different frequencies as per its particular requirement. The details of CSIR-NPL monostatic SODAR are described (Table 1).

The antenna is encased in an acoustic shield to constrict the outside noise and has been described at anechoic chambers at CSIR-NPL for the transmitting and accepting proficiency and directional qualities. The transducer yield productivity is measured to be 1.32 Pa V − 1 in the anechoic chamber utilizing a sound level analyzer and is in this way traceable to the national models of sound weight acknowledged at CSIR-NPL, India [4]. Highly directional short bursts of sound energy are radiated into the atmosphere, which after scattering from atmospheric fluctuations of eddy sizes within the inertial subrange of 0.1–10 m are being received back by the receiving antenna, conditioned through a preamplifier, and fed an analog input signal at the microphone input terminal of the computer. Each gained information is perused with an 8-bit determination and put away in the information record with a pre-doled out

Table 1 Characteristics of CSIR-NPL (New Delhi) Monostatic SODAR

Transmitted power (electrical)	90 W
Transmitted power (acoustical)	15 W
Pulse width	100 ms
Pulse repetition period	6 s
Operational range	1000 m
Receiver bandwidth	50 Hz
Frequency of operation	2250 Hz
Acoustic velocity	340 m/s (average)
Receiver gain	80 dB
Transmit–receive antenna	Parabolic reflector dish surrounded by conical acoustic cuff
Receiver area	2.5 m^2
Pre amplifier sensitivity	Fraction of a micro-Volt

document name contingent on the date and time toward the start of the information securing. The dynamic scope of the acquired signal 0–5 V is separated into eight stages, and each progression is pre-allocated an uncommon shading code. Contingent on the time passed t after transmission of tone burst, and digitalization of individual information focuses, the gained information point is doled out a stature estimation of

$$h = \frac{ct}{2}$$

where c is the speed of sound noticeable all around and t is the time passed measured in seconds. Each data point with assigned color is displayed as a two-dimensional image in time versus height graphics, on the computer monitor in real time. Line by line joining of various sweeps creates a pictorial perspective of the SODAR echograms [4]. A tight band channel is utilized as a part of the equipment, hardware, to stifle the commotion at undesirable frequencies and enhance the flag to clamor proportion. The signals are processed to produce an online facsimile display of the dynamics of ABL thermal structures. The SODAR framework has been adjusted utilizing a calibration detailed by Danilov et al. [5] in anechoic chambers at CSIR-NPL. SODAR echograms are reflex pictures of the turbulence in the lower climate. This turbulence is accountable for the dispersion of pollutants. Thus, the measured height of thermals plumes in the daytime and of shear echoes for the duration of night time. The height of the thermal plumes by SODAR during the daytime will always give an underestimated value unless they are capped by a low-level elevated shear echo layer [4]. The below empirical relation has given the mixing height during the daytime:

$$y = 4.24x + 95$$

where y is the blending stature (m) for temperamental ABL and x is the profundity of the SODAR measured thermal plume (m).

3 SODAR Structure and Characteristics of the Different Season ABL

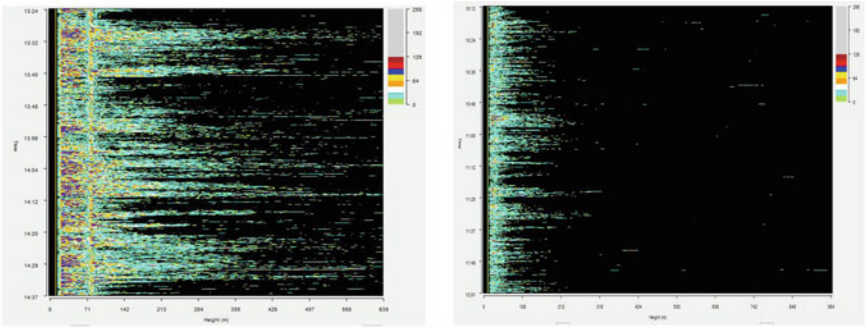
Five thousand eight hundred fifty (approx. one year) SODAR echograms that have been seen at the examiner area (CSIR-NPL, New Delhi) for various seasons were analyzed and classified into different structures. Figure 1 shows the different structures (Table 2) under SODAR echograms [6].

The convection layer structure, that is, the characteristic highlight of the daytime unstable conditions, disseminates in the evening after dawn because of sun-powered go down of the ground and the temperature profile changes its shape [3, 4]. The time is taken for a convection layer to disperse after dawn changes from every day and season to season contingent on the nearness of overcast cover, the quality of the reversal layer framed amid the night, the flood of sun based warmth, and the nearness of rising layer or haze layer. Figure 1a, b, c, d, e displays the thermal plume with tall spikes which were observed during the daytime. They are more common in the month of May due to the high temperature (or solar radiation). Due to high solar radiation, it uncovers that the height of thermal plumes is generally 470 m and can go up to 625 m. In this period, ABL height is more; because of this, the dispersion area of pollutants is more. Therefore, this is a more unstable class and more favorable condition for the industry and human being.

Figure 1k, l displays the multilayer which was observed during nighttime. Due to more variation in temperature, wind speed, wind direction, and relative humidity, it uncovers that the height of the inversion layer is average 100 m and can go up to 600 m. In this period, ABL height has varied and as a result, the dispersion area of pollutants is varied. This is a stable class and unfavorable condition for the industry and human being.

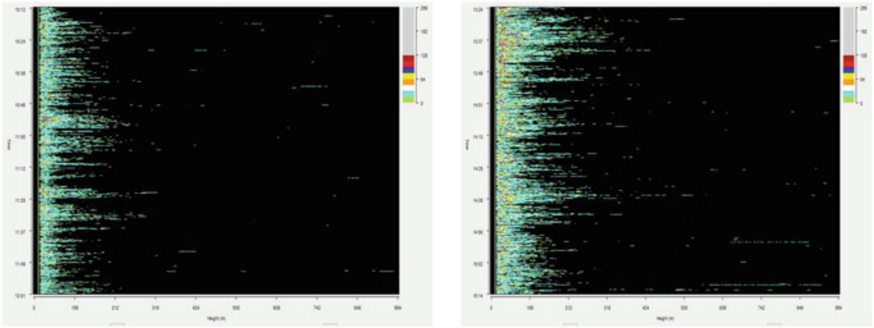
Waves structure (Fig. 1j) is another class of ABL structures, which have been watched and grouped specifically on the SODAR echograms. The wave structure, for the most part, is found in the April, May, and June months, that is, in the pre-monsoon season. This type of structure is essential in the investigation of wave movement [2]. This type of structure forms due to high wind speed and change in direction.

The inversion layer structure (Fig. 1g, h, i, j, k), that is, a characteristic highlight of the nighttime stable conditions, disseminates in the morning after dawn because of sun-powered warming of the ground and the temperature profile changes its shape. The time is taken for an inversion layer to disperse as follows the above convection layer after dawn changes from every day and season to season. Contingent on the



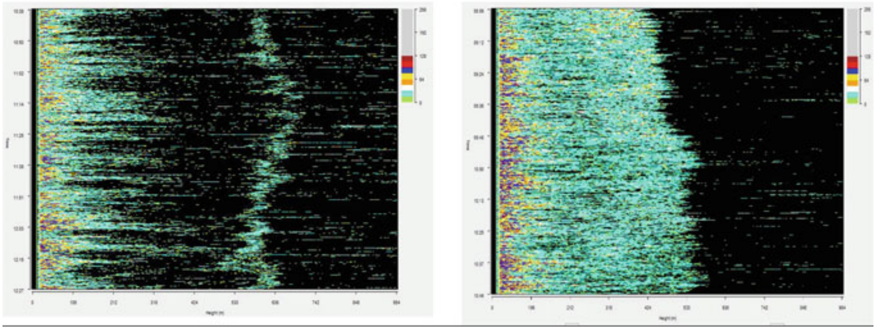
(a) Thermal plume long

(b) Thermal plume during Rainy Day



(c) Thermal plume during Before Rainy Day

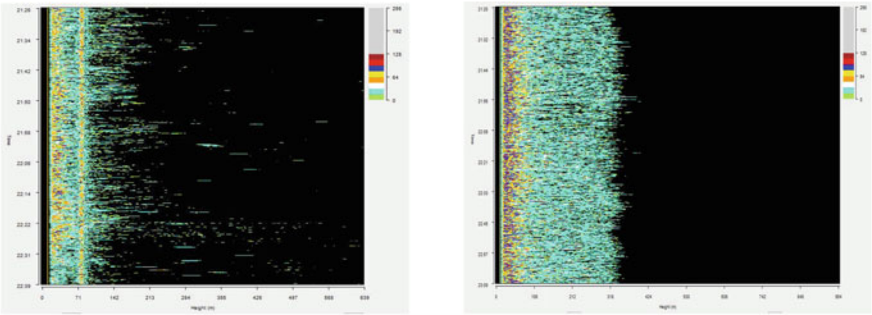
(d) Thermal plume during winter



(e) Thermal plume with Foggy

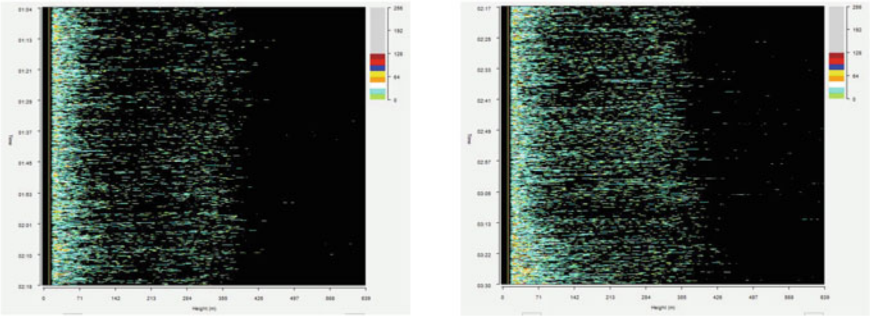
(f) Rising layer during WinterSeason

Fig. 1 Different structures of ABL



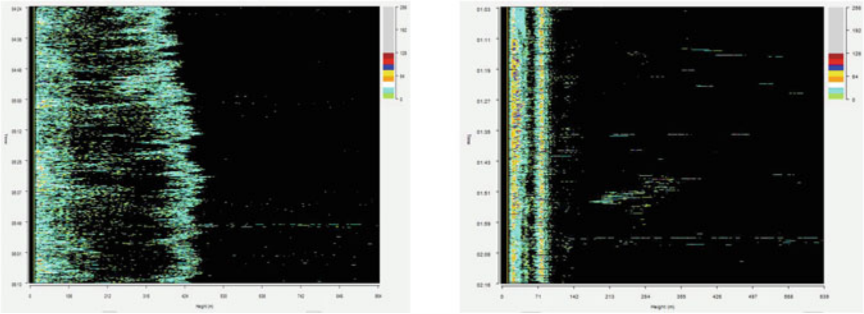
(g) Inversion with long Spikes

(h) Winter Inversion



(i) Inversion with one or two elevated layer in motion

(j) Inversion with wave motion



(k) Inversion With Fog

(l) Multilayer

Fig. 1 (continued)

nearness of overcast cover, the quality of the reversal layer framed amid the night, flood of sun based warmth, and the nearness of rising layer or haze layer. In the rising layer (Fig. 1f), the rising rate is quicker in the pre-monsoon season than in the winter and post-monsoon season because of the adjustment in the temperature profile. The night-time inversion while scattering demonstrates its essence as a rising layer, which ranges to a specific most extreme height and after that vanishes. This kind of structure

Table 2 Description of SODAR Structure and Class Numbers

Class	Description of SODAR structure
1.	Inversion with force convection
2.	Inversion with a tall spike
3.	Inversion with a single elevated layer
4.	Inversion with two elevated layers
5.	Inversion with wave motion
6.	Inversion with one or two elevated layers in motion
7.	Inversion with a small spike
8.	Stratified layer
9.	Diffuse thermal plumes
10.	Thermal plumes with normal days
11.	Thermal plumes with a foggy layer
12.	Transition structure

is not common in the morning time. During rainy and cloud cover days, the rising layer does not exist and inversion directly converted into the convection. As a result, less rising layer is found in the monsoon season.

4 Discussion and Conclusion

SODARs have been successfully used to study microclimates and to provide an integrated approach to the meteorological classification of pollutants concentration in major city. The inversion and convection height have a very important parameter for control of air pollution and predication. For the reason that the inversion height has below 300 m [2], and this has been perfectly measured using SODAR. SODAR echogram information is a good option to obtain atmospheric information as well as a real-time picture of the spatial distribution of the ABL structural features. It has been used for prediction of parameters like inversion height, average height of ABL, therefore this information has been helpful for authorities of environmental services. In predication, the direct view on the backscatter echo structure is much more helpful than code information, because the pictorial view of ABL provides more information of atmosphere. The SODAR echogram has provided many valuable ABL structures. On the other hand, SODAR echograms have given the lots of other atmospheric information, i.e., carry capacity of atmosphere, convection condition, fog, rain condition and other seasonal information. As it has been found, SODAR becomes necessary in operation of modern air-quality monitoring systems, which are responsible for operations of far-reaching economic and ecological consequences [2, 3]. Author is deeply convinced that SODARs should be considered as mandatory element of big air-monitoring systems and that this fact should be taken into account in national and international regulations for meteorological and environmental services.

References

1. Singal SP, Gera BS (1982) Acoustic remote sensing of the boundary layer. Sadhana 5(2):131–157
2. Singal SP (ed) (2006) Acoustic remote sensing applications, vol 69. Springer
3. Bradley S (2007) Atmospheric acoustic remote sensing: principles and applications. CRC Press
4. Kumar N, Soni K, Garg N, Agarwal R, Singh DSM, Singh G (2017) SODAR pattern classification and its dependence on meteorological parameters over a semiarid region of India. Int J Remote Sens 38:3466–3482
5. Danilov SD, Gur'yanov AE, Kallistratova MA, Petenko IV, Singal SP, Pahwa DR, Gera BS (1992) Acoustic calibration of sodars. Meas Sci Technol 3(10):1001
6. Chandara ND, Pal S, Chandra Patranabis C, Dutta HN (2010) A neurocomputing model for SODAR structure classification. Int J Remote Sens 31(11):2995–3018