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Wind shear studies in the lower atmosphere using forward scattering sodar system*

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सार — पवन दाब की उपस्थिति का अध्ययन करने के लिए राष्ट्रीय भौतिक प्रयोगशाला, नई दिल्ली में एक अग्रवर्ती प्रकीर्ण सोडार प्रणाली की स्थापना की गई है। इसमें तापमान और पवन इन दोनों ही असमरूपों का अनुभव करने की क्षमता है। मार्च-जलाई 1983 में लिए गये प्रेक्षणों से पता चला है कि तरंग की हलचल के सहित या इसके बिना नुकीले शीर्ष स्थिर परत, उद्गामी परत और उन्नत/बहुपरती संरचनाओं से ये प्रमुख पवन अपरूपण घटक होते हैं। यह समग्र योगदान उष्मीय असमरूपों के कारण होता है। प्रेक्षित पवन अपरूपण की अवधि, ऊंचाई, घटना का समय और उसकी सीमा का विश्लेषण करके उसकी सूचना दी गई है। वायुमण्डल में व्याप्त मौसम अवस्थाओं के संबंध में पवन अपरूपण की खतरनाक और गैर-खतरनाक प्रकृति का भी अध्ययन किया गया है।

ABSTRACT. For study of wind shear, a forward scattering sodar system has been set up at the National Physical Laboratory, New Delhi. It has the capability to sense both temperature and wind inhomogeneities exclusively. The observations made for the period March-July 1983 have shown that a large part of the spiky top stable layer, rising layer and elevated/multilayer structures with or without wave motion have predominant wind shear component over and above the contribution due to thermal inhomogeneities. Duration, height and time of occurrence and the extent of observed wind shear have been analysed and reported. Studies have also been made of the hazardous and non-hazardous nature of the wind shear with respect to weather condition prevalent in the atmosphere.

1. Introduction

It is now well known that wind shear in the lower few hundred metres of the atmosphere can be hazardous to aviation (Beran 1974) causing long and short landings as shown in Fig. 1. However, most of the time, the only data available are the ground level wind velocity measured by the anemometers, the routine measurements (twice a day) of winds at a few levels in the troposphere by radiosonde and the tower or balloon measurements at a few places in the lower atmosphere which lack both temporal and spatial resolution necessary in a real time system. Methods to monitor wind shear parameter at the airports and at places close by are, therefore, needed to be established to provide the pilot a warning to plan and execute timely and appropriate action to save a severe air accident.

In this paper, the results of a simple remote sensing technique of forward scatter sodar used in conjunction with back scatter sodar have been described to detect the presence of wind shear in the lower atmosphere. The attempt has been made after analysis (Singal *et al.* 1982) of the many stable layer structures observed on back scatter sodar echograms had indicated the presence of wind shear component in them. The system has the capability to identify the effects of both temperature and wind inhomogeneities.

2. Theoretical background

An acoustic wave propagating in the atmosphere is scattered (Little 1969) both due to temperature inhomogeneities (represented by temperature structure parameter C_T^2) and wind inhomogeneities (represented by velocity structure parameter C_V^2). The scattering cross-section $\sigma(\theta)$ per unit volume at an angle θ can be written as :

$$\sigma(\theta) = 2\pi k^4 \cos^2\theta \left[\frac{C_V^2}{C^2}\cos^2\frac{\theta}{2} + \frac{C_T^2}{4T^2}\right] \left(\sin\frac{\theta}{2}\right)^{-11/3}$$

where k is the wave number, C is the sound velocity and T is the ambient temperature of the atmosphere. Fitted into the sodar equation $P_r = P_t \cdot \frac{C\tau}{2} \cdot \frac{AL}{R^2} \cdot E. \sigma(\theta)$, it gives information about the received power and helps to determine the structure parameters. Here P_r is the received power, P_t is the transmitted acoustic power, A is the received area, R is the range, L is the attenuation function, τ is the pulse duration and E is the efficiency function taking into account antenna parameters.

*Based on the paper presented at the Second International Symposium on Acoustic Remote Sensing of Atmosphere and Oceans held at Rome from 29 August 1983 to 1 September 1983.

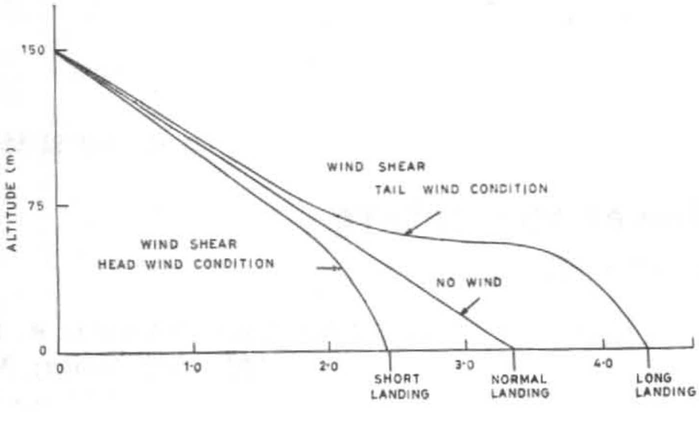

Fig. 1. Long and short landing of an aeroplane due to the presence of a wind shear layer in the boundary layer

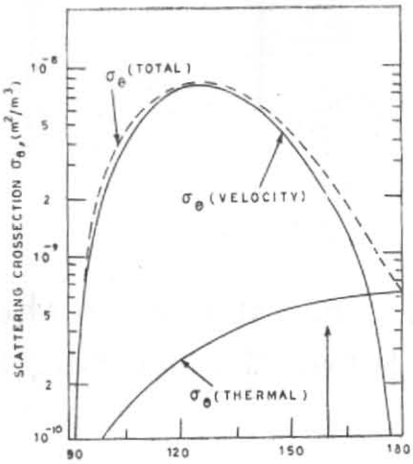

Fig. 2. Plot of the acoustic scattering cross-section as a function of angle of scatter

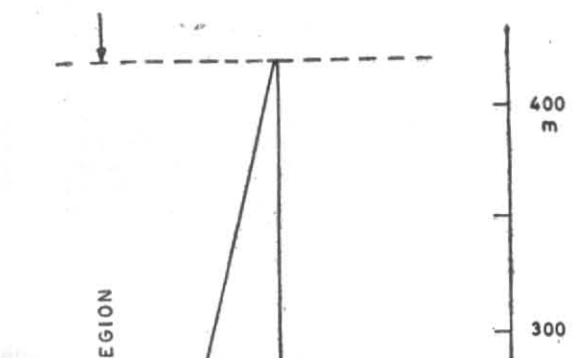

Fig. 3. Plan of the forward and back scattering sodar system setup at the National Physical Laboratory, New Delhi

The scattering cross-section plot shown in Fig. 2. on the basis of the above equation clearly shows that back scattering is only due to temperature inhomogeneities and occurs in the range of angles 171-180 degrees; forward scattering takes into account both temperature and wind inhomogeneities, however, with the difference that scattering due to wind inhomogeneities is, in general far higher than scattering due to temperature inhomogeneities making it thus possible to consider the effects of thermal and wind inhomogeneities separately and finally that there is no scattering at an angle of 90 degrees. For these computations we have assumed the following values of the parameters :

$$C_T^2 = 4\times10^{-3}\ \text{k}^2\ \text{m}^{-2/3}\ ;\quad C_V^2 = 8\times10^{-2}\ \text{m}^{4/3}\ \text{sec}^{-2}$$

$$T = 300\ \text{K}\ ;\quad C = 340\ \text{m sec}^{-1}$$

3. Experimental set-up

The forward scattering sodar system consists of a back scatter sodar complete with its transmit and receive system and an obliquely transmitting toneburst generator placed at a distance of 100 m from the back scattering sodar system (Fig. 3.) The specifications of the obliquely transmitted toneburst are the same as that of the back scattering sodar (Singal and Gera 1982) but its transmission is always delayed by a few hundreds of milliseconds compared to the toneburst of the back scattering sodar. The range of the back scattering sodar is 700 m. The oblique transmission is at an angle of 20° with the vertical so that the volume of air scattering the oblique toneburst is in the height range of 200-425 m vertically above the back scattering sodar.

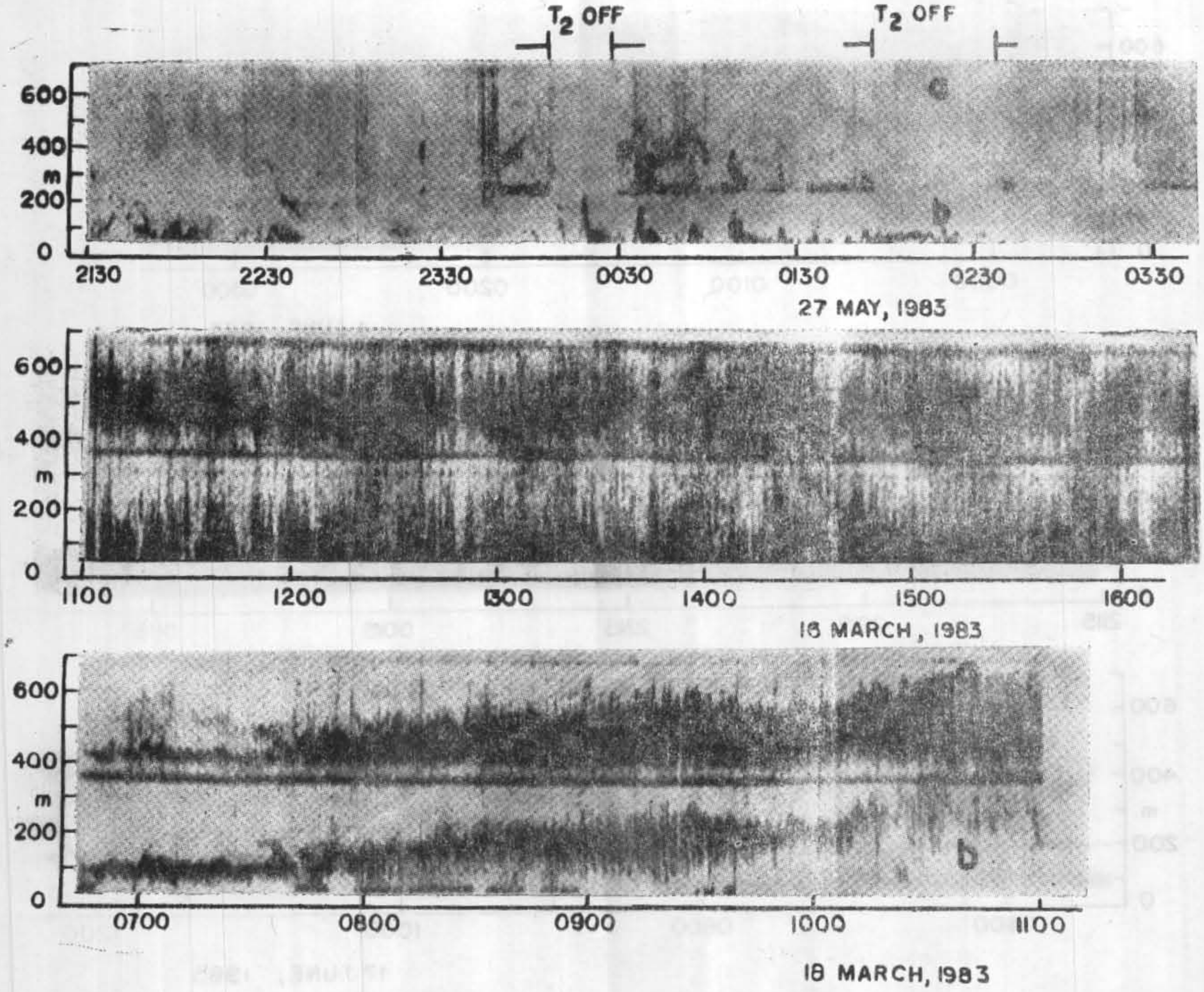

Fig. 4. Foward and back scattered sodar echograms showing (*i*) Switching off the oblique transmission to confirm that the upper layer represents forward scattered echoes; (*ii*) scattering due to thermal plumes, and (*iii*) scattering due to rising inversion layer

The back scattering sodar received not only the back scattered but also the forward scattered echoes (delayed) from the same inhomogeneities in structure. To distinguish clearly the effects of thermal and wind inhomogeneities, care has been taken that transmitted intensity in both the tonebursts is the same.

4. Results and discussions

The preliminary experiment (Singal *et al.* 1983) on forward scattering was conducted in December 1980 and January 1981 wherein it had been seen that forward scattering could be a potential technique to identify wind shear layers. To study the use of the technique further, in the following are discussed the results of observations made by the forward scattering sounder at the National Physical Laboratory, New Delhi (India) during the premosoon and mosoon months of March-July 1983. The period is very interesting for studies since many elevated/multi-layer structures are observed on sodar echograms due to frontal motions in the lower atmosphere. The echograms could be obtained for 62 days during this period.

Echograms showing characteristic behaviour of forward scattering *vis-a-vis* back scattering under various atmoshpheric conditions are represented in Figs. 4 & 5. The intermittent switching off the oblique toneburst generator (T_2) represented in Fig. 4(*i*) clearly shows that lower structures are due to back scattered received echoes while upper structure are due to forward scattered received echoes. Delay time in the transmission of oblique tone-burst can be clearly seen by a strong continuous horizontal line at a height around 200 m in the figures. It may also be noted that forward

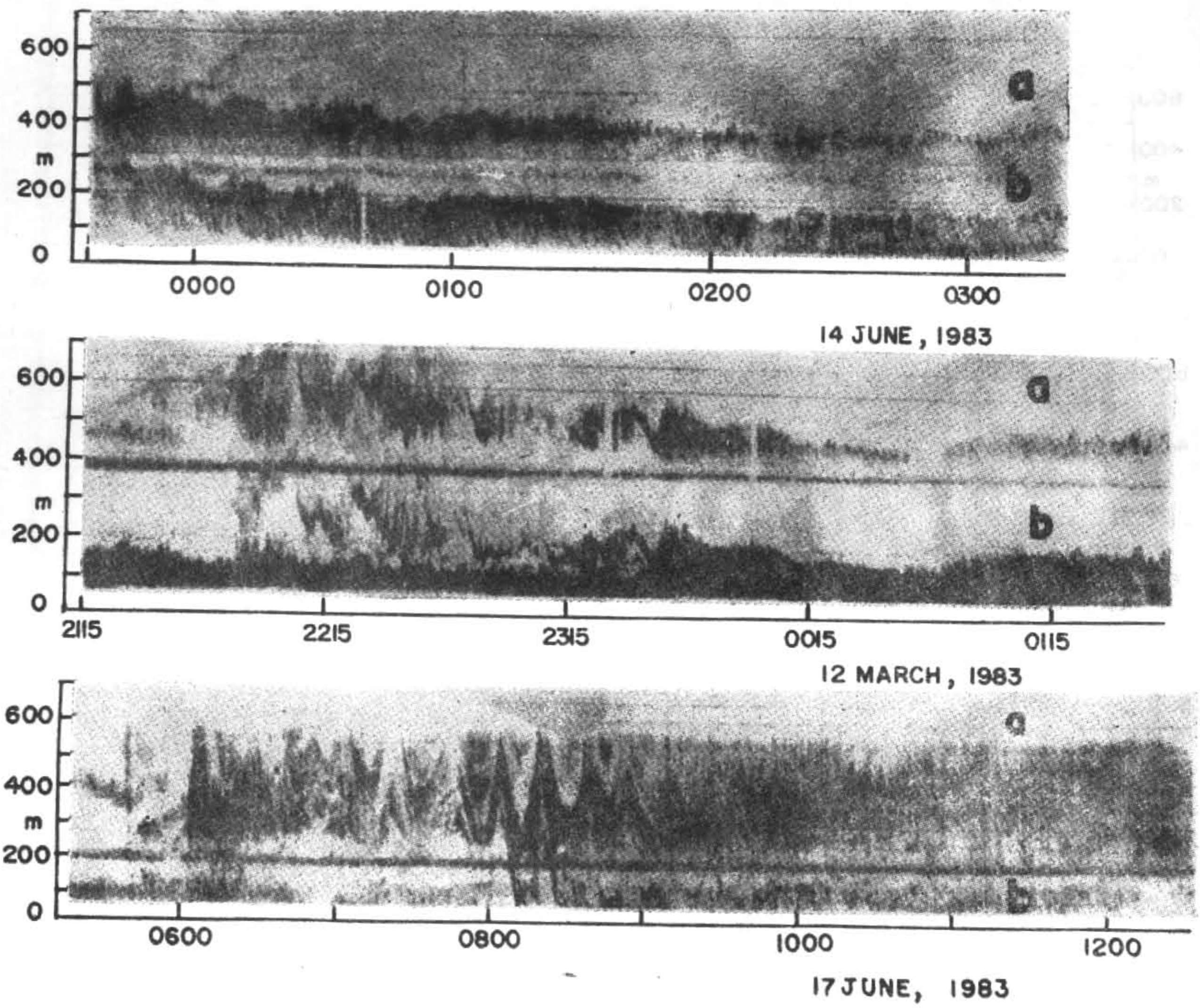

Fig. 5. Forward and back scattered sodar echograms showing (*i*) scattering due to surface based layer, (*ii*) scattering from elevated layer, and (*iii*) scattering from wavy structures

scattered echoes do not pertain to the marked height which indicates the depth only of the back scattered received echoes.

The observation of the upper layers on the sodar-echograms in the forward scattering configuration can be due to either specular reflections or scatter from temeprature fluctuations alone or scatter from velocity fluctuations alone or scatter from both temperature and velocity fluctuations. It is felt that these layers cannot be due to specular reflections since specular reflections should always appear at the same place undisturbed and should be seen even on other normal days which has not been true. These layers cannot also be due to back scatter from another higher level. Evidently then the observed forward scattered layer can be due to either temperature fluctuations alone in the layer or wind inhomogeneities alone in the layer or both temperature and wind velocity inhomogeneities in the layer, contributions which can be identified through a study of the intensity of the received echoes.

A look at the echograms given in Figs. 4 & 5 show that forward scattered intensity can be relatively more equal or less than the back scattered intensity when compared for the same height ranges. A detailed qualitative study of the forward and back scattered intensity of the received echoes has been made for the period under study from where the following can be clearly inferred:

(*i*) In case of thermal plumes forward scattered echces are not as sharp as back scattered echoes and further that intensity of forward scattered echoes is more or less comparable to that of back scattered echoes. This may indicate that forward scattering from regions of thermal echoes may be due to temperature fluctuations alone.

(*ii*) Rising layer in the height range of 250-350 *m* has even chances of showing both higher and comparable intensity in the forward scattered

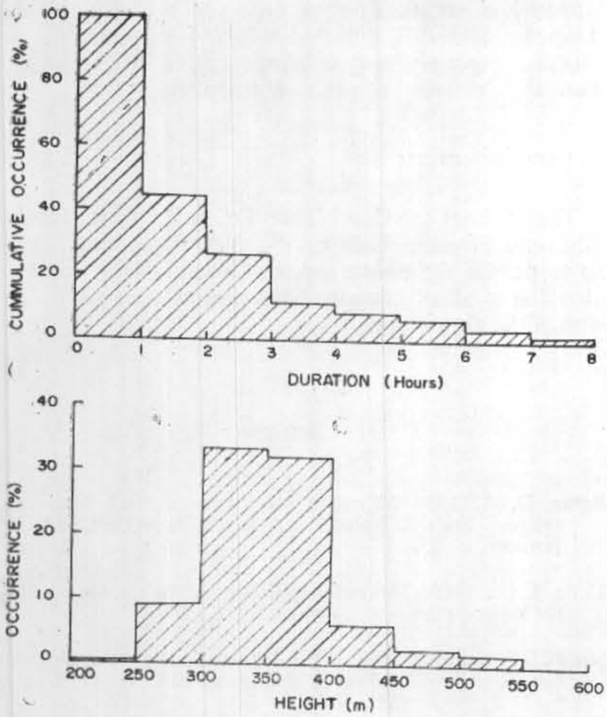

Fig. 6. Occurrence probability plot of the duration period and height of the wind shear layers

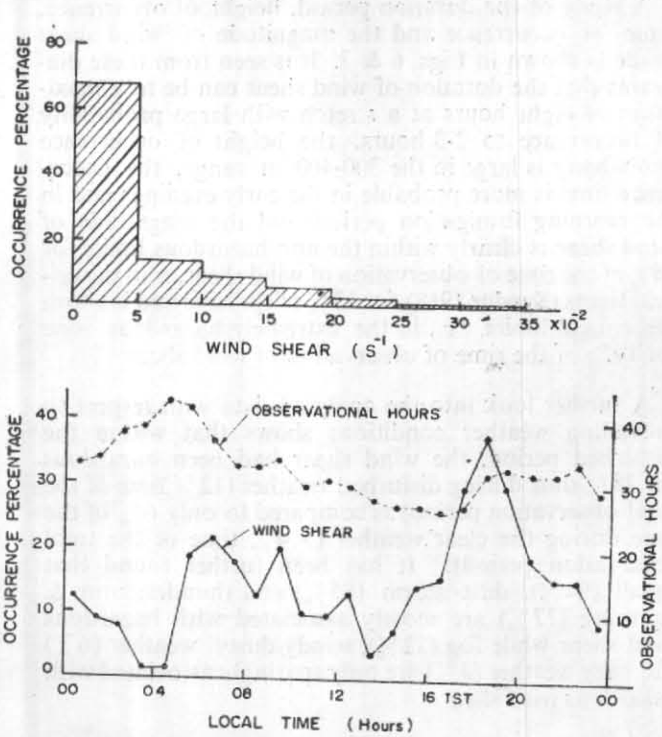

Fig. 7. Occurrence probability plot of the time of occurrence and magnitude of wind shear

echoes as compared to back scattered echoes indicating the presence of wind inhomogeneities in such structure on many occasions.

(*iii*) In case of ground based surface layer the structures with tall spikes at the top have higher intensity in the forward scattered echoes as compared to back scattered echoes. This indicates that tall spiky structures have a dominance of wind inhomogeneities while flat or short spiky structures may indicate mainly the presence of temperature inhomogeneities. It may, however, be pointed out here that in short spiky top or flat top structures the height of the observed structures was generally less than 250 m, a range where in the shape of the transmitted oblique tone-burst lobe can introduce biasing in the interpretation of the results.

(*iv*) Elevated/multilayers observed under clear weather conditions have even chances of the presence of both wind shear and thermal inhomogeneities. However, on days of frontal disturbances the forward scattered structures show higher intensity as compared to back scattered echoes indicating dominance of wind shear under such conditions.

(*v*) Wave motions obtained on sodar echograms under clear weather conditions have chances of their being associated with wind inhomogeneities, however, the chances of the wave motion indicating the presence of wind inhomogeneities are more on days of frontal disturbances.

By feeding the hourly averaged intensity data of both back scattered and forward scattered echograms, quantitative studies of temperature and wind velocity structure parameters have also been carried out using the sodar equation for the received intensity in conjunction with the scattering cross-section equation. Wind shear information has been drawn subsequently from the velocity structure parameter C_V^2 following its basic definition according to which

$$C_V^2 = \left\langle \left(\frac{V(x) - V(x+r)}{r^{1/3}} \right)^2 \right\rangle_{\text{aver.}}$$

For our computations we have taken the distance vector r equal to 10 m which is our sodar range resolution.

The analysis of the data has shown that out of the total 789 hours of observation, for 13.1% cases only temperature structure parameter C_T^2 has been responsible for acoustic scattering, for 20.1% cases only velocity structure parameter C_V^2 has been responsible for acoustic scattering while for 66.8% cases both the structure parameters have been contributing to observed acoustic scattering. Evidently, the echograms due to temperature structure parameter alone have no wind shear information, the echograms due to velocity structure parameter alone represent the exclusive presence of wind shear layers in the atmosphere while the echograms due to both the parameters have chances of the presence of wind shear. It has been further found that for 43% of the observed time, the weather had been disturbed while for the rest 57% of the time, the weather had been clear.

A study of the duration period, height of occurrence, time of occurrence and the magnitude of wind shear made is shown in Figs. 6 & 7. It is seen from these diagrams that the duration of wind shear can be to a maximum of eight hours at a stretch with large probability of occurrence to 2-3 hours, the height of occurrence probability is large in the 300-400 m range, the occurrence time is more probable in the early evenings and in the morning fumigation period and the magnitude of wind shear is clearly within the non-hazardous limits for 68% of the time of observation of wind shear, is in the critical limits (Synder 1968) for 13% of the time and is above the critical limits, *i.e.,* in the extremely hazardous zone for 19% of the time of observation of wind shear.

A further look into the analysed data with respect to prevailing weather conditions shows that within the disturbed period, the wind shear had been hazardous for 28% time during disturbed weather (12% time of the total observation period) as compared to only 6% of the time during the clear weather (3.4% time of the total observation period). It has been further found that squall (94%), dust storm (85%) and thunderstorm & lightning (77%) are mostly associated with hazardous wind shear while fog (22%), windy/dusty weather (6%) and hazy weather (4%) are only sparingly associated with hazardous wind shear.

5. Conclusions

From the analysis of the observed results it has been shown that forward scattering sodar system has a large potential for its use to detect the presence of wind shear component in the layer structures formed under stable conditions. A quantitative estimation of wind shear has further shown that squall, dust storm and thunderstorm & lightning are mostly associated with hazardous wind shear for a couple of hours even after the fury of the storm had subsided. It is, however, felt that the use of Doppler Sodar is required where wind shear is to be studied precisely and continuously in the lowest few hundred metres of the atmosphere.

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