Mausam, (1982), 33, 4, 439-444

551.554 : 551.551.8

Studies of correlation between sodar observed stratified layer structures and wind shear

S. P. SINGAL, S. K. AGGARWAL and B. S. GERA

National Physical Laboratory, New Delhi

(*Received 23 December 1980*)

सार – मौसम की सभी दशाओं में रा० भौ० प्र०, दिल्ली में अंकित सोडार इकोग्रामी सतही आधारी परतों के अतिरिक्त स्तर विन्यास परतों को अनेक बार दर्शाते हैं । ये परतें एकल या बहु, सतत या असतत एवं क्षोभों से अध्यारोपित हो सकती है । मई 1977 से अप्रैल 1979 तक की अवधि में प्रेक्षित आंकड़ों की उनकी ऊँचाई, मोटाई, समय, व्युतक्रमण प्रवणता का अंश और पवन अपरूपण के संदर्भ में विश्लेषण किया गया है यह देखा गया है कि सभी प्रकार के प्रबल एवं दुर्बल पवन अपरूपण एवं व्युतक्रमण दशाओं में स्तर विन्यासी/उन्नयित परतें पाई जाती हैं । इस प्रकार झंझाओं या शीत वाताओं के आने के दिनों में प्रेक्षित परतों को प्रबल पवन अपरूपण की दशाओं के साथ देखा गया है । तूफान के दौरान सतही तापमान में यकायक गिरने के दिनों में पवन अपरूपण के परिमाण की गणना की गई है । गणना से प्राप्त पवन अपरूपण मान विमानन के के लिए एक हानिकारक स्थिति को दर्शाते हैं ।

ABSTRACT. Sodar echograms recorded at Delhi (NPL) under all weather conditions have shown many a times stratified layers in addition to the surface based layer. These layers may be single or multiple, continuous or intermittent and may be superposed with perturbations. Data observed for the period May 1977-April 1979 have been analysed with respect to their height, thickness, time, degree of inversion gradient and wind shear. It has been seen that stratified elevated layers occur under all kinds of strong or weak wind shear and inversion conditions. However, layers observed on days of occurrence of thunderstorm or cold fronts have been seen to be accompanied with strong wind shear conditions. The magnitude of wind shear has been calculated on days of sudden drop in surface temperature occurring during the storm. The calculated wind shear values show a hazardous situation for aviation.

1. Introduction

Analysis of several major aircraft accidents (Hardesty *et al.* 1977; Fujita & Caracena 1977) has established beyond doubt that low level wind shear can sometimes reach magnitudes that exceed the design capabilities of the aircraft and the ability of the crew to take corrective action. The sudden change in the lift power of an aircraft within any altitude interval in the lower atmosphere can be critical for safe take off and landing phases. To overcome this complex problem of wind shear in aviation, a need has arisen to monitor wind shear at airports.

Wind shear (Hardesty *et al.* 1977) is recognized to be of two types. It may be associated with large scale frontal or inversion surfaces and usually occurs above the ground with little or no surface manifestation. Alternately, it may be related to the fronts that result from cold down currents generated by or associated with intense convective activity and produces marked changes in surface wind, temperature and pressure. It can be measured rapidly and continuously with improved spatial and temporal resolution using remote sensing devices (Derr & Little 1970) involving electromagnetic and acoustic waves. However, electromagnetic devices as compared to the acoustic devices give only a limited information in the boundary layer. Doppler sodar can give a measure of the wind shear to a height varying between ground and 500 m while a vertically sounding sodar can give a continuous picture of the turbulent structure in the boundary layer from a lowest height of about 25 m to a height varying between 500 and 1500 m. Herein height and time variation of temperature inversions and wind shear zones can be monitored (Holmgren *et al.* 1976). Although the backscattering sodar looks only at the thermal structure of the boundary layer, it has however, been shown (Wyngaard *et al.* 1971) that wind shear is a parameter incorporated in the thermal structure parameter itself.

In a vertically sounding acoustic sounder, a stable layer near the ground gives rise to one or more quasi-horizontal echoes with band structure in small intervals of height. These layer/layers,

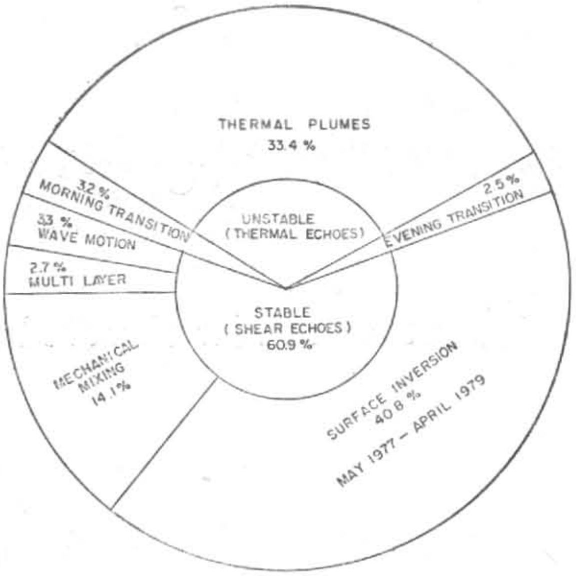


Fig. 1. Occurrence percentages of the various types of sodar structures on the NPL sounder (Data pertains to the period May 1977 to April 1979)

usually a few tens metres thick, correspond in height to regions of sharp vertical gradients in refracting index. In the presence of a marked wind shear within an inversion, structures similar to refractive waves may also occur. Ottersten *et al.* (1973) have ascribed these clear air scattering layers to zones of enhanced static stability with vertical shear of the horizontal wind accentuated. Small scale overturning and turbulence may breakout within these thin zones or layers after the strengthening of the shear by large scale processes. Holmes *et al.* (1976) have linked the slightly rounded saw tooth appearance of the wave reflecting layers to the existence of cold fronts. The appearance of these waves is accompanied with a drop in temperature of about 2° C during the event measured on a continuously recording Stevenson screen. The echoing layers mark the dynamically unstable upper limit of the cool downdraft and the somewhat broken waves indicate the presence of strong wind shear.

It is also possible that echoes from wind shear without pronounced temperature inversion can come about even in the presence of weak to medium surface winds. With these points in view the sodar observed data of stratified/elevated layers under stable conditions have been analysed and reported in the following.

2. Experimental results and discussions

During the course of the two years observations from May 1977 to April 1979, data were recorded for 400 days covering 8840 hours of observations. Out of the 60.9 per cent time of the occurrence of shear echoes, for 6 per cent of the time stratified/elevated layer structures with or without the wave motion superposed over it were seen (Fig. 1). Layers superposed with wave motions were seen for 3.3 per cent of the time (waves over elevated layers for 2.0 per cent of the time and over stratified layers for 1.3 per cent of the time) while for 2.7 per cent of the time layer structures without waves (stratified layers for 1.5 per cent of the time and elevated layer for 1.2 per cent of the time) were seen. It has been further seen that for most of the time (around 80 per cent) of the wave structure was of the broken wave type.

The few distinct types of structures of the horizontally stratified/elevated layers are shown in Fig. 2. It is seen that these echo patterns are of the following types :

(*i*) an elevated layer over and above the surface based layer,

(*ii*) thin multiple layers alongwith the surface based layer and

(*iii*) slow sinusoidal undulations on the layers showing sometimes overturning features like a sharp vortex or a slightly rounded sawtooth appearance.

These stratified/elevated layer structures over Delhi have been found to be mostly occurring within a height range of 150-300 m (Fig. 3a) although they have also been seen to exist sometimes upto a height of 500 m. The most probable thickness of these layers (Fig. 3b) is within the range 25-50 m while layers as thick as 100 m have also been seen. These layers occur very often after midnight although they can occur at any other time of the day also. The duration time of the layers with superposed undulations is mostly within a couple of hours (Fig. 4) although they have been seen to exist as long as ten hours at a stretch.

To link the occurrence of the stratified/elevated layer structures to the existence of temperature inversion and/or to the presence of wind shear the observed features of these layers have been

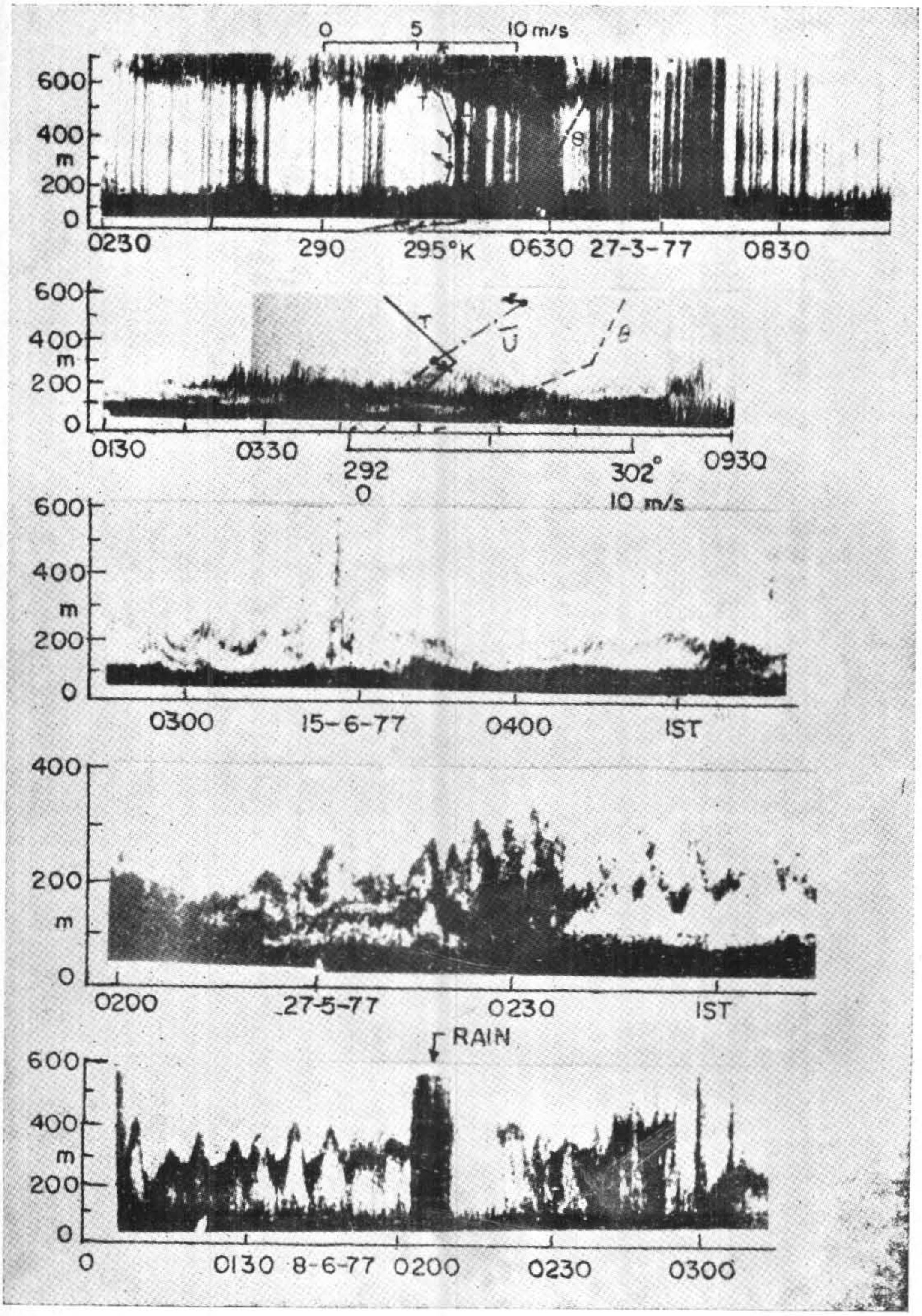
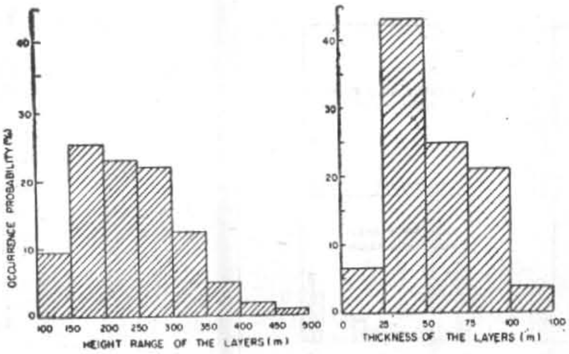


Fig. 2. Time height sodar records of the stratified/elevated layer structures



(a) (b)

Fig. 3. Plot of occurrence probability and (a) height range and (b) thickness of the stratified/elevated layers

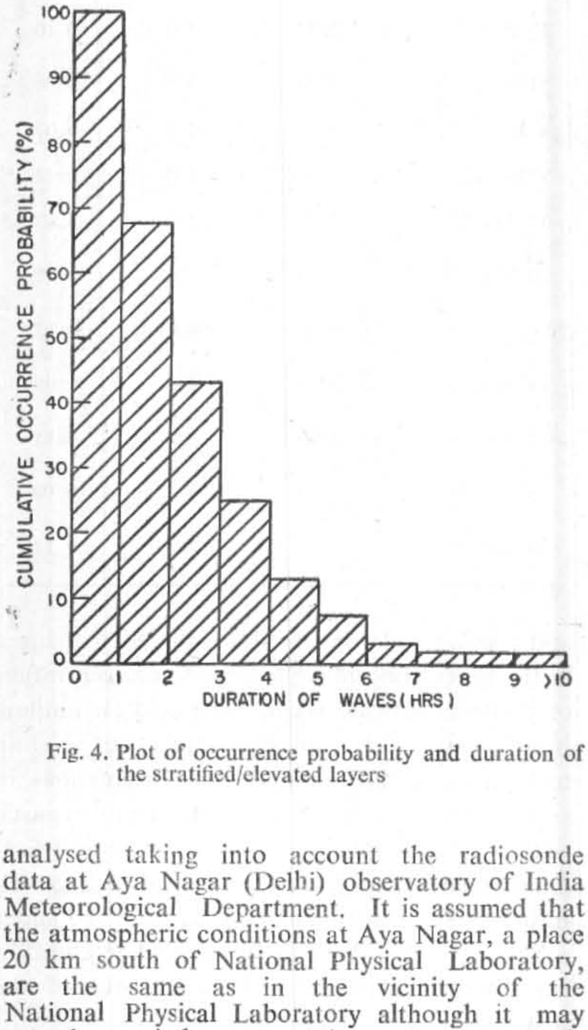


Fig. 4. Plot of occurrence probability and duration of the stratified/elevated layers

analysed taking into account the radiosonde data at Aya Nagar (Delhi) observatory of India Meteorological Department. It is assumed that the atmospheric conditions at Aya Nagar, a place 20 km south of National Physical Laboratory, are the same as in the vicinity of the National Physical Laboratory although it may not be strictly true. These data are available here twice daily at 0000 and 1200 GMT over a height range of about 25 km but for our purpose only the data at the surface level and at the first significant level at a height around 250 m above ground are important. Potential temperature gradient and wind shear have been computed from these data for the days of stratified/elevated layers for times close to the occurrence of the layers. Wind shear equal to or more than 0.4/sec in magnitude or equal to or more than 45° in direction has been taken to be strong while lower values have been termed to represent weak. The selection of these limits has been made on the basis of the analysis of the available data with respect to the ambient conditions.

On the basis of the above data from the radiosonde, it has been found that the stratified layer can be categorized under the following four kind of combinations of inversion and wind shear :

(*i*) strong wind shear and weak inversion,

(*ii*) strong wind shear and strong inversion,

(*iii*) weak wind shear and strong inversion and

(*iv*) weak wind shear and weak inversion.

The existence of the layers under conditions of strong wind shear and weak inversion is 18 per cent, under conditions of strong wind shear and strong inversion is 15 per cent, under conditions of weak wind shear and strong inversion is 35 per cent while under conditions of both weak wind shear and weak inversion is 32 per cent. From this it seems that layers under strong wind shear conditions exist only for one third time of the presence of layer structures, *i.e.*, for 2.0 per cent of the total time of observation of the sodar echograms for the two years period. Further it is seen that strong stable conditions can be associated with both strong and weak wind shear and that the strong wind shear is not always related to the observation of waves on sodar

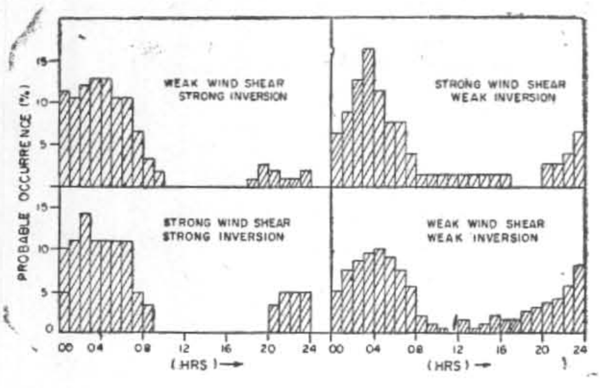


Fig. 5. Diurnal variations of the occurrence probability of the layer structures under the four conditions of stability and wind shear

echograms. The surface winds on days of strong wind shear have been blowing from light to moderate (4-8 m/s), clear nights have mostly strong temperature stability while under weakly stable conditions the weather had been cloudy, dusty, rainy or has experienced a thunder storm. A cold front has been mostly followed by a sudden drop in surface temperature and a wave like turbulence has also been seen on the sodar echogram. Strong wind shear has been mostly witnessed either in pre-monsoon weather or post-monsoon weather while weak wind shear has been seen scattered all over the year.

The diurnal variations of the probable occurrence of the layers for the four different conditions of temperature inversion and wind shear are shown in Fig. 5. It is seen from this diagram that wind shear under strong inversion conditions is visible mostly after mid-night, *i.e.,* in the early hours of the morning while wind shear under weakly stable conditions is possible at any hour of the day, however, the maximum probability is in the early morning hours only.

3. Wind shear studies on days of thunderstorm

A duststorm/thunderstorm (Byers & Braham 1949) quite often generates a vigorous rain cooled downdraft which spreads out horizontally as it reaches the surface. The resulting cold outflow is led by a strong front (wind surge) along the discontinuity between the cold dense air and the less dense ambient environment and causes rapid wind speed and direction changes in the lower atmosphere leading to the generation of pronounced wind shear. The cold air outflow from storms is statically stable but hightly turbulent and thus exhibits large fluctuations in acoustic refractive index leading to strong acoustic echoes. The signatures of the meteorological phenomena are made in the form of a deep well mixed layer or an undulating layer on the sodar echogram and a drop in surface temperature on the Stevenson screen with the arrival of the first surge.

Mitchell (1975) has shown that a temperature drop due to a cold front is always associated with wind shear and further that the larger the temperature drop, the greater the observed wind

TABLE 1

Sodar data and values of derived wind shear on days of fronts

Date	Time of occurrence of the front (IST)	Temperature drop $\triangle T$ (°C)	Wind shear (s^{-1})
7 Jun 77	1945	8.0	0.16
13 Jun 77	1945	4.5	0.12
14 Jun 77	0630	3.0	0.08
15 Apr 78	2000	3.5	0.09
18 Apr 78	2130	4.0	0.10
31 May 78	1830	3.5	0.08
8 Jun 78	0500	2.5	0.07
9 Jun 78	2330	7.0	0.12
14 Jun 78	1530	2.0	0.07
30 Mar 79	2100	3.0	0.10
24 Apr 79	0945	4.0	0.13
14 May 79	2030	4.5	0.09
12 Jun 79	1300	4.0	0.11
15 Jun 79	1630	3.5	0.09
30 Jun 79	1545	5.0	0.12

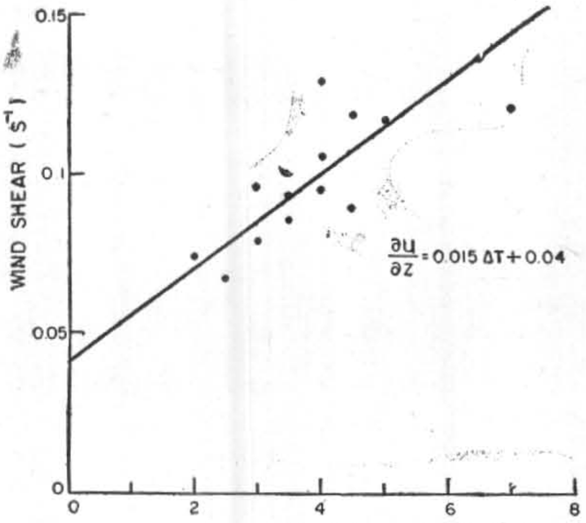


Fig. 6. Plot of calculated wind shear and temperature drop for the various days of front

shear associated with it. Hall *et al.* (1976) have worked a model relating temperature drop to wind shear. According to this model :

$$\frac{\partial u}{\partial z} = \frac{1}{\alpha R_i}\left(\frac{\triangle T}{ghT}\right)^{\frac{1}{2}}$$

where α is a constant whose value has been worked out to be $\sqrt{2}$ when the dissipative processes (Benjamin 1968) are neglected, R_i is the Richardson number, $\triangle T$ is the drop in temperature, T is the atmospheric temperature and h is the height range of the cold front.

The above equation has been applied to the many cold fronts observed by the NPL sounder to calculate the wind shear using the drop in temperature seen in the surface temperature during the course of the duststorm/thunderstorm. The height range of the cold front was measured from the observed height of the layer/layers on the sodar echogram while the Richardson number R_i was assumed to be equal to 0.2 in all the cases as this is the most probable value under these conditions. It may be remarked here that on all these days the echo structure on the sodar echograms is of the broken wave type with a sharp peak.

The calculated values of wind shear are given in Table 1 for the various days on which a layered structure was observed after a duststorm/thunderstorm. It is seen that on quite a few days of the cold out-flow wind shear is greater than 0.1 s^{-1} while on the rest of the days it is close to 0.1 s^{-1} which can be hazardous (Synder 1968) to large, swept wing, jet-powered aircraft for a couple of hours or more after a duststorm/thunderstorm has blown over. The value of wind shear obtained in Table 1 have also been plotted (Fig. 6) against the corresponding drop in temperature observed during the occurrence of the front. The representative behaviour of these plots is seen in the shape of a straight line which can be expressed mathematically as :

$$\partial u/\partial z = 0.015\ \triangle T + 0.04$$

This empirical equation offers an easy solution to determine the wind shear at a place from the temperature drop alone noticed on the day of a cold front. It may, however, be seen that in the above calculations, we have assumed a value of 0.2 for R_i which may not be strictly valid. A detailed analysis of R_i at any place is, therefore, needed before arriving at the final equation for wind shear in terms of temperature drop on a day of cold front.

4. Conclusion

It has been thus seen that under stable conditions stratification of the surface based inversion layer is due to wind shear. Echoes representing wind shear have been observed both with and without the presence of pronounced temperature inversion, although, Beran *et al.* (1971) have observed that areas of maximum temperature structure parameter are associated with regions of vertical wind shear. It may be remarked that relation between sodar records and temperature and wind profiles is difficult to establish with the present work since these measurements have not been made at the same place and at the same time with high resolution.

Wind shear associated with fronts has been calculated for the cases where a drop in surface temperature during the occurrence of front had been available. It has been seen that in these cases wind shear far exceeds the safe limits required for aircraft safety for their take off and landing phases. These cases can be easily distinguished on sodar records by their typical broken wave structure.

The above studies suggest that probing by conventional techniques and Doppler sodar should be taken up at the earliest to measure wind velocity and wind shear in the planetary boundary layer. These measurements may also help to develop a pattern recognition technique using monostatic sodar to monitor boundary layer for wind shear information.

Acknowledgements

Authors are thankful to Dr. A.P. Mitra for his keen interest and encouragement in carrying out the above work. Thanks are also to India Meteorological Department for their supplying us the radiosonde data to help us to interpret the sodar results.

References

Benjamin, T. B., 1968, *J. Fluid Mech.*, **31**, p. 209.

Beran, D. W., Little, C. G. and Willmarthn, B. C., 1971, *Nature*, **230**, p. 160.

Byres, H. R. and Braham, R. R., 1949, *The Thunderstorms*, U. S. Department of Commerce, Weather Bureau, Washington, D.C.

Derr, V. E. and Little, C. G., 1970, *Appl. Optics*, p. 1976.

Fujita, T. T. and Caracena, F., 1977, *Bull. Am. met. Soc.*, **58**, p. 1164.

Hall, F. F. (Jr.), Neff, W. D. and Frazier, T. V., 1976, *Nature*, **264**, (5585), p. 408.

Hardesty, R. M., Mandics, P. A., Beran, D. W. and Strauch, R. G., 1977, *Bull. Am. met. Soc.*, **58**, p. 910.

Holmes, N. E., Lunken, A. C. and Mellveen, J. F. R., 1976, *Weather*, p. 218.

Holmgren, B., Jacobson, C. and Ottersten, H., 1976, 'Sounding of the boundary layer of atmosphere by means of a vertical sodar', FOA Report C 300 77-E, p. 75, Defence Research Institute 10450, Stockholm 80, Sweden (in Swedish).

Mitchell, K. E., 1975, 'A numerical investigation of severe thunderstorm gust fronts', NASA Report CR-2635, Pennsylvania State Univ. Contr. NAS8-27334.

Ottersten, H., Hardy, K. R. and Little, C. G., 1973, *Boundary Layer Met.*, **4**, p. 47.

Synder, C. T., 1968, 'Analogue study of longitudinal response to wind shear and sustained gusts during landing approach', NASA TND 84447, Amer. Research Centre, Moffett Field, California.

Wyngaard, J. C., Izumi, Y. and Collins (Jr.), S. A., 1971, *J. Opt. Soc. Amer.*, **61**, p. 1646.