Wind shear and correlation with turbulence parameters

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MST radar: Wind shear and its correlation with turbulence parameters

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ST/MST clear-air Doppler radar has become an important tool in observational meteorology because of its capability to remotely observe dynamic parameters of the atmosphere. Wind shear measurements made with the Indian MST radar are presented. Significant wind shear is consistently observed between 7.0 and 8.5 km. Wind shear is correlated with different turbulence parameters.

1 Introduction

Vertical shear in horizontal wind is important from atmospheric dynamics point of view as well as from practical point of view. Wind shear is widely recognized as a significant hazard for rocket launching and missile launching. The effect of wind shear on launch vehicles for heavy payloads is a serious problem. Wind information is needed for programming the steering of the launch vehicles and to assess mechanical stress during the ascent[1]. Wind data with a good height resolution is required up to the altitude where wind generated stress on the launch vehicles is no longer a problem, typically 20 km (Ref. 2).

MST radar is an excellent ground-based instrumentation system for remote sensing of the atmosphere. It has the capability of measuring winds over a large height range, with a good height resolution and an excellent time resolution. Thus the data provided by MST radar can be used to complement and supplement the data provided by balloon soundings. Data provided by the Indian MST radar could become an important component for determining acceptable launch conditions of augmented satellite launch vehicle (ASLV) and polar satellite launch vehicle (PSLV) from SHAR Centre, Sriharikota, which is at a distance of 80 km from the MST radar site.

2 Experimental description

The ST mode of the Indian MST radar[3], which has been installed at Gadanki (13.47°N, 79.18°E), near Tirupati in Andhra Pradesh, has now become available for scientific observations. The specifications of the ST mode of this system are given in Table 1.

The Indian MST radar uses pulse compression technique which enables a height resolution of 150 m. Thus the wind velocities provided by Indian MST radar are very much useful in computing wind shear in height intervals as small as 150 m.

With the objective of measuring wind shear in the troposphere, an experiment was conducted with 6-beam positions (East, West, zenith-X, zenith-Y, North, South) with 16 μs coded pulse and 1 ms inter-pulse period, 128 coherent integrations, and 128 FFT points. Thus the frequency resolution is 0.06 Hz and the velocity resolution is 0.17 ms^{-1}. The minimum detectable wind shear coefficient becomes equal to 0.001 s^{-1}. Experimental specifications are given in Table 2.

A typical Doppler spectral plot taken on East beam is shown in Fig. 1. A small change in Doppler frequency can be seen up to an altitude of 6.5 km and a large Doppler shift is observed between 6.5 km and 8.0 km. A change in Doppler frequency of 2 Hz is also observed between 9 km

Table 1—Main specifications of the ST mode of Indian MST radar

Frequency	: 53 MHz
Peak radiated power aperture	: 3.00×10^8 Wm^2
Average radiated power aperture	: 4.80×10^6 Wm^2
Total peak power	: 180 kW
Maximum duty	: 2.5%
Height resolution	: 150 m
Total No. of Yagi elements	: 256 (16×16)
Polarization	2 (EW and NS)
Physical aperture	: 4018 m^2
Effective aperture	: 3661 m^2
Beam width	: 4.6°
Beam direction	6 [zenith (X, Y)], ±20° from zenith in meridional and ±20° from zenith in zonal plane)

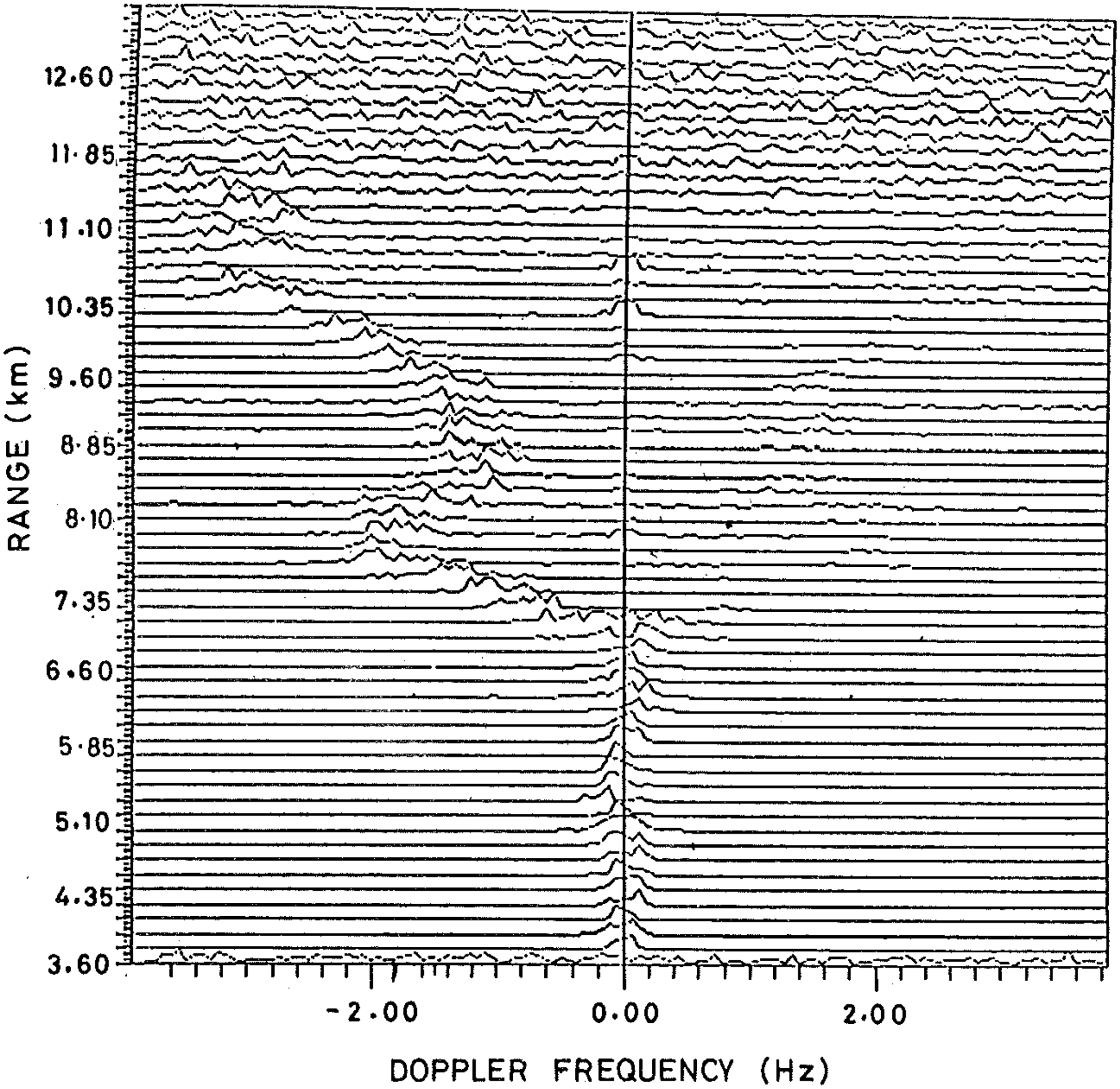

Fig. 1—A typical Doppler spectral plot using East beam on 25.4.'92 taken at 1:30:4 hrs IST.

Table 2—Experimental specifications

No. of range bins	: 129
No. of FFT points	: 128
No. of coherent integrations	: 128
No. of incoherent integrations	: 1
Pulse width	: 16 µs
IPP	: 1000 µs
Window 1 start	: 24 µs (3.6 km)
Window 1 length	: 128 µs (19.2 km)
Receiver attenuation	: 10 dB
No. of beams	: 6 (E, W, Z_x, Z_y, N, S)

and 10.5 km. This corresponds to a change in wind velocity of 16 m/s in a height interval of 1.5 km. Large wind shear regions are observed on either side of 8 km and the direction reversal is seen at about 8 km.

Wind shear is observed in the height range 7-10 km with an average value of 0.01 s^{-1} and a maximum of 0.03 s^{-1} occurring around 8 km. Wind shear coefficient of 0.03 s^{-1} corresponds to a change in wind velocity of 30 m/s in a height interval of 1 km.

Figure 2 shows the profiles of meridional (V) (North-South) and zonal (U) (East-West) compo-

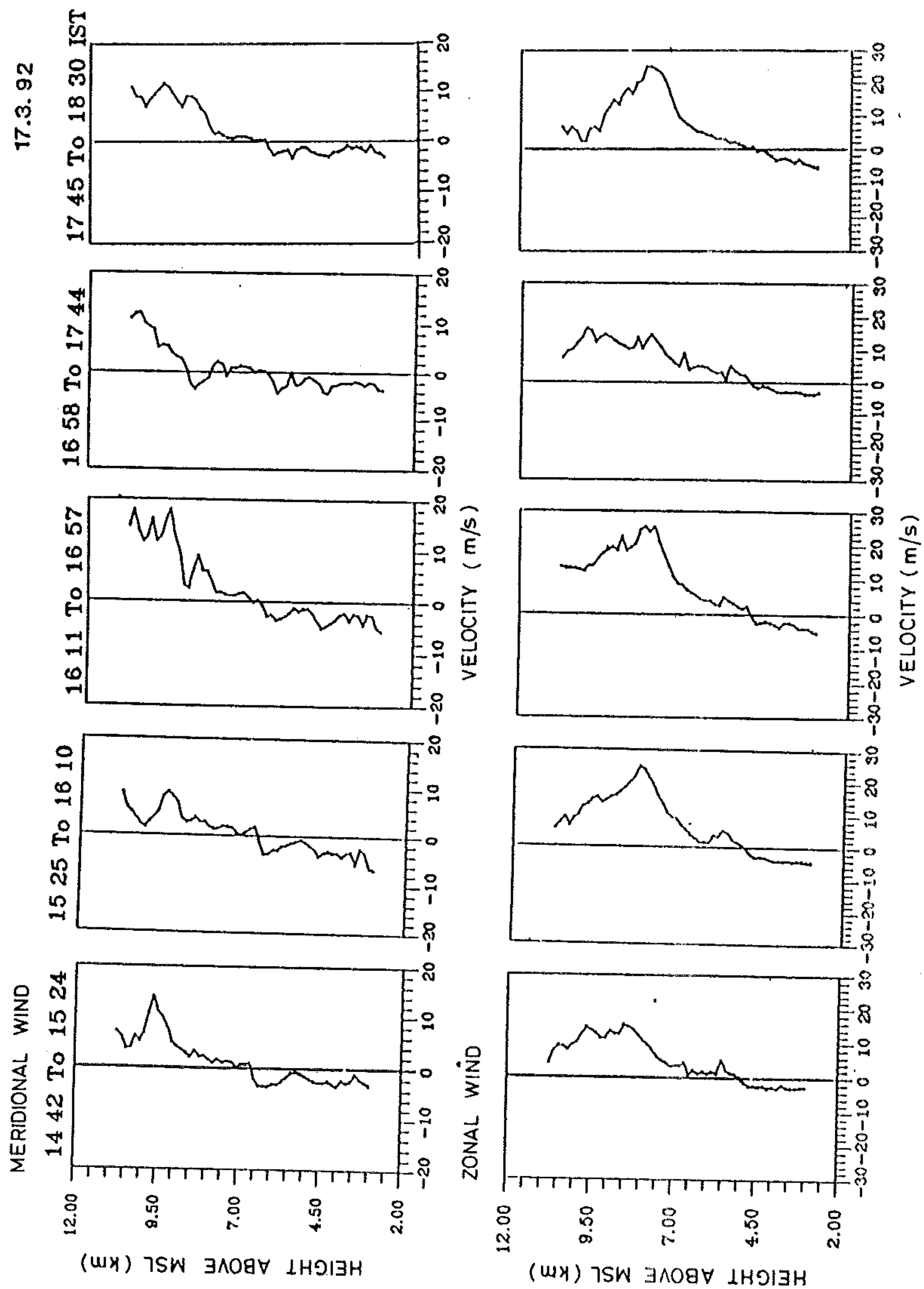

Fig. 2—Plot of different profiles of meridional wind (upper) zonal wind (lower) for different radar scans, each averaged over a 45-min duration.

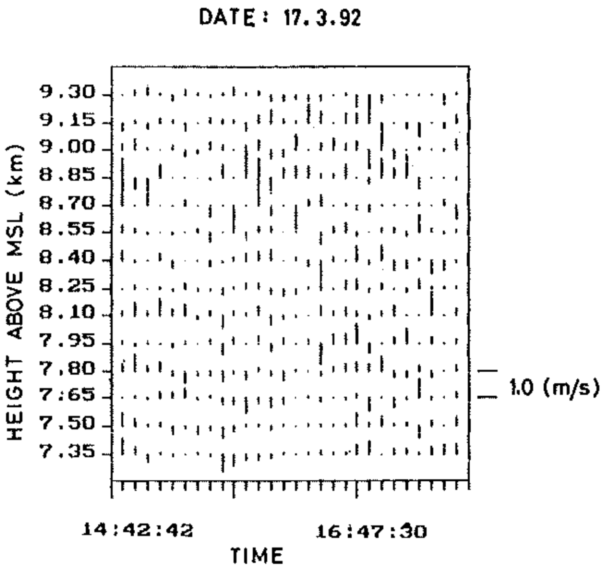

Fig. 3—Range time velocity diagram (RTVD) observed during 1442 to 1750 IST on 17.3.'92.

nents of the horizontal wind taken on 17 Mar. 1992 during 1442-1830 hrs IST. The profiles are averaged for 45-min duration. The 16 μs (coded) spectral signal is traced up to a range of about 11 km. Height profile of the zonal wind during the period of observation shows a sharp change in the zonal wind component at 8.25 km during 1525 to 1610 hrs IST. A sharp change is also seen at about 8.0 km during 1611 to 1657 and 1745 to 1830 hrs IST. To examine whether this represents a vertical movement of the layer, a profile of the vertical velocities observed during 1442-1750 hrs IST is given in Fig. 3. From the figure it is seen that the average vertical velocity at 8.25 km during 1525-1610 hrs IST is -0.1 m/s. Thus the sharp change observed in the horizontal velocity at 8 km during 1611-1657 hrs IST could be due to the vertical movement of the layer downwards.

Figure 4 shows a three-dimensional plot of vertical wind shear in zonal wind. At a height of 8.7

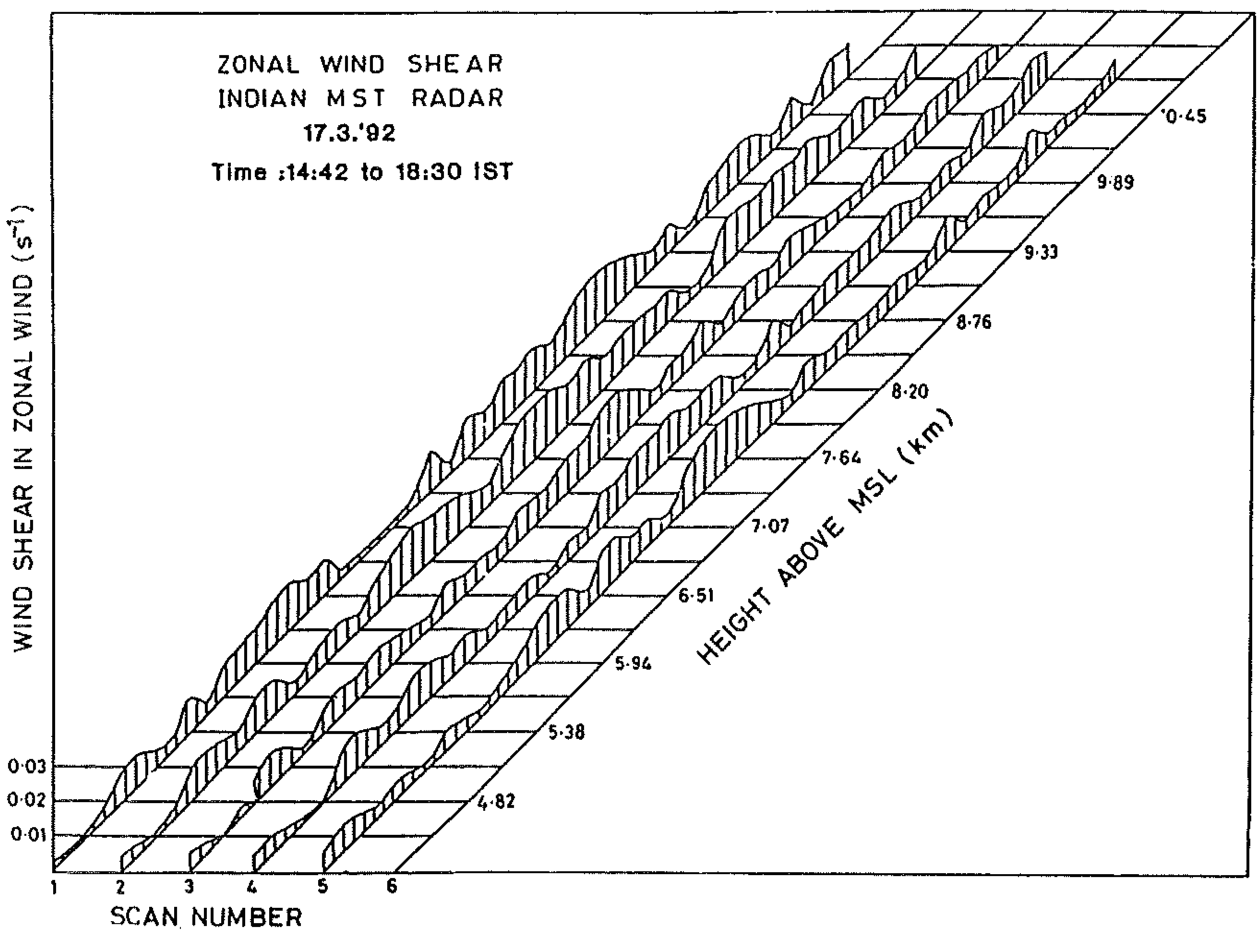

Fig. 4—A three-dimensional plot of vertical shear in zonal wind showing time-height development of these shears on 17.3.'92 taken at 1442 to 1830 hrs IST.

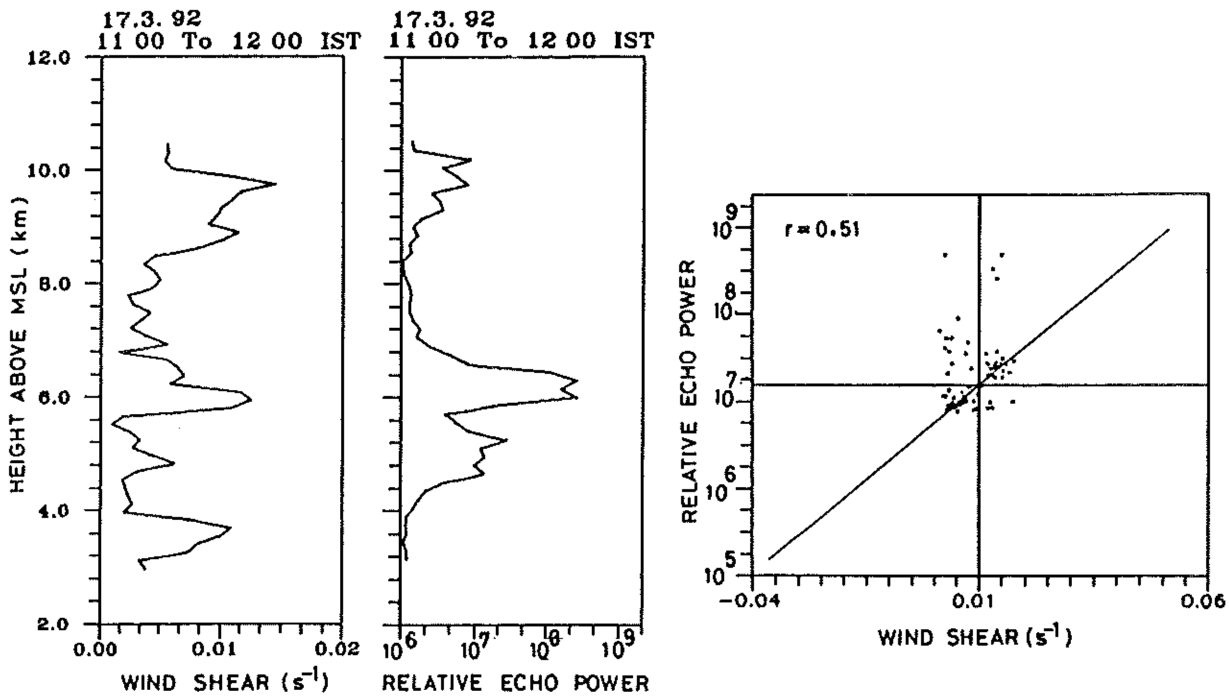

Fig. 5—Plot of wind shear and echo power. The last panel shows correlation between wind shear and echo power.

km, a wind shear coefficient of 0.02 s^{-1} is observed. This corresponds to a wind velocity difference of 20 m/s in a height interval of 1 km.

3 Correlation of wind shear with relative echo power, Doppler width, turbulence structure constant, Richardson number, Brunt-Vaisala frequency

Figure 5 shows wind shear observed at different altitudes on 17 Mar. 1992. It can be seen that there is a significant wind shear at different altitudes. Relative echo power multiplied by a factor proportional to the range square is also plotted in the figure. The multiplication is done for the reason that the received power is inversely proportional to the height in the atmosphere. Many of the peaks in the echo power profile have corresponding spikes in the wind shear profile. Thus the power profile seems to resemble the wind shear profile. From the figure it can be observed that the relative echo power, which is a measure of the degree of turbulence, is associated with wind shear. Correlation between wind shear and relative echo power is plotted in the same figure. Coefficient of correlation is seen to be 0.51.

From the echo power profile it can also be seen that at some altitudes there is an increase in the received echo power. The increase in the received echo power may be due to the shear instability.

Figure 6 shows a profile of wind shear and Doppler width. From the figure it can be seen that significant wind shear is associated with enhanced spectral width. It may be concluded that wind shear is contributing to the enhancement of Doppler width which is a measure of the degree of turbulence. Correlation between wind shear and Doppler width is also plotted and the correlation coefficient is seen to be 0.56 which indicates a fairly good correlation between the wind shear and Doppler width.

Wind shear and refractivity turbulence structure constant C_n^2 are shown in Fig. 7. C_n^2 is the most appropriate parameter to specify the intensity of refractivity turbulence in the velocity field. There is a good correlation between wind shear and C_n^2. Correlation between wind shear and C_n^2 is plotted in the same figure. The correlation coefficient is observed to be 0.60.

As simultaneous observation of the temperature profile at the same site is not available, it is not possible to precisely delineate the Richardson number. However, using the temperature profile measured by radiosonde at Madras, the Richardson number is roughly estimated. Wind shear profile and a profile of Richardson number are shown in Fig. 8. There is no good correlation between the wind shear and Richardson number. This could be due to the reason that temperature profile is taken from radiosonde observations of

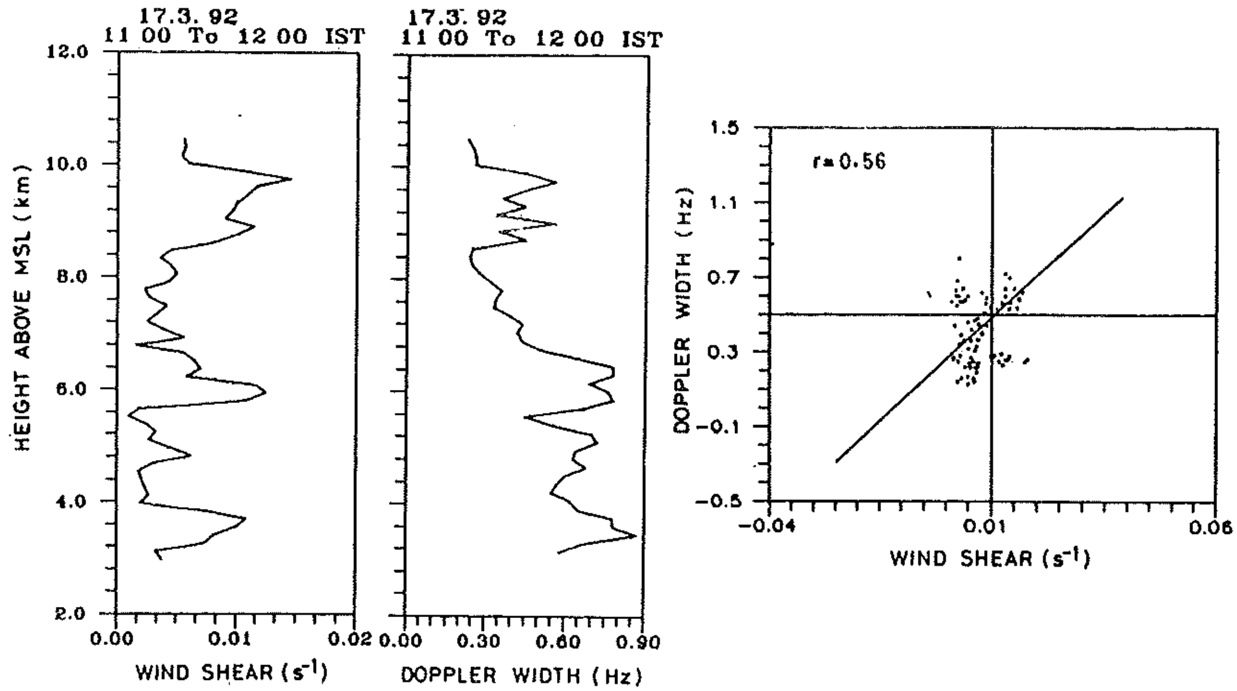

Fig. 6—Plot of wind shear and Doppler width. The last panel shows correlation between wind shear and Doppler width.

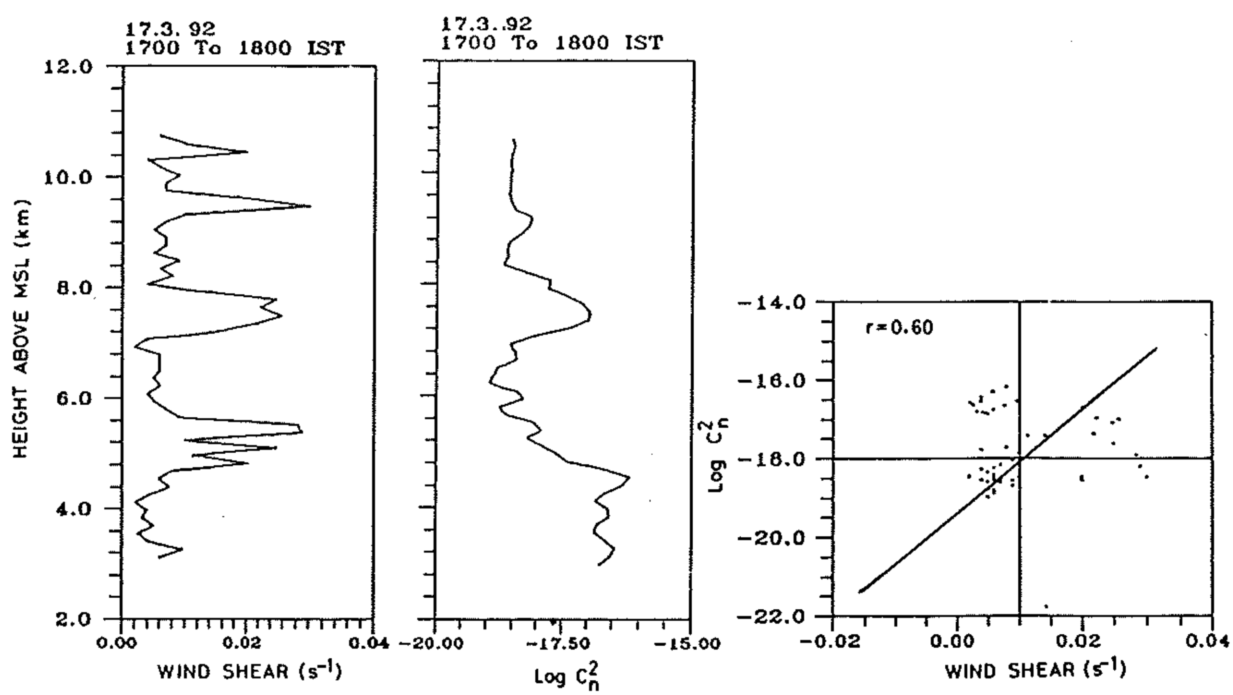

Fig. 7—Plot of wind shear and log C_n^2. The last panel shows correlation between wind shear and log C_n^2.

India Meteorological Department at Madras which is at a distance of 90 km from the MST radar site. The poor correlation could also be due to the fact that the height resolutions of radiosonde and MST radar are different.

Wind shear and Brunt-Vaisala frequency are shown in Fig. 9. Only a few of the peaks in the wind shear profile have corresponding spikes in

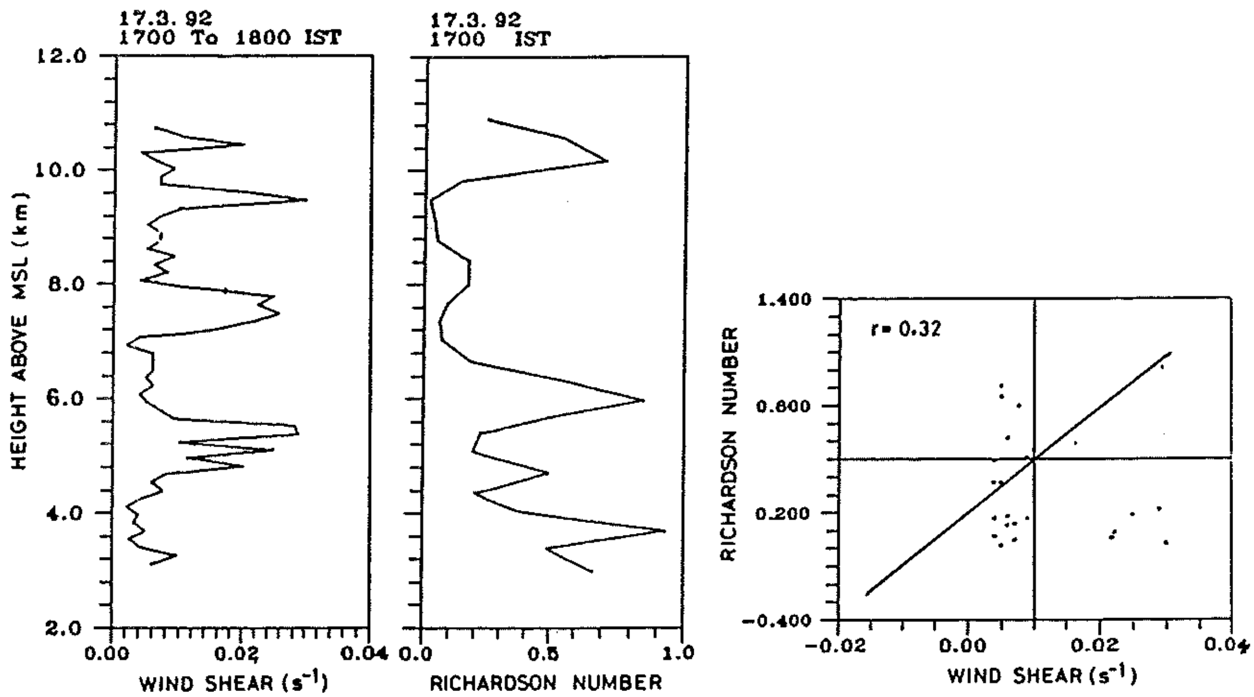

Fig. 8—Plot of wind shear and Richardson number: The last panel shows correlation between wind shear and Richardson number.

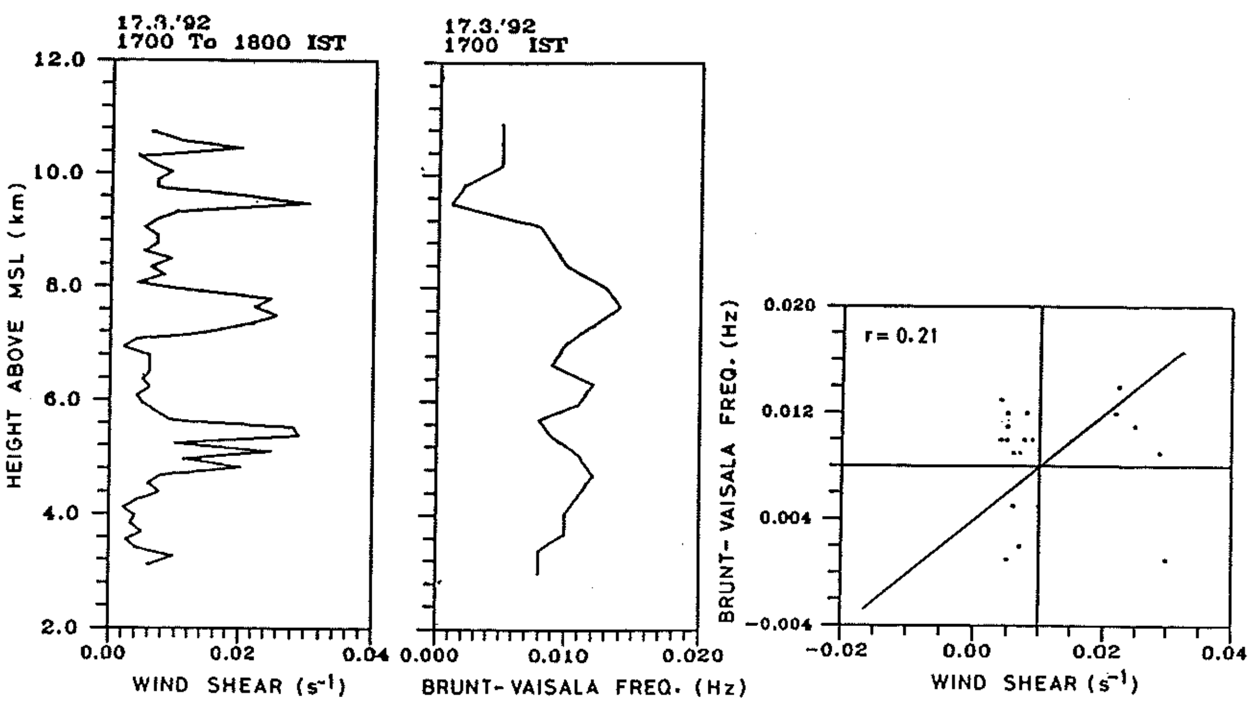

Fig. 9—Plot of wind shear and Brunt-Vaisala frequency, The last panel shows correlation between wind shear and Brunt-Vaisala frequency.

the Brunt-Vaisala frequency profile. There is not much correlation between the Brunt-Vaisala frequency and wind shear profiles. This poor correlation could be due to the large spatial difference between MST radar site and IMD observatory at Madras.

4 Conclusions

Significant wind shear is consistently observed between 7.0 km and 8.5 km and as well as between 9.0 km and 10.5 km. Wind shear coefficients as large as 0.03 s^{-1} are observed in the zonal wind. A good correlation is seen between wind shear and different turbulence parameters, viz. relative echo power, Doppler width, and C_n^2. The positive correlation among the three parameters, viz. vertical shear of the horizontal velocity, echo power, and spectral width can be easily interpreted by an intuitive model; when the vertical shear of the horizontal velocity becomes large, the flow becomes more unstable and the turbulence dissipates more energy into the scale size observed by the 53 MHz radar. The spectral width also becomes large since it reflects the line-of-sight component of the velocity distribution of the turbulence.

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References

1 Strauch R G, *J Aircr (USA)*, 26 (1989) 1009.
2 Tsuda T, Hirose K & Sato K, *Radio Sci (USA)*, 20 (1985) 1503.
3 Sarkar B K & Agarwal A, *Handbook for MAP*, edited by C A Liu and B Edwards (SCOSTEP Secretariat, University of Illinois, Urbana, Illinois, USA), 28 (1965) 523.