A study of wind velocity in lower troposphere using the Indian MST radar

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The Indian MST radar located at Gadanki (13.47°N, 79.18°E) near Tirupati, Andhra Pradesh, was operated in the ST mode for five days in February-March 1992 to obtain Doppler power spectra in the six beam positions, i.e. East, West, zenith-Y, North, South, and zenith-X. The power spectra were used to determine the zonal, meridional and vertical wind components in the lower troposphere (3.6 to 7.2 km). The Fast Fourier Transform (FFT) analysis of time series for 24-26 Feb. and 23-24 Mar. 1992 shows that the waves of 5-10 and 16-20 min periodicities dominate in the lower troposphere. The amplitude of the wave velocity varies between 0.3 and 3.0 ms⁻¹. The data were also used to study the wind shears, and significant shears were noted only above 6.0 km.

1 Introduction

Over the last two decades the VHF and UHF Doppler radars have been widely used to study the dynamics of the clear air in the middle atmospheric region (see e.g., reviews by Green et al., Balsley and Gage, Balsley, Rottger, Harper and Gordon, Browning). The radars give the signal returns from fluctuations in the refractive index at the scales equal to half the radar wavelength. By performing different experiments at different locations with different operating frequencies of radar, it has been clearly established that the Doppler shift obtained from radar is an accurate method of measuring wind velocity along the line-of-sight of the radar beam. Although the balloons and the rockets have been widely used to obtain the zonal and meridional wind components, the Doppler radars have several advantages over them. They measure not only the horizontal winds (zonal and meridional) but also the vertical winds which are too weak to be measured by the balloons or rockets. In addition the radar measurements give better time and height resolution and are almost free from the weather conditions.

The Indian MST radar located at Gadanki (13.47° N, 79.18°E) near Tirupati, Andhra Pradesh, was operated in the ST mode during February-March 1992. In this paper we present a study of zonal, meridional and vertical wind velocity components observed during 24-26 Feb. and 23-24 Mar. 1992. The presence of short and medium period waves and their associated amplitudes have also been determined. In addition, the wind shear in the zonal winds and the Richardson number have also been calculated up to 7.2 km.

2 Brief descriptions of the experiment and analytic procedure

The data of Doppler power spectrum were obtained during the ST mode campaign from 1630 to 1830 hrs during 24-26 Feb. and 23-24 Mar. 1992. The experiment was conducted with 4 \( \mu \)s uncoded pulse of inter-pulse period (IPP) 250 \( \mu \)s using 512 coherent integrations and 128 FFT points. The range resolution thus obtained was 600 m. The experiment was conducted with the East, West, zenith-Y, North, South and zenith-X beam positions in sequence to obtain the power spectrum for each scan. The off zenith beam of radar is inclined at an angle of ±20°. One complete cycle of observation (i.e. E, W, zenith-Y, N, S, zenith-X) takes about 115 s (including the switching time). Sixty such cycles of scans were obtained for each day of experiment. The whole data was recorded on magnetic tape for off-line analysis. Other details of the experiment are listed in Table 1. Though the experiment was designed to cover the height range from 1.8 to 25.2 km, the detectable data for the off-beam analysis was useful only above 3.0 km. Above 7.2 km the S/N ratio was too small and therefore the study...
where $V_{di}$ is the line-of-sight component of wind velocity vector for $i$th beam ($i=1, \ldots, 5$) and $\cos \theta_x, \cos \theta_y,$ and $\cos \theta_z$ are direction cosines of radar beam position. $V_{di} = f_{di} \lambda/2$, where $f_{di}$ is the Doppler shift for the $i$th beam and $\lambda$ is the radar wavelength.

The condition of minimum residual implies that the partial derivative of $\varepsilon^2$ with respect to the components of $v$ must be zero, i.e.

$$\frac{\partial \varepsilon^2}{\partial v_k} = 0 \quad \ldots \quad (2)$$

On solving Eqs (1) and (2), we get

\[
\begin{bmatrix}
V_x \\
V_y \\
V_z
\end{bmatrix} = - \frac{1}{\sigma^2} \begin{bmatrix}
\sigma^2 \cos^2 \theta_{xi} + \sigma^2 \cos \theta_{yi} \cos \theta_{zi} + \sigma^2 \cos \theta_{zi} \\
\sigma^2 \cos \theta_{xj} \cos \theta_{yi} + \sigma^2 \cos \theta_{yi} \cos \theta_{zi} \\
\sigma^2 \cos \theta_{xj} \cos \theta_{zi} + \sigma^2 \cos \theta_{zi}
\end{bmatrix}^{-1} \begin{bmatrix}
\sigma_i \cos \theta_{xi} \\
\sigma_i \cos \theta_{yi} \\
\sigma_i \cos \theta_{zi}
\end{bmatrix} \\
\begin{bmatrix}
\sigma_i \cos \theta_{yi} \\
\sigma_i \cos \theta_{zi}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\sigma_i \cos \theta_{xi} \\
\sigma_i \cos \theta_{yi} \\
\sigma_i \cos \theta_{zi}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\sigma_i \cos \theta_{xi} \\
\sigma_i \cos \theta_{yi} \\
\sigma_i \cos \theta_{zi}
\end{bmatrix}
\]

where $i = 1$ to 5

The zonal, meridional and vertical wind vector components were calculated using Eq. (3). These were then converted to time series and the fast Fourier transform (FFT) was applied to study the periodicity of the waves. The wind shear and the Richardson number, $R_i = (g \delta \ln \theta / \delta z) / (\delta u / \delta z)^2$, were also calculated.

### 3 Results

Figure 1 shows the average of 15 scans (corresponds to $\approx 30$ min) for 25 Feb. and 24 Mar. 1992. To distinguish among the curves, the successive curves in the zonal and meridional components have been shifted by three units on the horizontal scale, whereas the vertical components by 0.5 units. For example, for the second curve in the zonal wind in Fig. 1(a), the value of wind velocity should be read as 7.0 instead of 10.0, and so on. The analysis of five days' data reveals that in the zonal wind during 24-26 February, the velocity is twice as large compared to that in March, but in the meridional wind, the velocity in February is less than half the velocity in March. The vertical wind velocity is more or less of the same order. In general wind velocity pattern seems to be steady for the two hours of observation (1630-1830 hrs).
From the zonal wind shear study we find that the average wind shear is very small in the region 3.6-6.0 km. The maximum average wind shear in this region is \( \approx 0.004 \text{ ms}^{-1}/\text{m} \). Above 6.0 km, the average shear on 23 March and 24 February is \( \approx 0.006 \text{ ms}^{-1}/\text{m} \), whereas on 25 and 26 February it is 0.008 ms\(^{-1}\)/m and 0.014 ms\(^{-1}\)/m respectively. Thus it is observed that the shear develops only above 6.0 km. The potential temperature gradient in this region obtained from the IMD Madras balloon data gives the value of Richardson number \( R_i \) greater than 3. This is much greater than 0.25, the critical value of \( R_i \) below which the instability is set in the region having appreciable shear.

The periodicities in time series, as studied by the fast Fourier transforms (FFTs), show that waves of periodicities 5-10 min and 15-20 min dominate in the region 3.6-4.8 km in March, whereas only 15 to 20 min waves dominate in this region in February. The FFT output for 25 February and 24 March are shown in Figs 2 and 3 respectively. In the region above 5 km, the waves of periodicities 5-10 min and 15-20 min dominate in February as well as in March.

It has been noticed that on each day of observation, the zonal, meridional and vertical wind components have waves of nearly similar periodicities dominating at the same height. This is expected due to the fact that all the three components have been derived from the same wind vector. The amplitudes of the dominant waves vary with respect to height between 0.3 and 3.0 m/s.

Although a more accurate vertical wind velocity can be derived directly from the radar Doppler shift using zenith beam, the velocity obtained from Eq. (3) is found to be in good agreement with the former. A typical comparison has been shown in Fig. 4. The profiles shown are 30 min average and the second pair of curves have been shifted by 50 cm from the zero on the horizontal scale.
Fig. 2—Amplitude spectra of wind components after applying FFT to the time series for 25 Feb. 1992.

Fig. 3—Same as Fig. 2 but for 24 Mar. 1992.
medium period waves have been reported by Ecklund et al.\textsuperscript{19}. They have reported waves of periods 4-10 and 15-20 min in the lower region. In our study we have found the period of dominant waves to lie in the regions 5-10 min and 15-20 min. The experiments conducted by Kumar et al.\textsuperscript{20} for the study of vertical wind, performed two hours before this experiment, also show similar periodicities in this region. This further suggests that the wave periodicities are stable over the four-hour period.

From the study of zonal wind profiles it is found that the wind shear develops only above \( \approx 6.0 \text{ km} \). Our study is limited only up to 7.2 km, and therefore a complete study of the shear has not been possible. Although the Richardson number \( R_i \leq 0.25 \) is a necessary criterion to produce dynamic instability in the fluid undergoing shear, it is far from being a sufficient criterion. Hence it would not be possible to comment on the stability of the atmosphere, based on the Richardson number alone. In order to do a detailed study of instability of the atmosphere, simultaneous observation of potential temperature and a better range resolution of the radar data are required.

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**References**


**4 Discussion and conclusions**

The wind velocity profiles have been extensively studied by Doppler radars and compared with the radiosonde observations by several workers\textsuperscript{10,16–18}. It has been established that the wind velocity components obtained by the Doppler radars are quite accurate. Since most of the MST radar observations have been aimed above 10 km, not many studies of the short period waves have been reported in zonal and meridional winds. In the vertical wind, however, the study of short and


