GEOPHYSICAL RESEARCH LETTERS, VOL. 23, NO. 3, PAGES 285-288, FEBRUARY 1, 1996

Deduction of temperature profile from MST radar observations of vertical wind

K. Revathy

Department of Computer Science, University of Kerala, Trivandrum, India

S.R. Prabhakaran Nair

Department of Physics, University of Kerala, Trivandrum, India

B.V. Krisha Murthy

Space Physics Laboratory, Vikram Sarabhai Space Centre Trivandrum, India

Abstract. From the temporal spectra of vertical wind obtained from MST radar observations, the Brunt-Vaisala frequency is identified. Altitude profile of temperature in troposphere and lower stratosphere is derived from the altitude profile of the Brunt-Vaisala frequency thus obtained.

Introduction

The atmospheric temperature variation with altitude plays an important role in the studies on turbulence structure and atmospheric stability. Regular Meteorological balloon soundings (Radiosonde) provide altitude profiles of temperature on twice a day basis. However, the published radiosonde data do not give enough altitude resolution for turbulence studies. That temperature profile can be derived from MST radar data of vertical winds has been pointed out by Rottger (1986). As MST radar provides high altitude resolution data of vertical winds on a continuous basis (temporally) in troposphere and lower stratosphere, temperature profiles can be obtained from such data with corresponding altitude resolution which is much better than that of the published radiosonde data and also with good temporal coverage over a day.

The method of deriving temperature mainly depends upon identification of Brunt-Vaisala frequency (B-V frequency) in the spectra of vertical wind velocity oscillations. These spectra reveal the "Brunt-Vaisala cut off" (e.g., Rastogi, 1975; Rottger, 1980 a,b; Ecklund et al., 1985) characterised by a spectral peak at the B-V frequency with a steep decrease on its high frequency side and a fairly shallow decrease on the low frequency side. The spectral peak at B-V frequency can be attributed to energy input at that frequency (Scheffler and Liu, 1986) and can be partially explained by the theoretical prediction derived in Scheffler and Liu (1985). Using vertical wind observations from Indian MST radar at Gadanki (13.47°N, 79.18°E) in the altitude range 3.75km to 30.6km we obtained the altitude profile of Brunt-vaisala frequency from which temperature profile is derived. The results are presented in this communication.

Method of Analysis and Results

The Indian MST radar at Gadanki operates at 53 MHz, with an average power-aperture product of ~7.7×10^8 W m^2 and an altitude resolution of 150m in vertical direction. The radar system details are given in Rao et al. (1995). It may be pointed out here that with the MST radar at Gadanki backscatter signals in the vertical direction are, generally, obtained from ~3.75km to altitudes ranging from ~25 to 31 km in the stratosphere. On March 15, 1995 observations have been carried out from 1333h to 1433h IST with the antenna beam pointing in vertical direction. During this period backscatter signals could be obtained in the altitude range from 3.75km to 30.6km. The data of I and Q channels are subjected to FFT to obtain doppler spectra at intervals of 46 sec. For each of the doppler spectra the first moment (=mean Doppler frequency) which gives the vertical wind velocity is derived. Thus a time series of vertical wind velocity sampled at 46 sec is obtained in the altitude range 3.75km to 30.6km at intervals of 150m. These time series are subjected to FFT to obtain the spectra. As the data length is 3496 sec with a total of 76 samples the frequency resolution of the spectra is ~0.000286Hz and the Nyquist frequency is ~0.0109Hz. In these spectra, spectral peak corresponding to the B-V frequency is identified using the following criteria.

(i) Of the prominent spectral peaks, it should be the one with highest peak frequency.

(ii) The spectra on the high frequency side (of the peak) should show a steep decrease followed by no significant peaks.

Vertical wind spectra at 3.75km, 15.0km, 20.55km and 29.55km are shown in Fig. 1 as illustrative examples. The identified B-V frequency is shown by an arrow mark in the figure. In the spectra at 3.75km and 15.0km, there are no spectral peaks at frequencies less than the B-V frequency. At the stratospheric altitudes of 20.55km and 29.55km spectral peaks appear at frequencies less than the B-V frequency. At tropospheric altitudes data of longer duration are required to obtain the necessary spectral resolution for identifying spectral peaks at frequencies less than the B-V frequency.

The identified Brunt-Vaisala frequency (in radians/sec) as a function of altitude is shown in Fig.2. We could unambiguously identify the B-V frequency in the altitude range 3.75km to 30.6km for which the vertical wind data are available. It is seen from Fig. 2 that the B-V frequency fluctuates around ~0.01 rad/sec at altitudes below 16.8km and around ~0.022 above 16.8km indicating the demarkation between troposphere and stratosphere.

From the B-V frequency, atmospheric temperature can be obtained from the relation

$$N^2 = \frac{g}{T}\left[\frac{dT}{dz}+\Gamma\right] \quad (1)$$

Paper number 96GL00086
0094-8534/96/96GL-00086$03.00

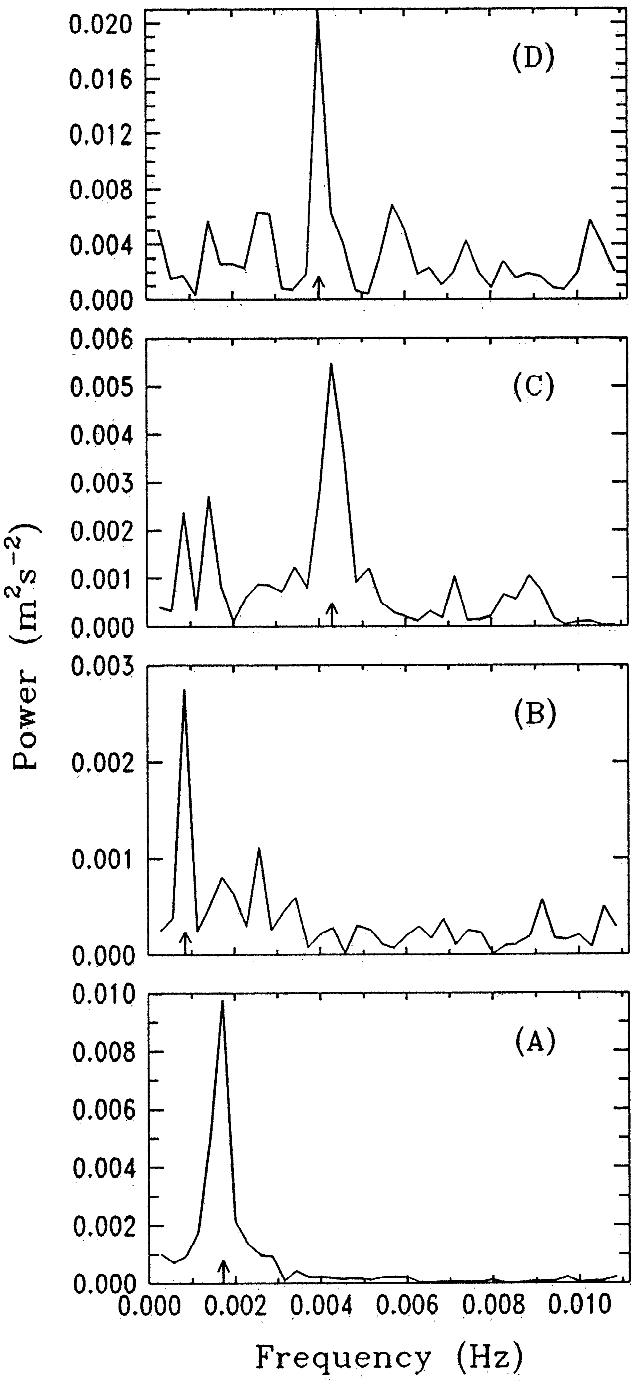

Figure 1. Temporal spectra of vertical wind velocity at (A) 3.75km, (B) 15.0km, (C) 20.55km and (D) 29.55km.

where N is the B-V frequency in rad/sec,

T is the temperature,

g is the acceleration due to gravity,

z is the altitude

and Γ is the adiabatic lapse rate.

Equation (1) can be solved for T as

$$T(z^*) = \frac{1}{I(z^*)}\left[I(z_o)\, T_o - \Gamma \int_{z_0}^{z^*} I(z)dz \right] \quad (2)$$

where

$$I(z) = \exp\left[-\int \frac{N^2}{g} dz \right]$$

$T(z^*)$ is the temperature at height z^*,

and T_0 is the temperature at a reference height z_0.

In order to obtain the temperature profile from equation 2, temperature at a reference altitude is required. For this, we have adopted the following two procedures.

(1) From the measured ground temperature, the temperature at 3.75km is obtained assuming a lapse rate of 6K/km which is the average value in the lower troposphere applicable for Indian tropical region (Sasi, 1984) and is used as the reference temperature in equation 2 to derive the temperature profile. From this temperature profile, the lapse rate in the altitude range 3.75km to 5km is obtained and used to calculate the temperature at 3.75km from the ground value. This new reference value of T is used in

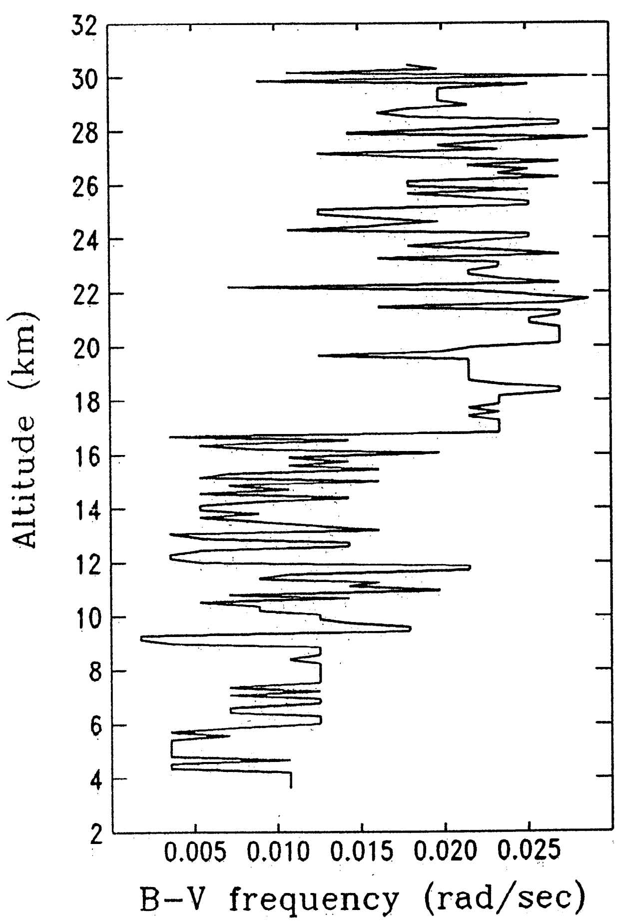

Figure 2. Altitude profile of the Brunt-Vaisala frequency, N.

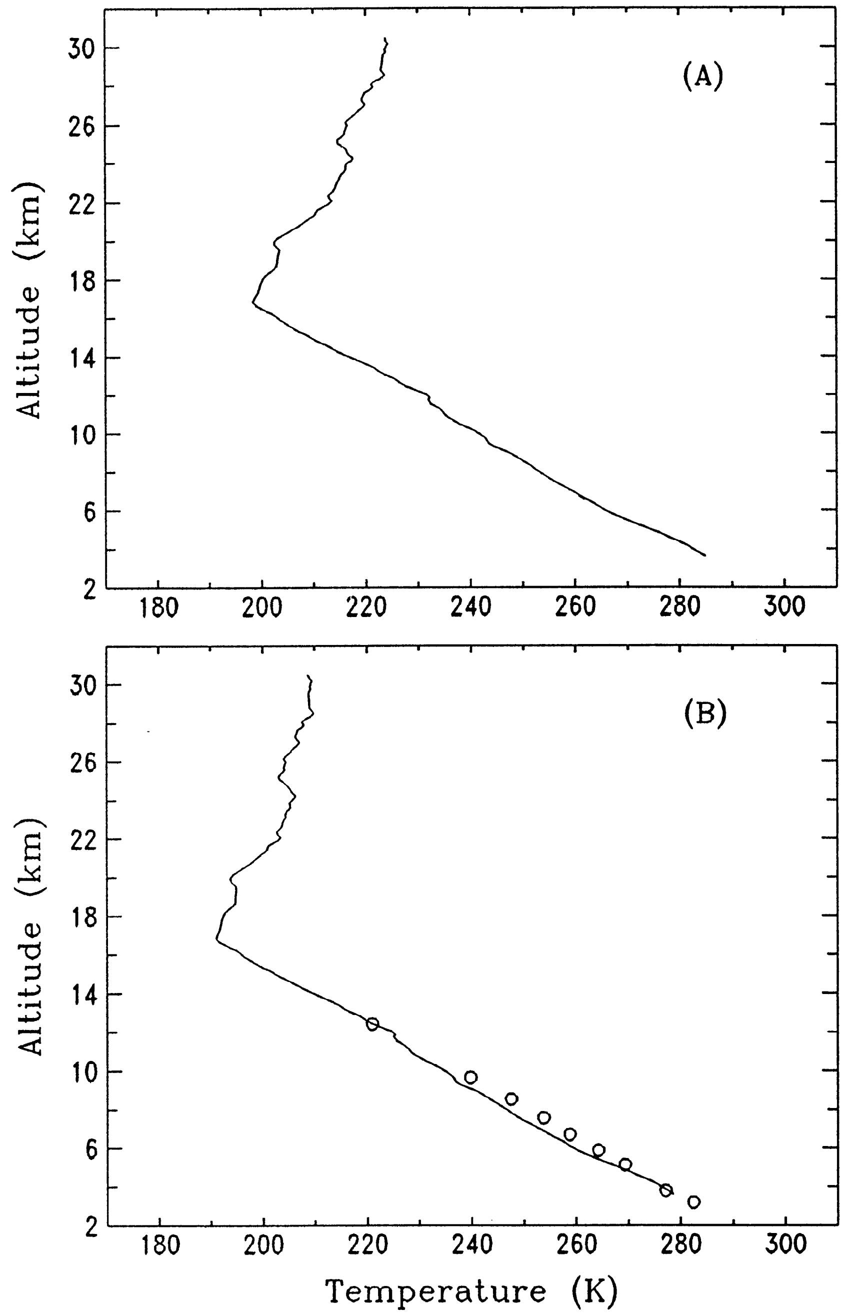

Figure 3. Altitude profile of temperature deduced from MST radar data, (A) obtained using procedure 1 and (B) obtained using procedure 2; the circles represent the temperatures from radiosonde data.

equation 2 to derive the temperature profile again. This iteration is repeated till the lapse rate in the range 3.75km to 5km converges.

(2) From the radiosonde temperature profile available at a nearby location, Madras (13.1°N, 80.3°E) at 1730 IST on March 15, 1995, the temperature at 3.75km is obtained and is used as the reference.

The temperature profiles derived from equation 2 using the two procedures are shown in Fig. 3 along with the radiosonde data (Madras) of temperature for the profile obtained using procedure (2). The radiosonde data was available only upto 12.5km. The agreement between the radiosonde profile and the profile from MST radar data (procedure 2) is quite good. The MST radar derived temperature profiles show a sharp tropopause located at 16.8km. The profile obtained by using procedure 1 can be considered to be applicable to Gadanki location as the prevailing surface temperature is used to obtain T_0. It should be pointed out here that the altitude resolution of the radar derived temperature profiles is ~300m as two consecutive values of N are used to obtain each temperature value.

The temperature gradient (dT/dz=T') derived from the temperature profile is shown in Fig. 4. It may be noted that the effect of any uncertainty in the reference temperature on T' would be quite insignificant. The fluctuations in T' are quite prominent. It is seen that T' is less than that corresponding to the adiabatic lapse rate

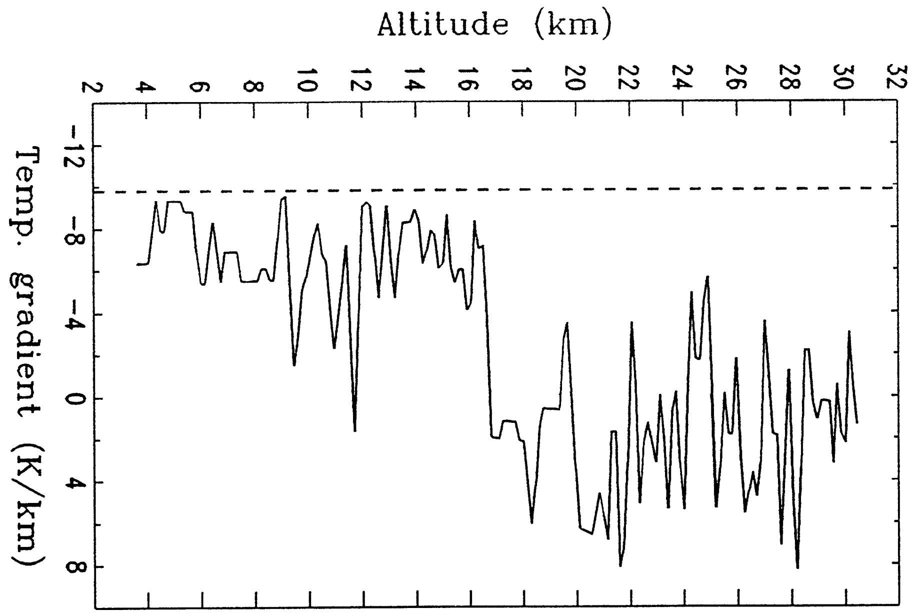

Figure 4. Altitude profile of temperature gradient, dT/dz. The dashed line represents the gradient corresponding to the adiabatic lapse rate.

(shown by dashed line in the figure) as it should be for observing the B-V oscillations. So, the region (3.75km to 30.6km) is convectively stable and turbulence in the region should be attributed mainly to generation by wind shear. Considering the Richardson number (Ri) criterian of Ri for turbulence, a lower limit can be ascribed to the wind shear that should be present to give rise to turbulence as

$$Ri = \frac{N^2}{\left(\frac{dU}{dz}\right)^2}$$

where U is the wind speed.

Thus for shear generation of turbulence $dU/dz > 2N$. From Fig. 2, it can be seen that dU/dz should be greater than around 0.02m/sec/m in the troposphere and 0.044 m/sec/m in the stratosphere for this condition for turbulence to be satisfied.

In conclusion, altitude profile of temperature can be derived from MST radar data of vertical wind provided the atmospheric region under consideration is not convectively unstable. It may be noted that a data (of vertical wind) length of about an hour is required to resolve and identify the B-V frequency. The requirement of a long data length may restrict the availability of useful data as the atmospheric conditions like stability may change during the period of the data. Further, doppler shift due to background wind can transfer energy to lower and higher frequencies (than B-V frequency) and this would tend to flatten or stretch the spectra making identification of B-V frequency difficult (Rottger, 1980b; Scheffler and Liu, 1985, 1986). Apparently, the present data corresponds to small background wind velocity conditions as the B-V frequencies could be identified unambiguously. It would be interesting to study the effect of background wind on the vertical wind spectra which is being pursued by us.

Acknowledgement: We express our thanks to Dr SK Srivastava, Indian Meteorological Department, for providing us the radiosonde data of Madras and to the staff of National MST Radar facility, Gadanki, for operating the MST radar and providing the vertical wind data.

References

Ecklund, W.L., B.B. Balsley, D.A. Carter, A.C. Riddle, M. Crochet and R. Garello, Observations of vertical motions in the troposphere and lower stratosphere using three closely spaced S-T radars, Radio Sci., 20, 1196-1206, 1985.

Rao, P.B.,A.R. Jain, P. Kishore, P. Balamuralidhar, S.H. Damle and G. Viswanathan, Indian MST radar Part 1. System description and sample vector wind measurements in ST mode. Radio Science, 1995 (In press).

Rastogi, P.K., Remote sensing of the mesosphere using the Jicamarca incoherent scatter radar, Aeronomy Report. No. 68, Dept. of Elec. Eng. Univ. Illinois, IL, USA.

Rottger, J. Structure and dynamics of the stratosphere and mesosphere revealed by VHF radar investigations, PAGEOPH, 118, 494-527, 1980a.

Rottger, J., Development of refractivity structures during anticyclonic weather conditions. Preprint volume, 19th AMS conf. Radar Meteorol. Miami, OL USA., 593-598, 1980b.

Rottger, J., Determination of Brunt-Vaisala frequency from vertical velocity spectra, MAP Hand book, 20, 168-172, 1986.

Sasi, M.N., A reference atmosphere for the Indian equatorial zone, I. Jour. Rad & Space Phys. 23, 299-312, 1994.

Scheffler, A.O., and C.H. Liu, On observation of gravity wave spectra in the atmosphere by using MST radars, Radio Sci., 20, 1309-1322, 1985.

Scheffler, A.O., and C.H. Liu, The effects of doppler shift on gravity wave spectra observed by MST radar, J. Atmosph. Terr. Phys., 48, 1225, 1986.

K. Revathy, Department of Computer Science, University of Kerala, Trivandrum 695 581, India.

S.R. Prabhakaran Nair , Department of Physics, University of Kerala, Trivandrum 695 581, India.

B.V. Krishna Murthy, Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum 695 022, India.

(Received August 8, 1995; Revised November 21, 1995; Accepted December 19, 1995)