

DETECTING DUCTING LAYERS WITH LOWER ATMOSPHERIC WIND PROFILER OVER GADANKI

D. Narayana Rao^{1,3}, T. K. Ramkumar¹, Madhu Chandra Reddy², N. V. P. Kiran Kumar¹,
A. Narendra Babu³ and Venkateshwara Rao¹

1. National MST Radar Facility, PB. No. 123, S. V. University, Tirupati-517502, India

2. Indian Institute of Tropical Meteorology, Pune, India

3. Dept. of Physics, Sri Venkateshwara University, Tirupati-517502, India

Email: profdnrao@nmrf.gov.in, tkramkumar@rediffmail.com

ABSTRACT

During the four days (2nd, 13th, 19th, and 20th in August 1999) of continuous operation of the Lower Atmospheric Wind Profiler (LAWP), operating at 1357.5 MHz at the Indian tropical station of Gadanki (13.47°N, 79.18°E), it has been detected the ducting layers (for a few minutes) at around 1.2 Km on 13 August 1999 at 06 Hrs. and 0 minutes (LT). Ducting layers are detected by utilizing the fact that the anomalously strong echoes observed at Ultra High Frequencies UHF) are often associated with anomalously strong potential refractive index gradients in air. More extensive data sets are stressed for future studies in order to delineate the seasonal evolution of occurrence probability of such ducting layers using LAWP and radiosonde techniques.

INTRODUCTION

Atmospheric wind profilers operating at Ultra High Frequencies (UHF) provide excellent information on atmospheric winds, turbulent parameters of scattering irregularities (say radio refractive index gradient, turbulent eddy dissipation rate (ϵ), irregularity structure function parameter, Cn^2 etc.) in the troposphere (Otterson, 1969; Battan, 1973; Gossard and R. G. Strauch, 1983; Doviak and Zrnic, 1984). Fluctuations in the air refractive index, caused by variations in air temperature, moisture, pressure etc., have significant influences on the characteristics of radio wave propagation in this lowest height region of atmosphere. In general, the abnormal change in the characteristics of radio wave propagation arising out of abnormal variations in refractive index is called as anomalous propagation (AP) of radio waves. For reference, Turton et al (1988) has summarized the various classes of anomalous propagation of radio waves in air. Ducting of radio waves is one of such anomalous propagation characteristics in which the radio waves become trapped within a shallow and near-horizontal layer. During ducting, the propagation range can be greatly enhanced and the concentration of radio wave energy within the duct will result in a corresponding reduction in the signal just above or below the ducting layer and the formation of a radar “hole,” where detection ranges are much reduced. Usually, the ducting layers are identified from the value of gradient in modified refractive index M, which is defined by (Bean and Dutton, 1968)

$$M = \frac{77.6}{T} (P + \frac{4810e}{T}) + \frac{Z}{10^{-6} r} = N + \frac{Z}{10^{-6} r} = N + 0.157 Z \quad (1)$$

Where T is atmospheric temperature in Kelvins, P is total atmospheric pressure in millibars, e is water vapor pressure in millibars, Z is height in meters, r is the earth's radius in meters, $N = (n-1) \times 10^6$ (n is refractive index) and M is dimensionless.. The ducting condition is given by:

$$dM/dZ < 0 \quad \text{or} \quad dN/dZ < -157 \quad [\text{ducting condition}] \quad (2)$$

DETECTING DUCTING LAYERS WITH LOWER ATMOSPHERIC WIND PROFILER (LAWP)

The LAWP, operating at 1357.5 MHz, at the Indian tropical station of Gadanki (13.47°N, 79.18°E) is a coherent pulse radar with an effective peak aperture product of about $1.2 \times 10^4 \text{ Wm}^2$. The antenna uses a phased array of $3.8\text{m} \times 3.8\text{m}$, organized in four quadrants, each having 24×24 circular conducting patch antenna elements. With beam width of 4° and peak power of 1KW, the beam was directed in three different directions (15°N , 15°E , and zenith) to obtain all the components of wind velocities and other turbulence parameters.

From (1) and (2), it is straight forward that ducting layers can be detected by knowing the height profiles of atmospheric temperature and pressure, water vapor pressure, which can easily be measured by radiosonde techniques. However, since the ducting layers occur sporadically in both space and time, it is highly desirable that the above mentioned atmospheric parameters should be monitored/measured continuously, which is not cost effective. As an alternative, the lower atmospheric wind profilers can be utilized to detect the ducting layers owing to the fact that anomalous variations in refractive index, occurring because of ducting conditions, will lead to enhanced scattering/reflection of the transmitted electromagnetic waves from the radar. Detection of ducting layers using lower atmospheric wind profilers is possible (Sengupta and Watson, private communication) because of the close relationship between the radar received backscattered power and radio refractive index gradients in air. Since the clear-air radar backscatter is concerned primarily with turbulent processes, which are adiabatic in nature, it is preferable and convenient to use potential refractivity, ϕ , which is given by:

$$\phi = \frac{77.6 P_r}{\Theta} \left(1 + \frac{7.73 Q}{\Theta} \right) \quad (3)$$

Where P_r is reference pressure level (1000 mb), Q is specific humidity (g kg^{-1}), Θ is potential temperature given by:

$$\Theta = T (P_r/P)^{0.286} \quad (4)$$

From Gossard et al. (1999), we have:

$$(d\phi/dz)^2 = (L_w/L_n)^{4/3} (du/dz)^2 C_n^2/C_w^2 \quad (5)$$

Where du/dz is the mean wind speed gradient, $d\phi/dz$ is the potential refractivity gradient, L_w and L_n are scale sizes of the vertical velocity and refractive index fields respectively. C_n^2 and C_w^2 are turbulent structure parameters of refractivity, N and vertical velocity, W . From the relation between radar reflectivity η and C_n^2 , we have:

$$\eta = 0.38 C_n^2 \lambda^{-1/3} \quad (6)$$

$$P_r \propto P_t A_e \Delta r \eta / r^2 \quad (7)$$

Where λ is radar wavelength, P_r (Watts) and P_t (Watts) are respectively the transmitted and received powers, A_e (m^2) is the effective antenna area, Δr is the radar range resolution and r denotes the range to the target. The relationship between the turbulence structure function parameter for vertical velocity C_w^2 and the eddy dissipation rate ϵ is given as:

$$C_w^2 = (4/3) B \epsilon^{2/3} \quad (8)$$

Where B is a Kolmogorov constant approximately equal to 2.1 and ϵ can be estimated from its relationship with variance in the radar Doppler velocity spectrum (Frisch and Clifford (1974)).

OBSERVATIONS AND RESULTS

Apart from measuring all the three components of wind velocities for a height range of ~ 0.3 to 4.5 km, LAWP also gives information on atmospheric turbulence parameters C_n^2 and ε from the received raw signals. Data obtained, using the three beam positions as listed above in the radar specifications, continuously on four days (2nd, 13th, 19th, and 20th) in August 1999 are considered for the present study. One profile (height) of data constitutes sometimes 4 or 7 minutes of observation. In total, 998 profiles of winds and turbulence parameters are obtained for these four days. Potential refractivity gradient calculated in the height region of from 0.450 km to 4.35 km for all the four days are shown as three dimensional (time, height and strength) surface mesh plots in three panels in Figure 1. The top (a), middle (b) and bottom (c) panels are respectively for North 15° , East 15° and Zenith beam positions. While calculating the potential refractive index gradient using the relation 5, we assumed arbitrarily that the scale sizes of vertical velocity and refractive index gradient are constant and substituted the value of 1 for them. The authors believe that this will not affect significantly the meaning of interpretation on detecting ducting layers from the calculated height profiles of potential refractive index gradient as it depends primarily on vertical shear of zonal wind and nature of scattering irregularities, which are considered as the dominant controlling factors on the parameters. After calculated the potential refractive index gradient with this constant scale value, it has been multiplied/normalized by 1000 arbitrarily so that we can have often the values of potential refractive index gradient greater than 0 instead of values to three decimal places as they are difficult to handle while interpreting the results obtained.

It may be noted that in all the three panels at around 316th profile (corresponding to 13 August 1999 at 06 Hrs. and 0 minutes (LT)), the value of normalized potential refractive index gradient is anomalously large (~ 50 with respect to ~ 5 of small values) at the height of about 1.2 km. This would indicate that at this height and around the above mentioned period for a few minutes, the LAWP has detected the ducting layers. This can be confirmed through the criteria of (2) by using the measured values of temperature, pressure etc. by using radiosonde techniques. In our future work, we have planned to carry out such comparison study on detecting ducting layers between the techniques of the above mentioned radar method (LAWP) and the radiosonde method.

ACKNOWLEDGEMENTS

This work is supported by the Dept. of Space, Govt. of India.

References

- H. Ottersten, "Atmospheric structure and radar backscattering in clear air", *Radio Sci.*, 4, 1179-1193, 1969.
- L. J. Battan, "Radar observations of the Atmosphere", University of Chicago Press, Chicago, IL, pp. 323, 1973.
- E. E. Gossard, and R. G. Strauch, "Radar observations of clear air and clouds", Elsevier, Amsterdam, pp. 280, 1983.
- R. J. Doviak, and D. S. Zrnic, "Doppler radar and weather observations", Academic Press, Orlando, FL, pp. 458, 1984.
- A. S. Frisch, and S. F. Clifford, "A study of convection capped by a stable layer using Doppler radar and acoustic echo sounders", *J. Atmos. Sci.*, 31, 1622-1628, 1974.
- E. E. Gossard, S. Gutman, B. B. Stankov and D. E. Wolfe, "Profiles of radio refractive index and humidity derived from radar wind profilers and the Global Positioning System", *Radio Sci.*, 34, 371-383, 1999.
- J. D. Turton, D. A. Bennetts, and S. F. G. Farmer, "An introduction to radio ducting", *Meteor. Mag.*, 117, 245-254, 1988.
- B. B. Bean, and E. J. Dutton, "Radio Meteorology, Dover Publications", pp. 435, 1968.
- N. Sengupta, and R. J. Watson, "Detection of ducts by wind profiler radar" (personal communication).

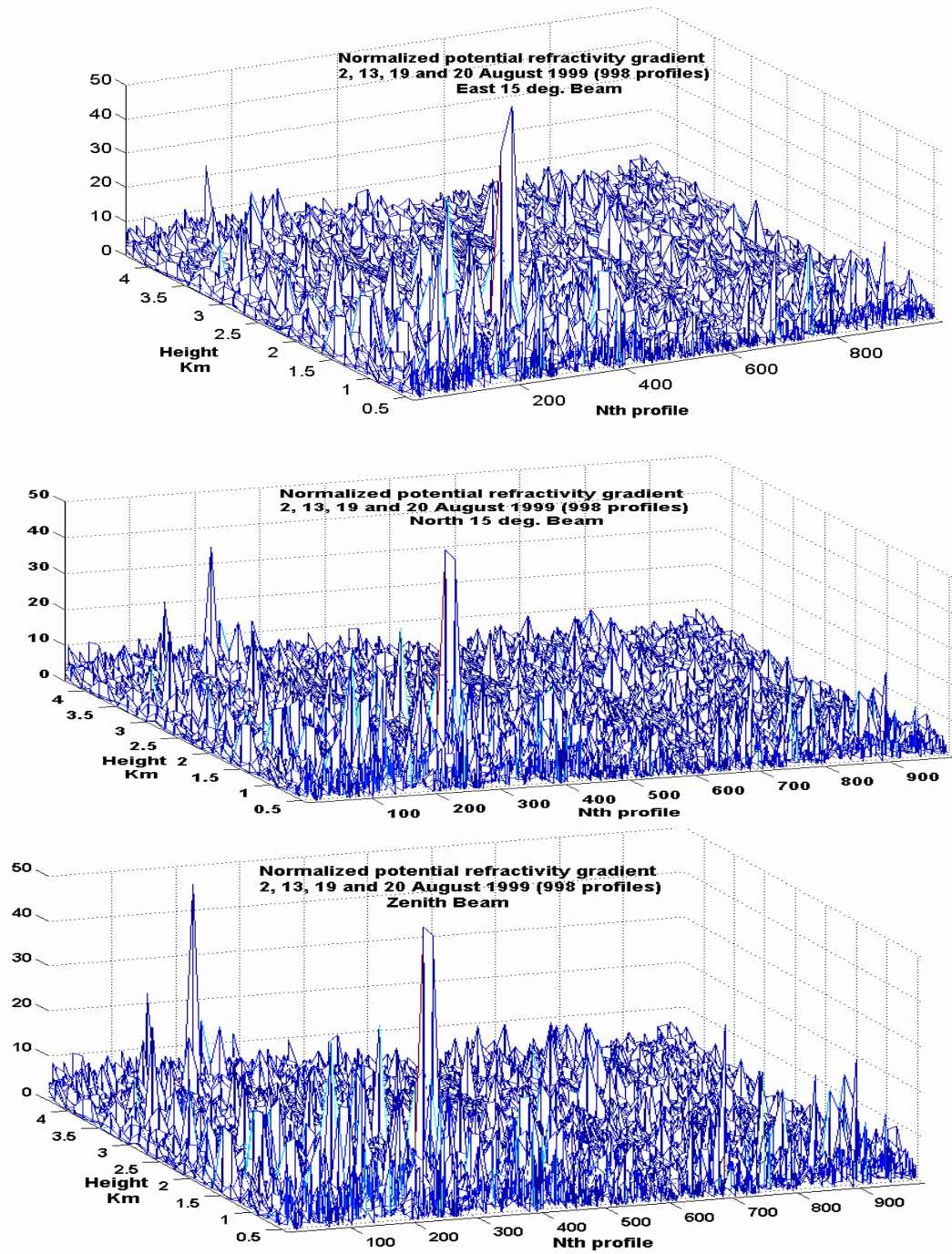


Figure 1. Time (x-axes) and height (0.3 to 4.5 km--y-axes) profiles of potential refractive index gradient calculated by using the received signals with lower atmospheric wind profiler operating at 1357.5 MHz at the Indian tropical station of Gadanki. The top, middle and bottom panels are respectively for East 15°, North 15° and zenith beam positions. See the details of the plot in the text. The strong echoes at around 316th profile (13 August 1999 at 06 Hrs. and 0 minutes (LT)) and at about 1.2 Km denotes the occurrence of ducting layers for a few minutes.