CHAPTER V

TROPOSPHERIC DUCTS
5.1 Introduction

Atmospheric wind profilers operating at Ultra High Frequencies (UHF)/L-band Wind profiler provide excellent information on atmospheric winds, turbulent parameters of scattering irregularities, radio refractive index gradient, turbulent eddy dissipation rate (e), irregularity structure function parameter, $c_n^2$ 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.

Tropospheric ducts occur due to sharp decreases in humidity with height often associated with corresponding temperature inversions. Radio-waves, within a ducting layer, can propagate over long distances thereby leading to interference between terrestrial links. Remote sensing of wind, temperature and humidity fields during ducting conditions can provide a valuable insight into duct dynamics. Wind profilers operating in the UHF and L-band range are sensitive to both Bragg scattering from
radio refractive index structure and Rayleigh scattering from hydrometeors. Refractive index fluctuations in the lower troposphere are predominantly due to fluctuations in specific humidity. Measurements of humidity gradients in this region are of interest for weather forecasting and low elevation microwave communications systems. It has been shown by Gossard et al (1992, 1995) that the vertical gradient of mean specific humidity can be inferred if potential temperature gradient (that can be deduced from radio acoustic sounding system (RASS) and vertical gradients of mean potential refractive index (that can be inferred from radar measurements) are known; and humidity profiles from combined radar, RASS and Global Positioning System (GPS) measurements have retrieved (Gossard et al., 1999). The Indian MST radar has been used by Mohan et al (2004) to obtain humidity profiles, which compare fairly well with those obtained from radiosonde measurements. A new technique has been demonstrated by Miyamoto et al (2000) to determine specific humidity profiles using turbulence echoes observed with the MU radar-RASS in Shigaraki, Japan.

The presence of ducts in the lower troposphere can cause interference on terrestrial and satellite links. Duct detection is therefore desirable to predict the statistics of potential interference and influences radar coverage. Radiosonde measurements yield this information directly through modified refractive index, $M_t$ gradient profiles. Unfortunately such measurements are sparsely distributed in time. Furthermore operational radiosondes are almost always launched periodically (with a period of 6 hours or 12 hours) and since there is good evidence that the statistics of
duct occurrence are non-stationary with strong diurnal variations then duct occurrence based on radiosonde ascents alone are likely to be incorrect. A means of sampling duct occurrence on a temporal scale that is short compared to duct persistence is therefore highly desirable.

5.2 Database:

Gadanki- Lower Atmospheric Wind Profiler (LAWP) measures the echo intensity and the wind profile up to about 6 km with height resolutions from 75 to 150 m as discussed in chapter III and Chapter IV. Wind profilers thus have several advantages over radiosondes, providing near continuous, low cost measurements of horizontal and vertical air velocity directly above the site. This chapter reports on the ability of wind profilers to detect ducting conditions in the lower troposphere, which can cause interference on communication links. Height profiles of structure function parameter, $C_n^2$ of the refractive index, $n$, were retrieved from signal to noise ratio data from LAWP. For the present study, Gadanki-LAWP and Chennai (spatial distance of about 110 km to Gadanki experimental site) Radiosonde [00 GMT (05:30 hrs Local Time) and 12 GMT (017:30 hrs Local Time)] data from October 1997 – December 2005 are utilized to compute the radio refractivity and its refractivity gradient. From these parameters, the vertical distributions of radio refractivity are then determined.
5.3 Vertical profile of radio refractivity gradient from Radiosonde Observations:

The structure of the radio refractive index in the lower part of the atmospheric boundary layer is very important. Multipath effects arise due to large scale variations in atmospheric radio refractive index, such as horizontal layers with very different refractivity. This effect becomes noticeable, when the same signal takes different paths to its target and the rays arriving at different times thereby interfering with each other during propagation through the troposphere. The consequence of this large scale variation in the atmospheric refractive index is that radiowaves propagating the atmosphere becomes progressively curved towards the earth. Thus, the range of the radiowaves is determined by the height dependence of the refractivity. Therefore, the refractivity of the atmosphere will not only affect the curvature of the ray path but will also provide some insight into the fading of radio waves through the troposphere.

Based on surface refractivity while refractivity gradients were based on intrapolated data from radiosonde measurements, at 100m altitude. Though the study presented some interesting results, it however lacked the necessary spatial resolution to observe the small scale changes in the vertical distribution of radio refractivity and propagation effects. The information on radiosonde measurements also lacks the spatial and temporal resolutions which are necessary for the measurement of small-scale variations particularly in the lower
atmosphere. Furthermore, it is generally recognized that radiosonde measurement do not have a sufficiently high degree of accuracy to be completely acceptable for use in observing changes in the degree of stratification of the very lowest layers of the atmosphere. In this study, the surface weather parameters (atmospheric pressure, temperature and relative humidity) and at altitudes of 50, 100, 150 and 200m respectively from which the radio refractivity and refractivity gradient are determined.

Radisonde and Wind profiler measurement covered both climatic seasons (dry season and wet season). The dry period is usually from December to April while the wet season months are usually from June to October every year. The Chennai climate is basically tropical; it is a zone where warm, moist air from the Bay of Bengal converges with hot and dry. The measured relative humidity was converted to water vapour pressure, e (hpa) by using Equation expressed in Chapter II. The data were used to compute the refractivity using Equation mentioned in Chapter II. From the calculated values of the refractivities, refractivity gradient at 50m, 100 m, 150m and 200m are then determined. Result obtained for the average monthlies calculated.

The refractive index values were observed to be generally high during the rainy season (June – October). The high values are due to high air humidity (very close to 100%) observed the influence of a large quantity of moisture air.
Low values of refractivity are observed in January–February months. The slight decrease in refractivity in the March–April months is mostly due to the high temperatures associated with the commencement of the rainy season in.

Fig. 5.2 shows the vertical gradient of refractivity calculated on the basis of the mean monthly statistical distribution of refractivities at each of the levels. It shows that the monthly variation peaks around February corresponding to the end of the December season characterised often with very cool nights and morning times and very dry day time. The values drop gradually between April–June and drastically between July and September corresponding to the period of rainy season or monsoon period.
In Figs. 5.1 and 5.2, there observed a large difference in the values of refractivity and refractivity gradients at zero (ground surface) and other levels from February to April. This can be associated with ground heat flux and the change of seasons which occurs in association with the meridional movement of the Inter-Tropical Discontinuity (ITD) which demarcates at the Surface, the warm and moist south-westerly trade winds from the warm and dry (continental) north-easterly winds leading to high temperature at the surface.

Fig. 5.2 shows the variation of refractivity with height from the ground surface to 200m altitude calculated on the basis of the monthly mean of refractivity. It shows that refractivity decreases with increasing altitude. At the height interval of 50–100m and 150–200 m, the refractivity profile is quite steep while it is gentle at other heights.

![Graph showing variation of refractivity gradient](image)

Figure. 5.2. Variation of monthly mean value of refractivity gradient
Figs. 5.1, 5.2 show the monthly statistics of the occurrence of propagation conditions (Sub-refraction, Super-refraction and ducting) over the one year period of this study. The statistics shows that the propagation conditions have varying degree of occurrence with subrefractive conditions prevalent at all the levels from January to May. Super-refractive conditions are prevalent at the altitudes of 150m and 200m from June to December while ducting at 50 m, 100m and 150m from the month of August to December. During the months when subrefractive conditions are present, stations around Chennai, suffer from effect of super-refraction and ducting. This effect may lead to frequent signal outage from the stations. When super-refraction and ducting are prevalent, very high radio signal strengths can be obtained at very long range (far beyond line-of-sight) and the signal strength may exceed its free-space value.

Figure 5.3. Summary of occurrence of sup-refractive conditions at all the levels.
5.4 Identification of ducts using Lower atmospheric wind profiler radar

Height profiles of structure function parameter $C_n^2$ (obtained from $\eta=0.38C_n^2\lambda^{-1/3}$, where $\eta$ denotes radar reflectivity and $\lambda$ denotes radar wavelength) and wind velocity from wind profilers have been compared with profiles of modified refractive index gradient obtained from coincident radiosonde measurements (obtained from $M = N + 0.157h$, where $M$ and $N$ are modified refractivity and refractivity, respectively and $h$ denotes the height in metres above sea level).
A case study is presented showing how modified refractivity gradient can be retrieved from wind profiler data. An example retrieved profile is compared with that obtained from a radiosonde in Figure 5.7. It is clear that the radar has the ability to detect ducting conditions in the troposphere. The discrepancy between the radar and radiosonde derived profiles of $dM/dz$ are attributed to a ground clutter removal algorithm used by the wind profiler.

Radiosonde data were generated to ascertain the occurrence of ducts indicated by negative values of $dM/dh$. On establishment of the presence of ducts the corresponding radar data were used to generate profiles of the structure function parameter $C_n^2$. Analyses of the data over the specified time period showed that negative gradients of $dM/dh$ and strong variations in humidity were always accompanied by an increase in $C_n^2$ over the duct height region (Figures 5.6, 5.7 and 5.8). The variance of $C_n^2$ values, in the absence of ducts, was found to be lower than the variance obtained during the presence of duct. This is in agreement with the absence of a predominantly sharp peak in values of $C_n^2$ when there are no ducts present in the lower troposphere.
Fig. 5.5 Profiles of modified refractivity gradient (solid line: radiosonde; dotted line: wind profiler) for Gadanki 1700 UTC on 17 June 2000
Fig. 5.6  Left Side: Modified Refractivity Gradient, Specific humidity and Temperature Profiles from Radiosonde measurements for 08-06-00, 05 UTC, Right Side: Structure Function Parameter and wind velocity profiles from LAWP data for 08-06-00, 05 UTC
Fig. 5.7: Left Side: Modified Refractivity Gradient, Specific humidity and Temperature Profiles from Radiosonde measurements for 08-06-00, 05 UTC, Right Side: Structure Function Parameter and wind velocity profiles from Gadanki-LAWP data for 08-06-00, 05 UTC
Fig. 5.8 Left Side: Modified Refractivity Gradient, Specific humidity and Temperature Profiles from Radiosonde measurements for 14-06-00, 05 UTC, Right Side: Structure Function Parameter and wind velocity profiles from Gadnki-LAWP data for 14-06-00, 05 UTC.
Figure 5.9 shows occurrence percentage using wind profiler radar data. It is clear from the above figure that the duct occurrence is maximum during the months of April to May. This result is similar to that of Radiosonde observations. So ducts can be identified by wind profiler data.
The simultaneous observations of duct measure by wind profiler data and Radiosonde data in the month April 1999 as shown fig 5.10. It show that good agreement between wind profiler and Radiosonde dat. The correlation is around 0.89 which is probably in view of differences in measurement technique.