

## Remote sensing of radio ducts using wind profilers

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A case study is presented of refractivity gradient height-profile retrieval using a 915 MHz wind profiler operated by the UK Meteorological Office at Camborne, UK. The retrieved gradient compares well with that obtained from concurrent radiosonde data gathered at the same location, thus demonstrating the potential of such profilers for the investigation of duct dynamics and the collection of unbiased duct statistics.

**Keywords:** Radio ducts, Refractivity gradient, Radiosonde, Wind profiler

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### 1 Introduction

Tropospheric ducts are regions of negative modified refractivity gradient, typically formed as a result of a rapid increase in air temperature, and/or a rapid decrease in humidity, with height. Radio waves can propagate over unusually long distances within ducts causing interference between nominally independent communication systems. They can also adversely affect radar coverage. The capability to predict the occurrence and severity of these effects, at least statistically, is, therefore, desirable.

Ducting conditions are normally determined from the radiosonde measurements. Such measurements, however, are sparsely and periodically, distributed in time. Operational radiosondes are normally launched with a period of 6 or 12 hours, which almost certainly under-samples the dynamic meteorological process. There is a good evidence that the statistics of duct occurrence are non-stationary with strong diurnal variation and the periodic nature of sparse data, synchronized to the diurnal cycle, will, therefore, lead to statistically biased estimates of both duct occurrence and duct parameters (e.g. height, thickness, intensity, etc.). Duct statistics based on radiosonde ascents alone are, therefore, likely to be incorrect. It is, thus, desirable to find a means of sampling duct formation and dissipation processes on a temporal scale that is short compared to duct persistence.

Wind profilers are Doppler radars designed, primarily, to recover volumetric estimates of wind speed and direction. Such radars give rise to signals scattered from refractive index inhomogeneities in the troposphere resulting from turbulence. In the case of classical Kolmogorov turbulence, such backscatter can be interpreted to yield the height profile of tropospheric structure function constant ( $C_n^2$ ). Enhancement of  $C_n^2$  in the vicinity of ducts means that such measurements can be used to detect and investigate ducts. Since wind profilers can operate (quasi-) continuously, the study of duct dynamics becomes feasible. In continuous operation, or using a duty cycle yielding unbiased data with respect to the diurnal cycle, statistically reliable duct occurrence and parameters can also be retrieved.

### 2 Instrumentation and data

Backscattered power and spectral width from the 915 MHz Radian Lower Atmospheric Profiler (LAP), operated by the UK Meteorological Office, have been analysed. The profiler is situated at an existing radiosonde and synoptic station (50.13° N, 5.1° W) in SW England. The radar makes observations in two interlaced modes; the low mode covers the approximate altitude range 0.1-2.0 km and high mode covers the approximate range 0.2-8.0 km. The results reported here are based on data obtained from the profiler operating in low mode, with a range resolution of 60 m.

\*Passed away on 9 June 2007, shortly after submitting her manuscript.

### 3 Theoretical background

Radiosonde measurements of pressure, temperature and dew point provide sufficient information to calculate tropospheric radio refractivity<sup>1</sup>,  $N$ , using

$$N = \frac{77.6}{T} \left( P + \frac{4810e}{T} \right) \quad \dots (1)$$

where  $P$  is the pressure (hPa),  $T$  the temperature (K) and  $e$  the water vapour partial pressure (hPa). By definition, ducts exist when  $dN/dz < -157$  N-units/km. It is conventional (and convenient) to use the related quantity, modified refractivity  $M$ :

$$M = N + 0.157z \quad \dots (2)$$

where  $z$  is the height (m) above sea level. The ducting condition then becomes  $dM/dz < 0$ .

Observations over several decades<sup>2,3</sup> have been made that confirm a close relationship between radar backscattered power and refractive gradients. An estimate of such gradients can be obtained as follows.

Radar reflectivity,  $\eta$ , is obtained from the radar equation:

$$P_r \propto \frac{P_t A_e \Delta r \eta}{r^2} \quad \dots (3)$$

where  $P_r$  is the received power (W),  $P_t$  the transmitted power (W),  $A_e$  the antenna effective area (m<sup>2</sup>),  $\Delta r$  the radar range resolution (m) and  $r$  the range to the target (m). Typically, clear-air radar backscatter is dominated by turbulent processes which are adiabatic in nature, both heat and moisture being conserved. In an adiabatic atmosphere, potential refractivity,  $\phi$ , is a convenient quantity by which refractivity gradient can be related to turbulence parameters<sup>4</sup>, i.e.

$$\left( \frac{d\phi}{dz} \right)^2 = \left( \frac{L_w}{L_N} \right)^{4/3} \left( \frac{du_0}{dz} \right)^2 \frac{C_\phi^2}{C_w^2} \quad \dots (4)$$

where  $du_0/dz$  is mean wind speed gradient,  $d\phi/dz$  the potential refractivity gradient, and  $L_w$  and  $L_N$  are outer scale sizes of the vertical velocity and refractive index fields, respectively. The parameters  $C_\phi^2$  and  $C_w^2$  are the turbulent structure function constants of potential refractivity and vertical velocity,  $W$ . The parameter  $C_\phi^2$  is related to the radar reflectivity<sup>5</sup> by

$$\eta = 0.38 C_\phi^2 \lambda^{-1/3} \quad \dots (5)$$

where  $\lambda$  is the radar wavelength. The structure parameter for vertical velocity is obtained from the eddy dissipation rate,  $\epsilon$ , using the relation<sup>3</sup>

$$C_w^2 = (4/3) B \epsilon^{2/3} \quad \dots (6)$$

where  $B$  is a Kolmogorov constant (approximately 2.1). The parameter  $\epsilon$  can be retrieved from the spectral width of the wind profiler data<sup>6</sup> using

$$\epsilon = \left( \frac{4\pi\sigma_{11}^2}{A_E (128.3 + 3.5(V_T t_D)^{2/3})} \right)^{3/2} \quad \dots (7)$$

where  $\sigma_{11}^2$  is the variance of the velocity component in the radial direction due to turbulence,  $A_E$  the Kolmogorov constant in the inertial sub-range,  $V_T$  the wind speed transverse to the radar beam and  $t_D$  the radar dwell time.

The modified refractivity gradient,  $dM/dz$ , is obtained from the radar retrieved potential refractivity gradient,  $d\phi/dz$ , using<sup>7</sup>

$$\phi \cong M - 0.13z \quad \dots (8)$$

### 4 Data analysis

Some results of the analysis of radiosonde data obtained during the month of June 2000 have been presented along with concurrent height profiles of modified refractivity gradient derived from the wind profiler measurements.

Received radar power is obtained from recorded signal-to-noise ratio and knowledge of the radar noise floor. Radar reflectivity is then retrieved from Eqs (3) and (5) and used to obtain the turbulence structure function parameter. The spectral width of the received radar signal and the wind field measured by the profiler are used to obtain the eddy dissipation rate using Eq. (7). The structure function constant of vertical wind velocity is calculated from Eq.(6) and the square of the potential refractivity gradient is calculated using Eq.(4). A negative value of the potential refractivity gradient is assumed. The square root of Eq.(4) is integrated to find the potential refractivity profile and, finally, Eq.(8) is used to retrieve modified refractivity. The resulting height

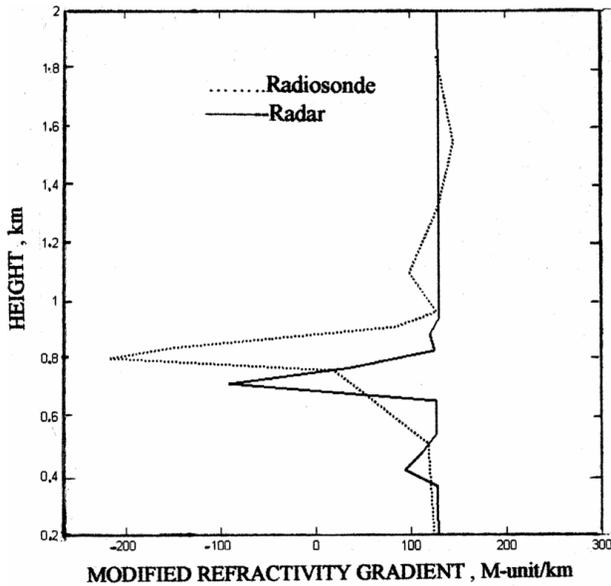


Fig. 1—Radiosonde (dotted) and radar (solid) modified refractivity gradient ( $dM/dz$ ) profiles on 7 June 2000 at 2300 hrs UTC

profile is then compared with that obtained from the radiosonde data.

The presence of an elevated duct at 2300 hrs UTC on 7 June 2000 is indicated by negative values of  $dM/dz$  obtained from the radiosonde data. The profile is shown in Fig. 1. The radar-retrieved modified refractivity gradient compares well with the corresponding gradient obtained from the radiosonde, and also indicates the presence of the duct.

Figure 2 compares the radiosonde and radar-retrieved profiles for 1700 hrs UTC on 17 June 2000. Here some discrepancies are observed. The radar data predicting a single duct is seen between the two ducting regions indicated by the radiosonde. Nevertheless, these plots clearly indicate that wind profilers have the potential to reveal useful data about duct presence and location.

**5 Conclusions**

A case study has been presented demonstrating the potential of wind profiler radars to detect ducting conditions, and, thus, to monitor the same on a quasi-continuous basis. Further investigation is needed to establish as to why there is not more exact agreement between radar- and radiosonde-inferred ducts in the case study presented here. But the present preliminary

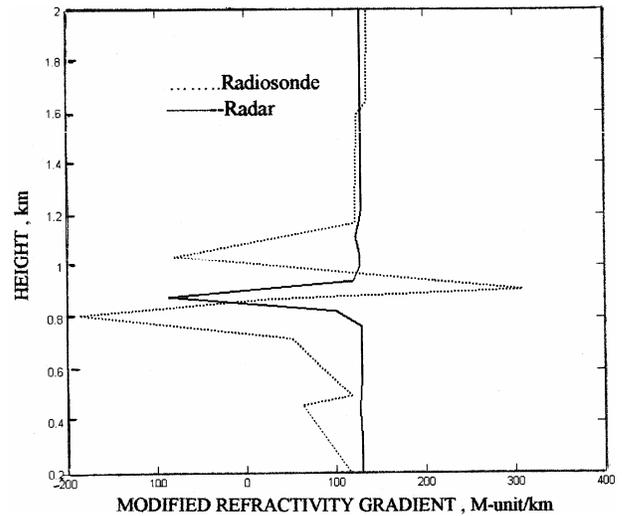


Fig. 2— Radiosonde (dotted) and radar (solid) modified refractivity gradient ( $dM/dz$ ) profiles on 17 June 2000 at 1700 hrs UTC

results provide good confidence that refinement of the method of analysis reported may yield improved agreement and that networks of wind profilers may then find routine application in collecting the reliable and unbiased ducting statistics and for detailed study of radio duct dynamics.

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**References**

- 1 Bean B R & Dutton E J, *Radio Meteorology* ( Dover Publications), 1968, p.435.
- 2 Friend A W, Theory and practice of tropospheric sounding by radar, *Proc IEEE (USA)*, 31 (1949) 1622.
- 3 Richter J H, High-resolution tropospheric rada, *Radio Sci (USA)*, 4 (1969) 1261.
- 4 Gossard E E, Wolfe D E, Moran K P, Paulus R A, Anderson K D & Rogers L T, Measurement of Clear-Air Gradients and Turbulence Properties with Radar Wind Profilers, *J Atmos & Ocean Technol (USA)*, 15 (1998) 321.
- 5 White A B, Radar remote sensing of scalar and velocity microturbulence in the convective boundary layer, *NOAA Technical Memorandum ERL ETL-276*, 1996.
- 6 Ottersten H, Atmospheric structure and radar backscattering in clear air, *Radio Sci (USA)*, 4 (1969) 1179.
- 7 Gossard E E & Strauch R G, *Radar Observations of Clear Air and Clouds* ( Elsevier, Amsterdam), 1983, p.280.