Turbulence structure function parameters retrieved in presence of ducting from the VHF radar and UHF wind profiler at Aberystwyth

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ABSTRACT

Tropospheric ducts, which can lead to anomalous radio wave propagation, are formed by a decrease of humidity with height, an increase in temperature with height or a combination of both. An analysis of radiosonde data for July 2000 and June 2001 has established the presence of elevated ducts on several occasions. Turbulence structure function constant (C_n^2) profiles, measured using co-located VHF and UHF wind-profiling radars, show duct associated enhancement Inconsistencies between the profiles for the two radars are attributed to significant contributions to scattering at the lower frequency due to processes other than classical turbulence. Some of the data examined underlines the care needed in the reliable extraction of turbulence parameters in the presence of Rayleigh scattering from rain.

INTRODUCTION

The path of electromagnetic radiation through the atmosphere is determined by the refractive index field, n. Since n is close to unity, it is usually represented by the scaled quantity radio refractivity, $N = (n\text{-}1)10^6$, related to atmospheric pressure, p (hPa), water vapour pressure, e (hPa), and temperature, T (K), [2] by:

$$N = \frac{77.6}{T}\left(p + \frac{4810e}{T}\right) \tag{1}$$

Sharp decreases in refractivity with increasing altitude (associated with sharp decreases in humidity and sharp increases in temperature) cause the propagation of radio waves to be confined in a duct. This may lead to anomalously long distance propagation. Tropospheric ducts can be associated with (i) subsidence in high-pressure systems, (ii) nocturnal radiation, (iii) evaporation over water surfaces and (iv) weather fronts. Radio waves propagating within duct layers may lead to forecasting errors [1].

Ducts are characterised by negative gradients of modified refractivity, M, defined in order to account for the curvature of the earth, i.e.:

$$M = N + 0.157z \tag{2}$$

where z denotes height in metres.

Although radiosonde data can be used to identify ducting conditions through equation (2), they are typically launched only once or twice a day. In this paper a case study is presented that compares the retrieved turbulence structure function parameter, C_n^2, from co-located VHF and UHF radars in the presence of elevated ducts. These typically operate continuously and can provide data at intervals of a few minutes in time and a few hundred metres in altitude. The height profiles of C_n^2 show general enhancement associated with the ducting region.

RADAR DESCRIPTION

Fig. 1 shows the antenna array of the MST radar. It operates at 46.5 MHz in the ST (Stratosphere Troposphere) mode, covering an approximate altitude range of 2 km to 20 km with a resolution of 150 m. The 915 MHz boundary layer wind profiler, Fig. 2, was operated by the UK Meteorological Office at the MST radar site between 1999 and 2002. The radar makes observations in two interlaced modes; low mode covers the approximate altitude range 0.1 - 2.0 km and high mode covers the approximate range 0.2 – 8.0 km.

Fig. 1 MST Radar at Aberystwyth, UK

Fig. 2 Met. Office 915 MHz Boundary Layer Wind Profiler at Aberystwyth, UK

The results reported in this paper are based on data obtained from the UHF profiler operating in high mode, with a range resolution of 192 m, to allow comparison with the MST radar data.

THEORETICAL BACKGROUND

The relationship between C_n^2 and potential refractive index gradient, ϕ, in the presence of turbulence is given by [3]:

$$C_n^2 = 2.8\phi^2 L_0^{4/3} \tag{3}$$

where L_0 is the outer scale size of turbulence and ϕ is the vertical gradient of refractive index given, in turn, by [3]:

$$\phi = -77.6\times10^{-6}\,\frac{p}{T}\left(\frac{d\ln\theta}{dz} + \frac{15500q}{T}\frac{d\ln\theta}{dz} - \frac{7800}{T}\frac{dq}{dz}\right) \tag{4}$$

p (hPa) in equation (4) is atmospheric pressure, T (K) is temperature, θ is potential temperature (K), q (kg/kg) is specific humidity and z (m) is height.

Backscatter from refractive index irregularities due to the turbulence and Fresnel reflection from large gradients of refractive index give rise to the observed radar echoes [4]. Radar reflectivity, η, is obtained from the radar equation, i.e.:

$$P_r \propto \frac{P_t A_e \Delta r \eta}{r^2} \tag{5}$$

where P_r denotes received power (W), P_t is transmitted power (W), A_e is antenna effective area (m^2), Δr is radar range resolution (m) and r is range (m) to the target. The refractive index structure function parameter, C_n^2, is related to radar reflectivity η by [5]:

$$C_n^2 = \frac{\eta}{0.38}\lambda^{1/3} \tag{6}$$

where λ is radar wavelength (m).

DATA ANALYSIS

Radiosonde data from Aberporth (46 km west of Aberystwyth), obtained from the British Atmospheric Data Centre, were analysed for the month June and July 2000 to determine the presence of ducting conditions. Height profiles of dM/dz (using equations (1) and (2)) were plotted using six-hourly radiosonde data. The date and time of duct occurrences were established by negative values of dM/dz. Height profiles of the turbulence structure function parameter were obtained from radiosonde data (using equations (3) and (4)) with L_0 = 10 m [6]). The corresponding VHF and UHF data were then analysed to obtain height profiles of C_n^2 (using equation (6)).

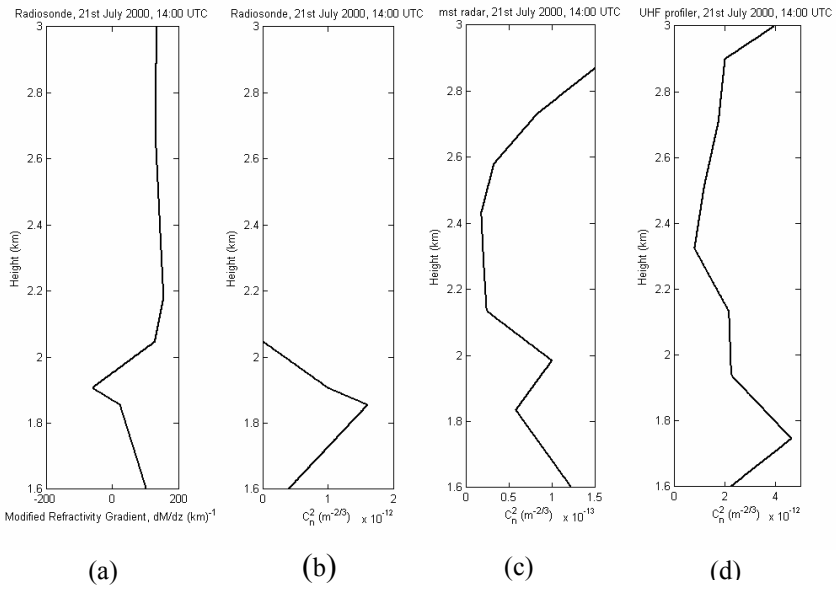

Fig. 3 Profiles for 21 July 2000 at 14:00 UTC: (a) dM/dz, (b) C_n^2 derived from Aberporth radiosonde data, (c) C_n^2 derived from MST radar data, (d) C_n^2 derived from UHF profiler at Aberystwyth

Fig. 3(a) indicates the presence of a duct on 21 July 2000 at 14:00 UTC. A general enhancement of C_n^2 in the region of the duct is noted, Fig. 3(b). The turbulence is well reflected in the wind profiler data, Fig. 3(d), but less so in the MST radar data, Fig. 3(c). It is presumed that the scattering phenomenon in the case of the lower frequency radar is less dominated by classical turbulence. The possibility of scattering contributions from gravity wave structures, fossilised turbulence and/or quasi-specular reflections from duct edges is currently being investigated.

CONTAMINATION BY RAIN SCATTER

It is well established that VHF and UHF wind profilers are sensitive to both Bragg scattering from turbulence and Rayleigh scattering from hydrometeors. A careful estimation of turbulence structure function parameter, C_n^2, from radar data is essential in the presence of precipitation. The surface meteorological observations on the radar site indicated presence of rain on 20 June 2001 at 05:30 UTC.

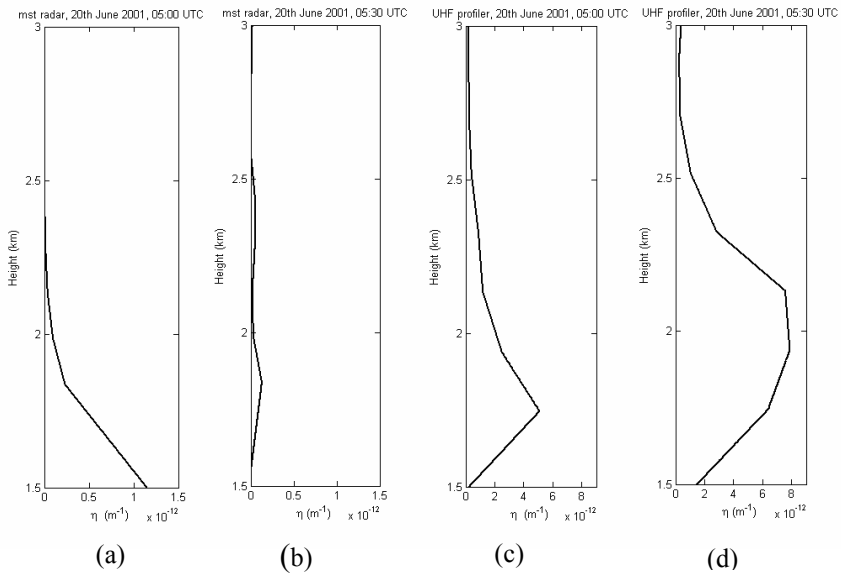

Fig. 4 Profiles for 20 June 2001 of η derived from (a) MST radar data (05:00 UTC), (b) MST radar data (05:30 UTC) in presence of rain, (c) UHF radar data (05:00 UTC), (d) UHF profiler data (05:30 UTC) in presence of rain

Rayleigh scattering from hydrometeors is frequency dependent. This is reflected in the disparate values of η derived from the UHF and VHF radars at 05:30 UTC when precipitation was recorded by rain gauges at the radar site, Fig. 4(d) and (b). This is consistent with previously reported observations [7].

SUMMARY

A case study of retrieved height profiles of turbulence structure function parameter, C_n^2, in the presence of elevated ducts, using a VHF (MST) radar and UHF wind profiler located at Aberystwyth, UK, shows general enhancement in the region of the duct. Agreement between the directly measured turbulence parameter and the radar data is better at UHF than at VHF. The discrepancy in the latter case may be due to significant scattering by phenomena other than classical turbulence. Future work will be focussed on distinguishing between the various scattering mechanisms contributing to VHF profiles in the presence of ducts. The case study underlines the care that needs to be taken in data interpretation during the presence of rain.

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