Impact of elevated atmospheric structures upon radio-refractivity and propagation

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***Abstract*—Analysis of radiosonde data simultaneously acquired from widely separated Australian ground stations on 13 March 2001 indicates that a typical subsidence duct created by the motion of a high pressure cell might possess a lateral spread of hundreds of kilometers and could persist for a time interval exceeding 24 hours. Propagation simulations utilizing the two-dimensional parabolic equation model have predicted that radio propagation from a transmitter located within the core of such a duct will exhibit substantial spatial regions of signal depletion (radio holes) of magnitude 20dB or greater, as well as possible regions of signal enhancement. These effects are manifested at ranges from the transmitter of tens of kilometers.**

***Index terms*—Elevated ducts, propagation, radio-refractivity**

I. INTRODUCTION

The propagation of radio waves and microwaves in the atmosphere is of interest in many different fields, from communications to defence applications. The prevalence within the boundary layer of wide-scale ‘non-standard’ refractivity profiles is a major factor leading to the formation of regions of signal loss known as 'radio holes', as well as possible regions of signal enhancement and regions of anomalous propagation generally known as 'ducts'. The atmospheric refractivity is a function of the temperature and humidity structure of the atmosphere, given by:

$$M = \frac{77.6}{T}\left\{P + \frac{4807.e}{T}\right\} + 0.157h \qquad (1)$$

Here, the modified refractivity M of the atmosphere is a function of altitude h (in meters) as well as range and time, and may be readily determined by directly measuring the temperature T (in degC), the atmospheric pressure P (in hectopascals), and the partial vapour pressure of water e (in hectopascals). The second term in equ (1) has been added to account for the curvature of the earth. The vapour pressure e is directly related to the dew point temperature T_d (also in degC), and is given by

$$e = 6.1078 \times 10^{\{AT_d/\ (B+T_d)\}} \qquad (2)$$

where A=7.5 and B=237.3 The dependence of refractivity on the physical structure of the atmosphere means that changing meteorological conditions can lead to changes in radiowave propagation. One of the overall goals of this research is to examine and predict the formation of radio holes, signal enhancement and ducts for different meteorological conditions. For this paper, we focus on one case, using meteorological measurements to delineate the horizontal and vertical refractivity structure, and numerical modeling to investigate the impact of observed ducts upon propagation.

II. ATMOSPHERIC OBSERVATIONS

Refractivity profiles were computed using data acquired from simultaneous radiosonde soundings on 13 March 2001 from five widely separated Australian ground stations. The results for the time 00.00 UTC are depicted in Figure 1. The prevailing synoptic situation is fairly typical for this time of year, with a large anticyclone in the Bight, extending a ridge over the southern portion of the continent. Temperature and dew-point structure is shown in the small diagrams on the left of each inset.

At the sites of Woomera, Adelaide and Mt Gambier, a strong increase in air temperature and a fall in dew-point temperature at around 2km altitude is clearly associated with the ridge. This feature is seen to a lesser extent and at a higher altitude at Hobart. Importantly, these features are responsible for the formation of a sharp drop in refractivity (Figure 1, right inset) which may lead to the formation of a duct. More specifically, and together with the large lateral spread, these features indicate the presence of a subsidence duct formed as the dry air associated with the high-pressure cell sinks to lower altitudes. The analysis of radiosonde soundings for each site on subsequent days (not shown here) also indicates that the elevated anomaly persisted over a substantial time span exceeding 48 hrs while maintaining a lateral spread of many hundreds of kilometers.

Radar observations were also made by the VHF boundary layer radar facility at Buckland Park in South Australia. These observations provided, from the radar return, a signal-to-noise ratio image of atmospheric features prevailing at around 40km north of Adelaide. This SNR image has been plotted in Figure 2, with an upper altitude of 4km. The persistent nature of the enhanced SNR for the layer at around 2km correlates well with the sharp changes in the refractivity, air temperature and dew-point temperature at this altitude, as evident in Figure 1.

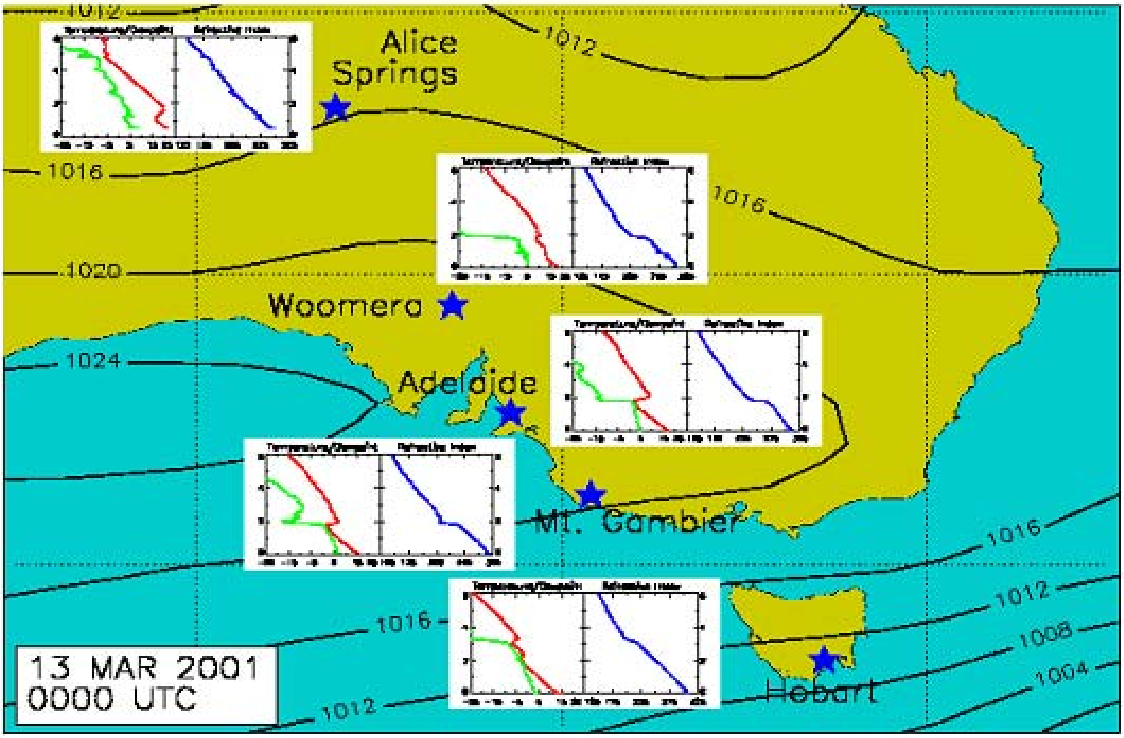

Figure 1: Altitude variation of air temperature in deg C (red), dew-point temperature in degC (green), and atmospheric refractivity in N units (blue) obtained from simultaneous radiosonde soundings at five widely separated Australian stations (blue stars).

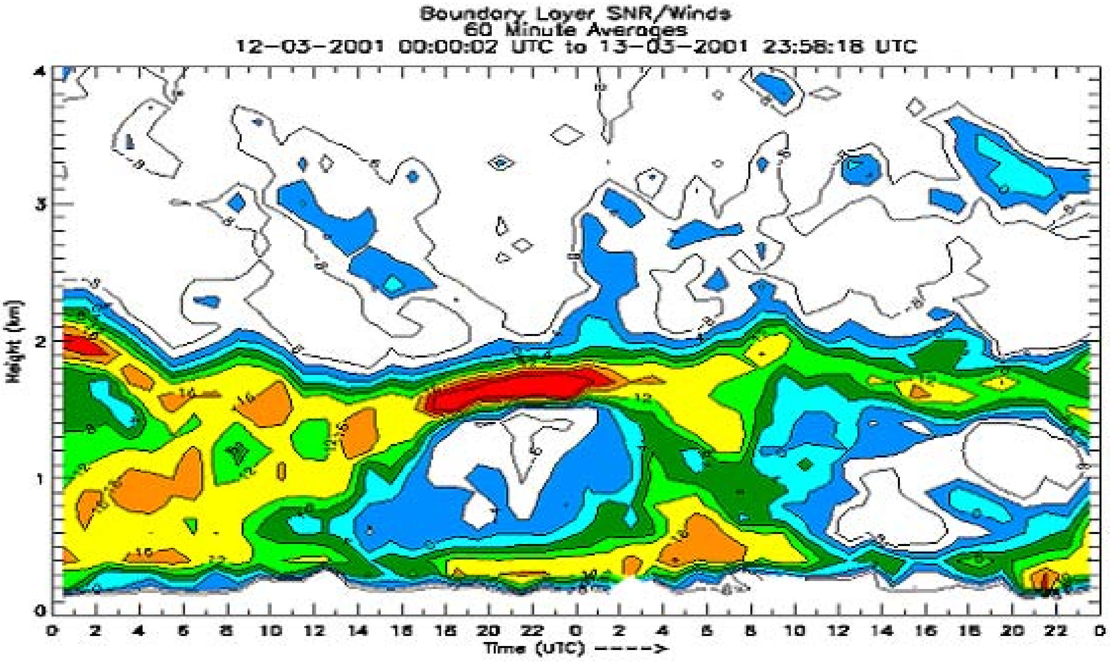

Figure 2: Signal-to-noise ratio contour plots (axes are altitude versus time) obtained using VHF radar facilities located at Buckland Park (north of Adelaide) over the time period 12-13 March, 2001. The SNR scaling varies from the lowest range –10 to –5dB (dark blue) to the highest range +20 to +25dB (red).

III. PROPAGATION SIMULATION

One of the refractivity profiles studied in detail is the Woomera profile depicted in Figure 3. The existence of spatial regions with negative modified refractivity gradient clearly indicates the presence of ducting. The profile was utilized as input for a modeling exercise aimed at simulating the propagation behaviour of a 10GHz transmitter located within the duct layer. This transmitter position was chosen in order to maximize any anomalous propagation effects that might be expected to occur downstream. In particular, a large radio hole was predicted within the propagation coverage, beginning at a range of a few tens of kilometers from the transmitter.

The propagation coverage was computed over a lateral range of 200km using the (deterministic) TERPEM propagation code, and is shown in Figure 4. We have also found that there is a narrow domain of the transmitter altitude below the duct, within which a signal *enhancement* effect appears, rather than a hole. This feature is more obvious at lower microwave frequencies, eg 1 GHz. Figure 4 also illustrates the point that relatively modest ducts can produce substantial regions of signal depletion and beam distortion, which obviously would have significant implications for the detection capability of airborne radar systems, for example.

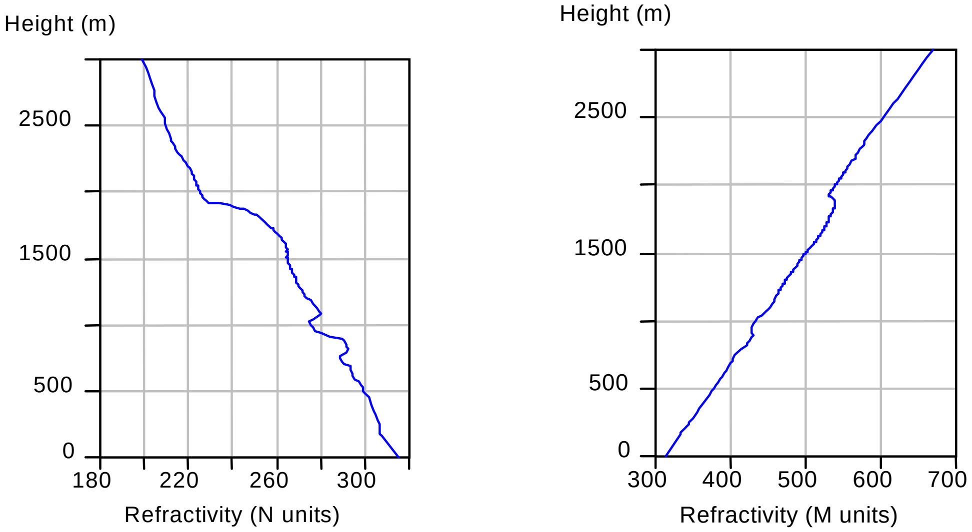

Figure 3: Detailed altitude variation of atmospheric refractivity from the Woomera radiosonde station soundings on 13 March at 00.00 hrs UTC

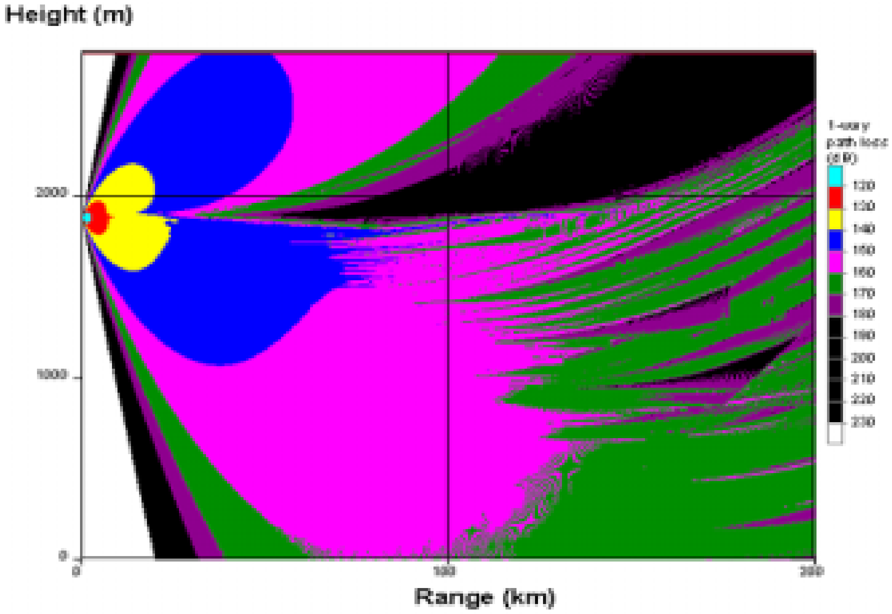

Figure 4a: Coverage diagram of the propagation factor for transmission within the Woomera defined by figure 3. The 10GHz transmitter, utilising a Gaussian antenna, is situated at an altitude of 1900m.

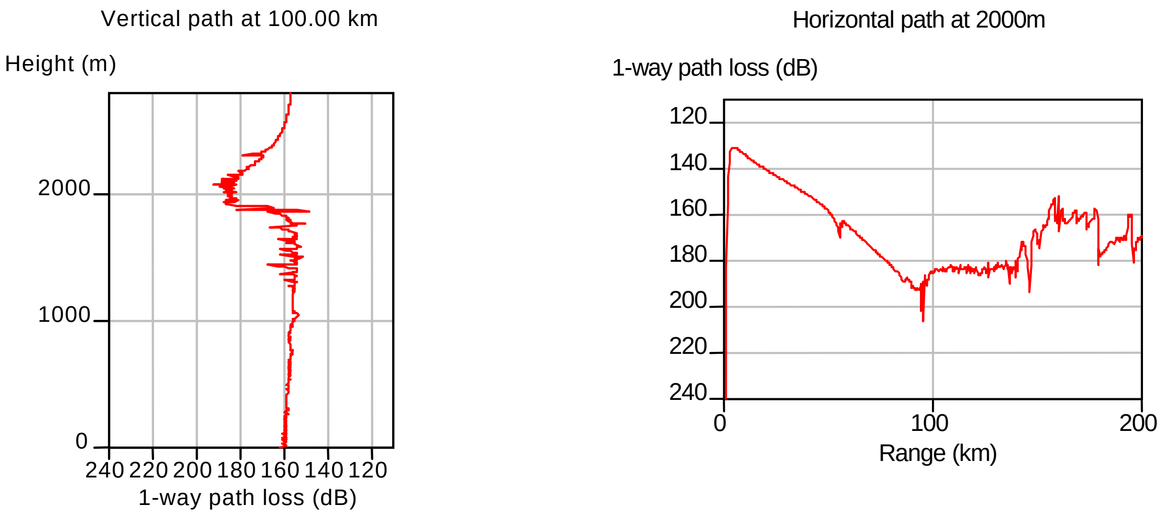

Figure 4b: Corresponding to figure 4a, the vertical path cross section at range 100km and the lateral path at altitude 2km, which both indicate the presence of a radio hole exceeding 20dB.

IV. DISCUSSION

Our previous experience in modeling a range of anomalous propagation effects attributable to non-standard refractivity profiles indicates that the magnitude and mix of these effects depends upon (a) the sharpness of the changes within the gradient of the modified refractivity, (b) the strength (width) in M-units and thickness of the anomalies, (c) the relative altitudes of the anomalies and the transmitter, and (d) the transmission frequency. Condition (a), in particular, has a strong impact upon the range from the transmitter and size of any radio holes produced “downstream”. As a general rule, the appearance of a significant signal enhancement requires strong ducting whereas the appearance of a radio hole does not. Indeed, the relatively modest duct at around 2km depicted in Figure 3 is responsible for producing a radio hole whose modeled depth exceeds 20dB. We have also found in previous modeling exercises that radio holes are predicted to appear in situations devoid of ducting, ie where a mere change in refractivity gradient occurs. Thus the gradient does not necessarily need to go negative.

The evidence of temperature inversions and dew-point temperature shifts at the altitude of the refractive anomaly, taken in conjunction with synoptic diagrams and satellite pictures, strongly suggests that the mechanism for the 2km duct is subsidence to lower altitudes of dry air associated with the motion of a high pressure cell. As the dry air descends it is heated by adiabatic compression, generating the temperature inversions. This phenomenon is sometimes visibly marked by trapping of atmospheric pollutants or by the formation of a cloud layer at the inversion level. Apart from the results for the Woomera station reported here, we have also computed refractivities obtained from subsequent radiosonde soundings, with additional ducting appearing over Woomera at altitudes of around 4-5km. This more general study will be reported elsewhere, however the higher level ducts have been found to be associated with very strong winds, suggesting that the mechanism in this case is somewhat different.

The large spatial extent and temporal persistence of the subsidence duct shown in Figure 3 has ramifications for propagation predictability using standard propagation codes such as AREPS and TERPEM. A number of issues arising in this context will need to be addressed however, including (a) how many spatial soundings would be needed in practice to provide a useful and meaningful propagation prediction, (b) what overall differences in the respective data sets would characterize high pressure and low pressure scenarios, and (c) what types of modifications to an overland propagation model would need to be applied in order to make it useful for coastline predictions.

V. CONCLUSION

The somewhat limited results reported here suggest that more systematic studies of spatially-extended elevated ducts, the atmospheric mechanisms producing them and the implications for propagation prediction would be both desirable and productive. We are currently pursuing this objective and the results will be reported elsewhere.

References:
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