IMPLICATIONS OF ANOMALOUS PROPAGATION IN THE EVAPORATION DUCT FOR RADARS AT X AND KU BAND

Andrew J. Kerans[1], Andy S. Kulessa, Graham S. Woods, and John A. Hermann

Abstract. The radio refractive index of the atmosphere is governed by the combination of atmospheric temperature, pressure and humidity. Over oceans, humidity gradients can cause an effect known as the evaporation duct. Such a duct has the property of trapping radio waves between the sea surface and the top of the duct, which can result in extended range or radio black spots. The amount of channeling is dependent on the carrier frequency, the duct structure and various transmitter and receiver properties including antenna tilt and height above sea level. Knowledge of the duct and how it affects propagation is therefore of some importance to people using or designing maritime radio equipment for use in maritime and littoral environments because it allows disadvantages to be overcome while making use of the advantages of extended range. This paper discusses research being undertaken at James Cook University on duct height determination and propagation within it. The paper also discusses current topical studies within the International Telecommunications Union (ITU) on sharing between radars and satellite links in the 13.75–14-GHz band and implications to this work arising from a predominant duct.

INTRODUCTION

Numerous works over the past two decades have noted incidences of reduced or extended radar detection ranges and extended radio link ranges over water (see for example [1,2]). These changes in detection or propagation range are usually associated with surface-based evaporation ducts.

Research over the past decade has shown that low-grazing-angle microwave radio propagation at low elevations over oceans will usually encounter an atmospheric refractive index gradient which will give rise to anomalous propagation or, *ducting*. Our research has shown this phenomenon to be particularly prevalent over warm tropical waters in the tropical littoral zone around the northern Australian coastal region. Surface-based ducting over oceans is referred to as the *evaporation duct*. The duct traps radio waves propagating at low angles, below about 0.5° to the horizontal and are therefore important in maritime radar and communications applications.

Ducting can result in enhanced or degraded propagation including:

- radar/radio ‘black holes’;
- interference beyond the ranges and occurrences predicted in ITU models; and
- extended-range radar tracking and signals interception.

A thorough understanding of ducting will therefore assist naval commanders understand information presented by radar systems as well as overcoming or taking countermeasures to reduce the adverse effects of radar black holes. Additionally electronic intelligence (ELINT) or signals intelligence (SIGINT) operations can benefit from a better understanding of the propagation mechanisms to make the reception of such signals easier and in some cases safer. From a civilian and military perspective this paper shows that further work is required on the ITU interference prediction recommendation contained in ITU-R Recommendation P-452 and that considerable care should be taken when studying sharing between radars and other systems over or near warm tropical oceans.

[1] PO Box 3060, Belconnen, ACT, Australia, 2617.

OUR EXPERIMENTS

A number of experimental systems have been developed by James Cook University (JCU) and the Australian Defence Science and Technology Organisation (DSTO). These experiments have involved the collection of both meteorological and radio data over warm tropical waters. Evaporation-duct profiles have been measured in the littoral zone and over blue water and the RF propagation within them compared to available models based on the parabolic equation method (PEM) prediction algorithm [3].

Meteorological Measurements

An evaporation duct results from the evaporation of water vapour from the sea surface. Water-vapour pressure at the sea surface is saturated and decreases in the first few metres above the sea surface. The resulting humidity gradient is usually sufficient to maintain a surface duct above the sea surface, provided wind speeds are not too great.

Measurements undertaken by James Cook University and the Defence Science and Technology Organisation show evidence of a link between duct height and horizontal wind speed, [5,6] for tropical as well as temperate littoral waters. The vertical profile of the structure parameter:

$$C_n^2(h) = \alpha^2 K^{4/3} (\kappa d)^2 h^{-2/3} \quad (1)$$

has been derived for a near-neutral atmosphere [7] and is dependent on the evaporation duct height, d. In this equation, α is a universal constant, K is the von Karman constant and κ is a parameter taking on the approximate value of 0.13, while h is the height above sea-level. Ongoing research suggests a direct relationship between this structure parameter, surface wind speed and duct height. An earlier analysis by [8], indicates an increase in $(C_n)^2$ with wind speed until a maximum value is reached. The limiting value may be associated with mixing in the atmosphere.

In order to estimate the duct height instrumented buoys (see Figure 1) capable of measuring the air temperature, humidity

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