Implications of the evaporation duct for microwave radio path design over tropical oceans in Northern Australia

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Abstract— **Examples of evaporation duct height statistics for coastal and oceanic waters in the North of Australia are presented. The range in duct height variation measured in coastal waters beckons further investigation of the effects of the evaporation duct on fixed link performance. Fixed link design issues are addressed in the context of the tropical evaporation duct and a suggestion made so that designers may avoid interference problems resulting from anomalous propagation inside the duct.**

***Index terms*—Evaporation ducts, propagation, terrestrial fixed-links**

I. EVAPORATION DUCT STATISTICS

Water vapour gradients in the lower part of the boundary layer, resulting from evaporation processes produce what is termed the radio evaporation duct. Experimental campaigns for measuring evaporation duct parameters have been undertaken by DSTO in collaboration with James Cook University. Since 1999, James Cook University School of Engineering and the University of Canberra's RSR group have continued in collecting evaporation duct statistics. Measurements of duct parameters have concentrated on coastal regions between Townsville and Hinchinbrook Island in the north of Australia as well as the Gulf waters of South Australia. The measurements have been carried out using instrumented buoys and more recently with remote sensing techniques.

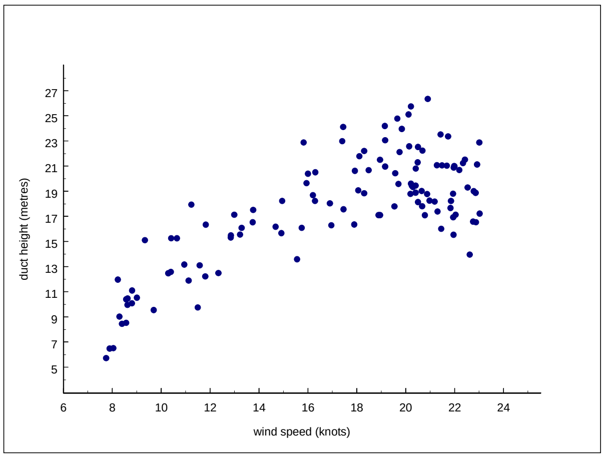

Figure 1 Duct height versus wind speed is plotted here from data measured in the Gulf of St Vincent on 10th January 1999. The duct height was derived from buoy measurements of atmospheric humidity, temperature and pressure measurements using a least squares parameter estimation technique.

Large variations in evaporation duct height can occur along coastal water over a diurnal cycle, when there is little apparent change in weather conditions apart from a wind speed change. Empirical evidence for duct height variation with wind speed was first reported in [1] and since then data as been collected from different locations and seasons. Two examples are depicted in figure 1 and figure 2 respectively. Figure 1 shows the duct height variation with wind speed from measurements taken in temperate waters in the Gulf of St Vincent near Adelaide, while the duct height versus wind speed trend shown in figure 2 is based on data collected in coastal waters near Ingham in 1998.

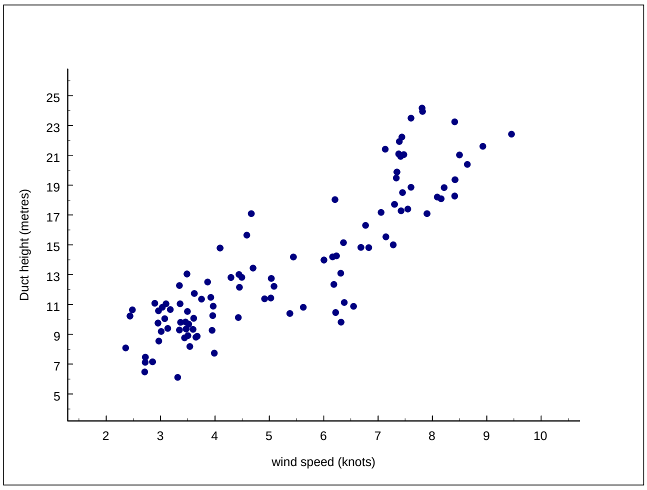

Figure 2 Duct Height versus wind speed is plotted here from data measured between the Palm Islands and the Australian mainland, in Northern Queensland, on 28th July 1998. The plot is based on measurements taken with an instrumented buoy (as in Figure 1)

Both graphs show a variation in duct height from approximately 5 to 25 meters, although the wind speed range in the figure 2 data is much less than in figure 1. Sea surface temperature is an important factor in evaporation processes and indeed influences the structure of evaporation ducts. Evaporation duct heights in tropical waters are typically larger than those found in temperate cooler waters as is evidenced in all our data taken collected so far in Australian waters and in other published reports.

The wind variations shown in these two examples represents the variation that can occur between times lasting several hours to one diurnal cycle. This type of variation is typical for a large percentage of our data set for coastal regions. In most cases it is indeed the sea breeze that we are seeing. The sea breeze attains a maximum speed in the afternoon before decreasing and eventually

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disappearing after sunset. A general theory which describes the evaporation duct height relationship to wind speed (and for that matter sea surface temperature) has yet to be developed.

Another way of displaying duct height statistics is to plot, for each ducting event, the duct height against the percentage of time that a duct height of a given value is exceeded. Now a ducting event can be said to occur between two successive times when no duct is measured. Alternatively we have also defined it as the time between equipment failures when we were unable to profile the atmosphere. Evaporation duct heights have been determined using instrumented spar buoys that directly measure air pressure, humidity and temperature. The radio-refractivity is a function of these three meteorological parameters. Furthermore, the evaporation duct refractivity profile can be modeled as a function of height above mean sea level with the duct height as the main free parameter. Determining the duct height then becomes a problem of parameter estimation given the refractivities obtained from the buoy measurements. Provided that data exists for the first few meters of the atmosphere (where indeed most of the change in refractivity occurs) the duct height can be estimated using a least squares estimation technique.

Figure 3 displays the percentage of time that duct height is exceeded for three ducting events in three different tropical regions, namely the Western Pacific Ocean, near the equator, the Coral Sea and the littoral region around Lucinda, Queensland.

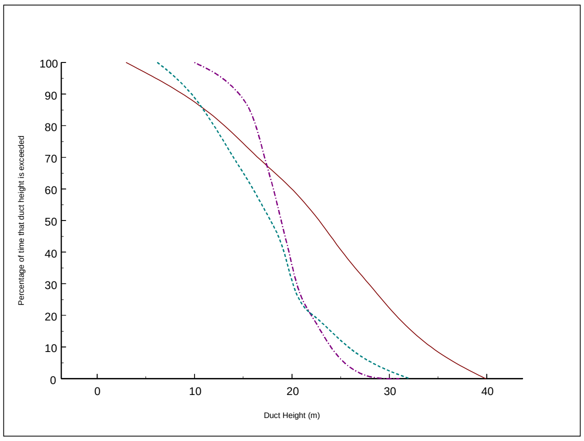

Figure 3 Plots of percentage of time that duct height is exceeded for three different ducting events in three different locations. The aqua coloured graph corresponds to data taken off Lucinda, Qld. The purple graph depicts data from the Coral Sea and the brown coloured graph is data from the west Pacific.

From figure 8 it is evident that that there is larger variation in duct height displayed in the Lucinda data compared to the Coral Sea ducting event. The reason for this has been attributed to the effect that the sea – breeze has on duct height variation in littoral regions. The ducting event measured in the Coral Sea occurred during stable weather conditions with little variation in wind speed. On the other hand, the ducting event in the western Pacific shows the greatest variation in duct height basically because of the highly variable weather that was experienced at the time.

From our data sets, duct heights in coastal regions have been measured to range from 0 to 36 meters and during a diurnal cycle, the duct height can vary by 20 meters or more. Furthermore, in tropical waters, large evaporation ducts can exist during times of relatively low wind speed. If we consider the effect of the evaporation duct on a low elevation microwave transmitter, we see that a strong duct, assuming it is extensive, can channel energy with little pathloss for many kilometers. This channeling effect can be seen in the example shown in figure 4 where signal pathloss for a height of 20 meters above sea level has been calculated for a 10.75 GHz transmitter at 20 meters above sea level in a 30-metre evaporation duct. Here we see pathlosses as little as 10 dB over 55 kilometers! However, the extended propagation that is provided by the evaporation duct may have a debilitating effect on a radio-link because it may enable signals from distant emitters to interfere.

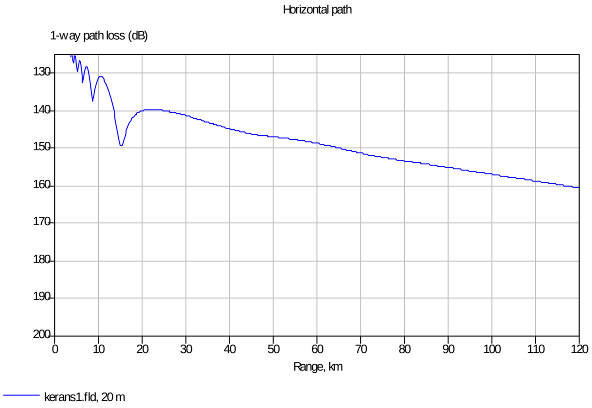

Figure 4 Signal pathloss from a 10.75 GHz transmitter measured at a height of 20 meters above mean sea level. Propagation takes place in a 30-metre high evaporation duct. The transmitter antenna is also assumed to be at a height of 20 meters above mean sea level.

Of particular interest in the context of this paper are the measurements taken in the littoral region around Lucinda. This zone has high evaporation ducts and also has a high variation in evaporation duct height owing mainly to sea breeze effects. Thus propagation conditions can be highly variable over time periods of several hours. In the Lucinda region there is also the likelihood of microwave fixed links having over water, or near over water paths.

Consider another example: Looking at Figure Three we can see that there is about a 15% probability of a duct exceeding 25 meters around Lucinda. This means if two transmit antennas are below 25 meters they will be wholly within the duct. Consider now the case where a distant unwanted transmitter is inside the duct. Also consider a wanted transmitter at say 35 meters AMSL, above the duct, transmitting to a receiver at 20 meters, again, inside the duct. We pose the question: Would this system suffer interference?

II. A HYPOTHETICAL DESIGN

A short haul system is required between Lucinda and Orpheus Island, some 19 km across the sea. To reduce reflection fading a high tower is used on Orpheus while a short tower is used at Lucinda. To achieve the required availability a flat fade margin of 50 dB is required for this path. The Lucinda receiver operates at 10.75 GHz. Both antennae are 28 dBi with 250 mW transmitters. Feeder losses are ignored for the purposes of this exercise.

A search is carried out to find other potential sources of interference. A low power GSM base station feeder link is found 72.2 km to the south. The transmitter, also at 10.75 GHz, is mounted at 5 meters. Antenna discrimination reduces the energy transmitted towards the design receiver by 27 dB for a total power of 40 dBm. The receiver also has antenna discrimination, with only 16 dBi gain in the direction of the unwanted transmitter. The unwanted link has a power given by:

$$P_{UW} = P_T - L_P + G_R$$

Where P_T = 40 dBm, L_P= 215 dB (Cylindrical loss model), G_R = 16 dBi.

$$P_{UW} = -159 \text{ dBm.}$$

The wanted link budget can be calculated in the same way to yield a wanted signal of –80 dBm to the input of the receiver, combining this with the required C/I this allows an unwanted signal power of –140 dBm. This gives a margin of 19 dB and, ignoring rain fade, the link closes.

III. INTERFERENCE SCENARIOS BASED ON LUCINDA MEASUREMENTS

Microwave radio systems design techniques rely on propagation information provided in ITU Recommendation ITU-R P-530. The derived information can then be used in the link design using ITU-R F. 1093. In Australia ACA RALI FX-3 defines requirements for frequency coordination based mainly on these two ITU documents. The ‘quick’ design, while not meeting all the requirements of ITU-R F.1098 does meet the requirements of RALI FX-3. Flat fade margins (FFM) are incorporated to ensure the systems meet the performance requirements outlined in ITU-T G821 and G826 in a fading environment, thus interference above the FFM threshold cannot be tolerated.

A long path duct propagation experiment at 10.6 GHz was carried out in July 2001 between Toolakeah Beach and Lucinda. Details of this experiment are given in paper 2 reported elsewhere in the WARS 2002 proceedings. The signals measured during this experiment were on average 60 - 100 dB higher than those predicted by simple cylindrical propagation models. Powers into the input of the victim receiver are in the order of –100 dBm, giving a C/I of 20 dB and in some cases, little or no FFM. Such a system would not meet any ITU-T availability criteria.

An even worse case is possible where the wanted transmitter is above the duct and both the victim receiver and unwanted transmitter are wholly within the duct. This situation is depicted in Figure 5 below.

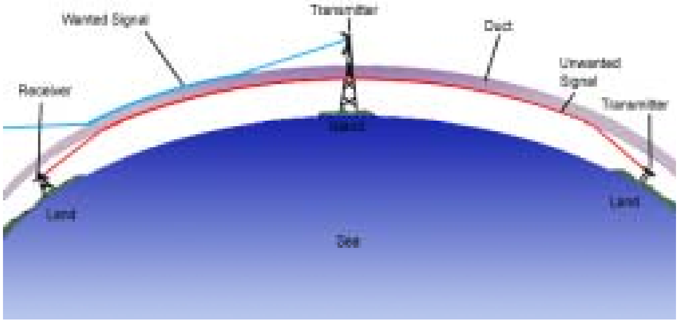

Figure 5 The evaporation duct interference scenario for a terrestrial radio link.

It is common practice on over water paths to use a low high antenna pair so as to move any multipath reflections out of the antenna main beam. When this is done the scenario in Figure Four becomes possible. Here we see the wanted signal mostly deflected by the duct while the unwanted signal is trapped. This could lead to a situation where the interfering signal was stronger than the received signal even allowing for antenna discrimination.

Looking back at Figure Three, we see that duct height exceeds 20 meters in the Lucinda area for more than 25% of the time. This suggests the possibility of the events pictured in Figure Four are highly likely in areas such as Lucinda if care is not taken with system design and coordination calculations.

IV. WIND AND SEA CONDITIONS

Figures 1 and 2 shows examples of how duct height relates to windspeed. Sea state is generally also dependent on windspeed but can also be affected by wind direction; ie onshore or offshore and the swell. Ignoring the effects of wind direction some Parabolic Equation Models can predict the changes due to scattering caused by rough seas. Levy in [2] has proposed a PEM model called TERPEM, which takes into account Sea State. This model would also be able to take into account wind direction through changes in the ‘terrain’ models used so as to cater for the smooth to rough transitions caused by land shielding.

Essentially a rough sea scatters the reflected wave so that less power is coupled into the duct than into a duct of similar height but over a smoother sea. We note, however, from the examples in figures 1 and 2 that for northern Australia where sea surface temperatures are greater, duct heights are sustained in low wind speed conditions. Ignoring the effects of sea swell, one can conclude that large ducts can exist over relatively calm tropical waters.

Thus losses due to sea scattering effects would be less in Northern Australian waters than in the south given the same duct height. Nevertheless an increase in sea surface scattering linked with an increase in duct height would be a mitigating factor in system design if it could be proved reliable.

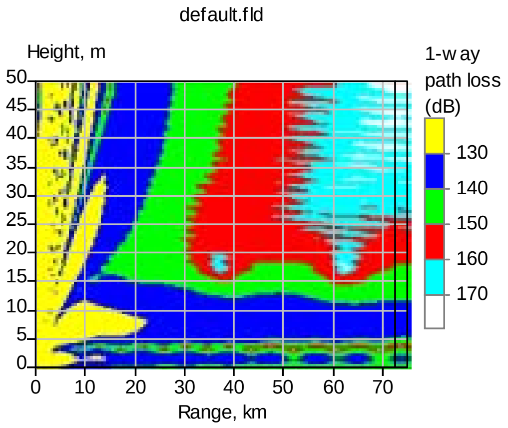

Figure 6 Calm Sea microwave propagation through a duct at 29 meters, transmit antenna is at 5 meters.

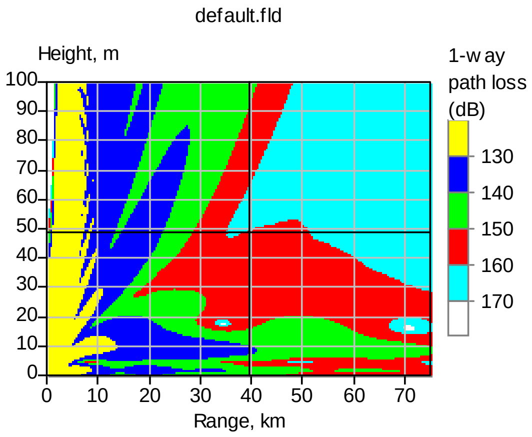

Figure 7 Rough Sea microwave propagation through the duct described in Fig. 6..

Figure 6 shows a propagation model simulated on TERPEM for a smooth sea state. The predicted one way path loss is significantly less than predicted by a free space cylindrical diffraction model. It is also less than the signal pathloss obtained in the same ducting conditions but over a rougher sea, as shown in figure 7.

V. CONCLUSIONS AND IMPLICATIONS FOR RADIO LINK PATH DESIGN

In coastal environments evaporation duct heights depend strongly on wind speed. When sea breezes are the dominant wind flow, duct heights can be highly variable over a 24 hour cycle. During periods when evaporation ducts are strong, extended propagation results for low elevation microwave emissions which in turn can lead to interference for fixed terrestrial radio links.

The theoretical approximation based on free space and cylindrical losses gave a received signal strength from our transmitter of around –159 dBm. The actual measurements and those predicted by TERPEM were around –33 dBm. A link designed to operate at Lucinda based on the cylindrical predictions would fail. While these measurements are made at 10GHz similar results are expected in most bands above 4 GHz.

In the case where the victim receiver and an interfering transmitter can both be expected to be within a duct, a PEM or other duct model should be used to calculate path losses and thus ascertain the probability of interference. In the absence of such a model the actual path losses appear within 10 dB of a free space model so this could be used as a first approximation provided some margin for error were allowed.

References:
1.A. S. Kulessa M.L.Heron & G.S.Woods (1997), 'Temporal variations in evaporation duct heights", Proceedings of WARS' 97, pp 165-170, published by the National Committee of Radio Science
2. M. Levy (2000), 'Parabolic Equation Methods for electromagnetic propagation", published by IEE, London, United Kingdom .