Propagation at 10.6 GHz over a long path in the tropical evaporation duct.

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Abstract. Much work is being undertaken on the characterisation of the evaporation duct above warm tropical oceans in Australia. This work is being carried out jointly by the University of Canberra's Radio Systems Research Group (RSRG), The Defence Science and Technology Organisation (DSTO) and James Cook University.

Previous work has established the average height of the duct and diurnal changes in the duct in various climatic conditions and seasons. Propagation at 10.6 GHz over a 20-km path has also been measured. This paper describes an experiment over a very long path of 72.2 km using a very low transmit antenna height (4 meters) and a receiving array ranging from 3.6 m AMSL to 11.7 m AMSL.

Analysis of received signal strength along with weather conditions is presented along with an analysis of anomalous received signal strengths and suggestions for causal effects. This data is compared to the AREPS model produced by the US Navy SPAWAR Centre[1] and conclusions are drawn for this path and for further work.

The path. The radio path was established from Toolakeah beach, 20 km north of Townsville - Qld, to the Bulk Sugar Terminal at Lucinda, North of Ingham. The overall path length was 72.2 km. The transmitter was positioned on the sand dunes at Toolakeah with an effective transmitter height of 4-m AMSL. The transmitter consisted of a 20 mW YIG source tuned to 10.6 GHz and a 0.6 meter 28-dBi parabolic antenna.

The receiver was positioned at the end of the Bulk Sugar Loading Jetty at Lucinda. This jetty extends approximately 6 km from shore and provides an excellent platform for over ocean studies. The receiver consisted of an array of receivers each having a 16 dBi slotted guide antenna and a 55 dB LNC. These were connected to a switching matrix from which the signal was sampled at approximately 90-second intervals for each array element.

Figure One shows the path diagram and associated earth bulge for a k=4/3 atmosphere. From this figure, it can be seen that the path is not free space and that earth bulge is significant. The diffraction path for this system had a 215 dB loss while the free space equivalent is 150.2 dB yielding a received signal of approximately -110 dBm or –45 dBm respectively, allowing for measured losses in the switch matrix.

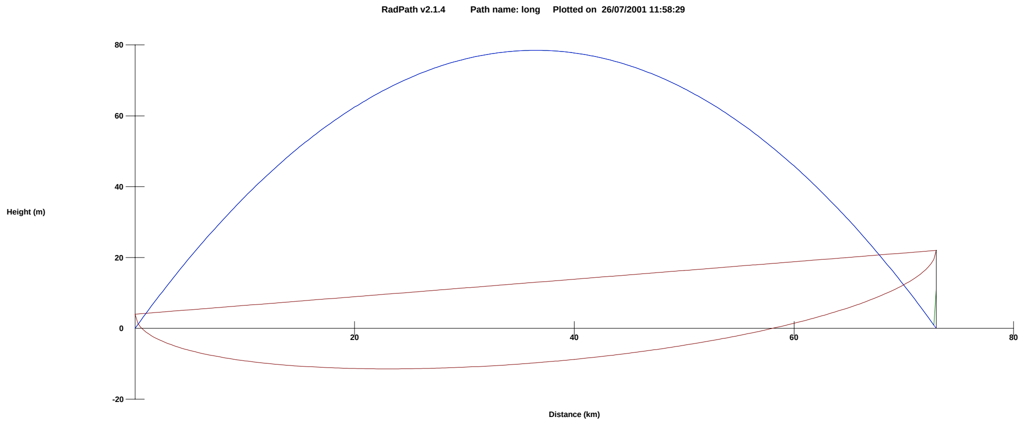

Figure 1
Path showing k =4/3 bulge and Fresnel zone
Blue curve = sea surface, brown lines represent straight path and first Fresnel zone.

This and all other calculations assume a smooth sea surface.

The weather. The weather for the entire experiment was fine with average daytime temperatures of 25 degrees Celsius and night-time temperatures around 16 degrees Celsius. Humidity varied from around 54% during the day to 73% at night. Wind speeds varied up to 24 kph.

In a previous campaign evaporation duct heights were measured around the Lucinda jetty at a similar time of year (Late July). These findings are discussed in the context of the receiver outputs later. Temperatures, barometric pressures and dew point were recorded for each day. NOAA has provided some sea surface temperatures. These values were used in the AREPS program to simulate ducting conditions.

Findings. The path showed good received signal strength, far greater than that predicted by the diffraction model. Received signal strengths were overall in agreement with those predicted by the AREPS program using the parabolic equation model (PEM). Superimposed over the average signal were large fluctuations of the order of 10 dB.

Figure Two shows the received signal for a two-hour period on 14 July 2001. Second order polynomial trend lines have been incorporated to show the slow fading response of the duct. These changes are of the order of change measured in the duct during the 1999 measurement campaign. The previously mentioned rapid changes in signal strength are evident which are possibly caused by the interaction of the propagating wave with a rough sea surface.

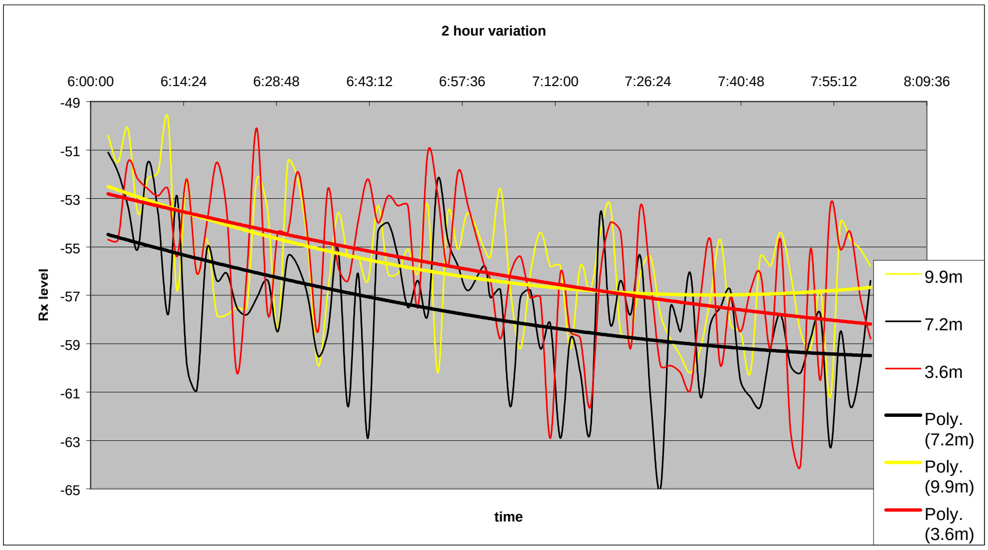

Figure 2
Two hour variations in received signal strength.

Figure Three shows the five-minute averaged received signal strengths over a 24-hour period on July 11 2001. Sea surface temperature varied diurnally from 24.5 degrees to 25.4 degrees (NOAA), temperatures from 16 – 25 degrees Celsius and relative humidity from 73% (night) to 54% (day).

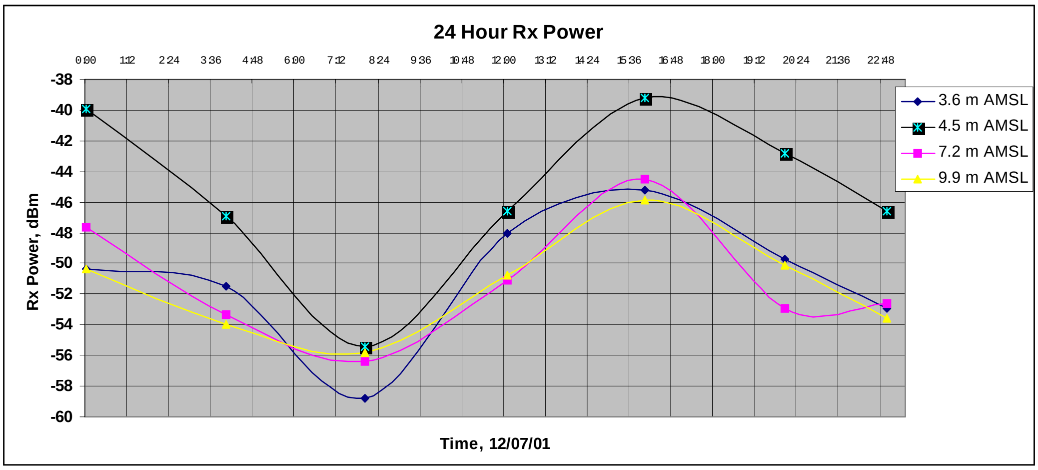

Figure 3
24-hour variation in average received signal power.

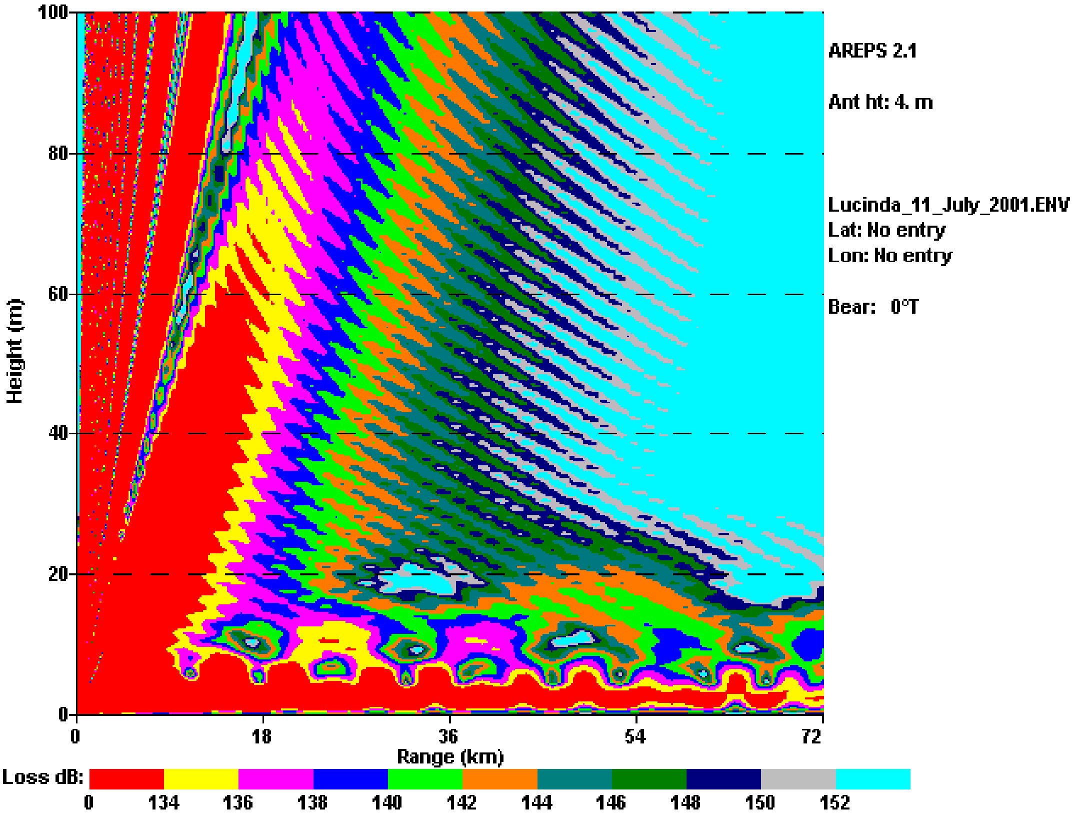

Figure 4
11 July 2001 Afternoon Profile

Using temperatures and humidity taken on the day, AREPS calculated a duct height of 29 meters and gave the complex propagation loss diagram seen above in Figure Four. At night, AREPS calculated a duct height of around 10 meters; the path loss as calculated by AREPS for this situation is depicted in Figure Five.

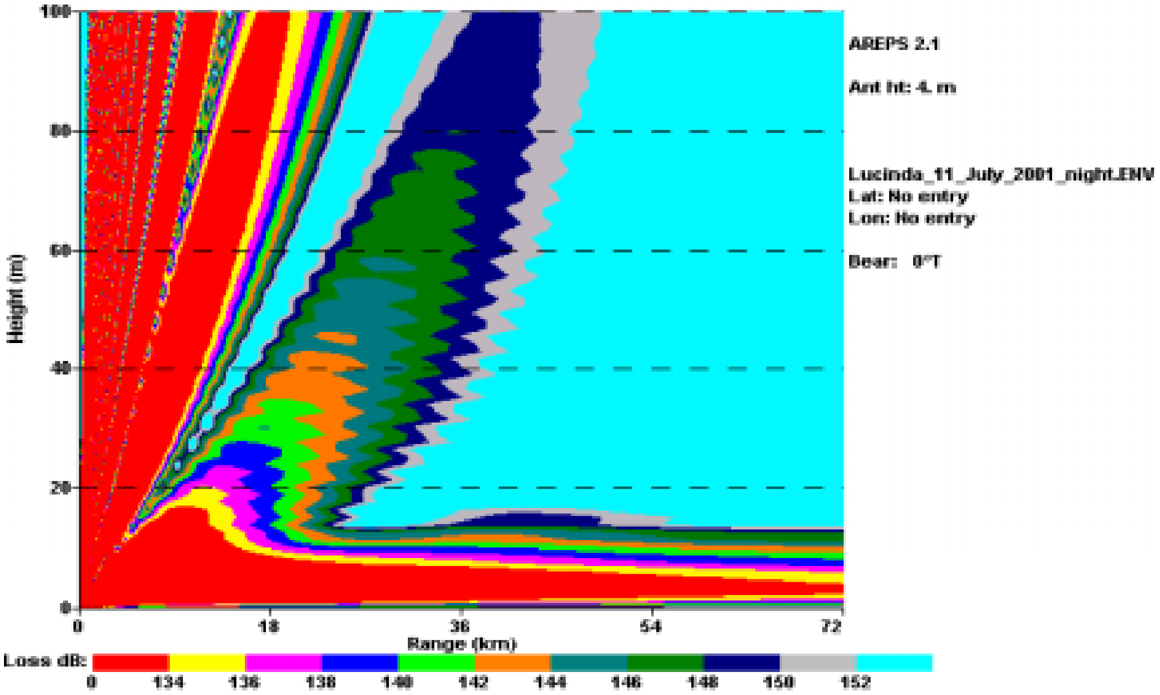

Figure 5
11 July 2001 Late Evening Profile

Figures Six and Seven show the vertical path loss profile at 72 km as calculated by AREPS.

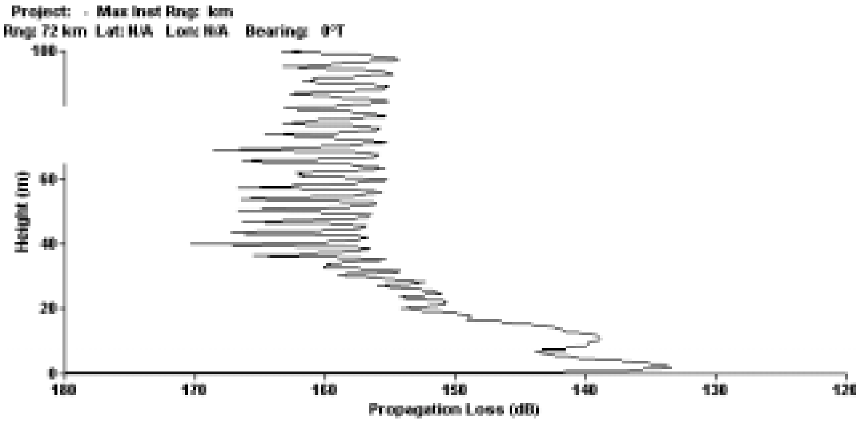

Figure 6
Afternoon loss vs. height from AREPS

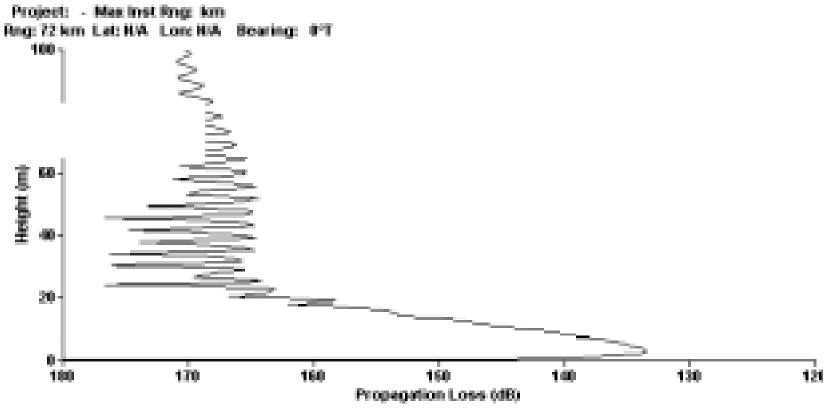

Figure 7
Loss vs. height, late evening, from AREPS

The above profiles measure propagation loss over a 100-meter height. Our array could only measure up to 11.7 meters. In Figures Eight and Nine below the AREPS data is adjusted for the measurement system and imposed over the signal strength measured in the array.

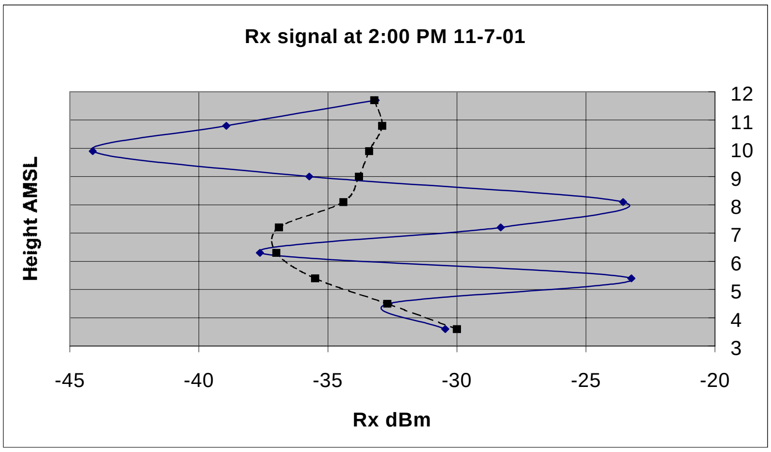

Figure 8.
2:00 PM measured signal (solid line) with AREPS simulation (broken line)

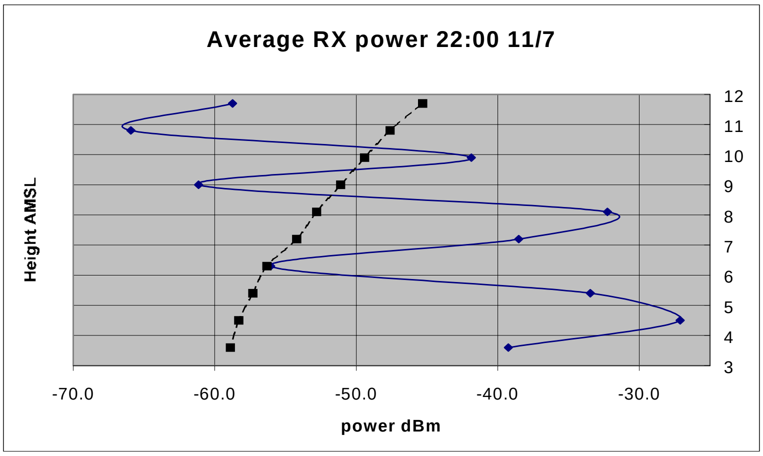

Figure 9.
Measured signal (solid line) with AREPS simulation (broken line), late evening.

It is obvious from the two figures above that the received signal strengths are of the same order as those predicted by AREPS. This information then, along with previous measurements taken in the area, indicates the presence of the evaporation duct over the full 24-hour period. This result in itself is significant for the planners of coastal microwave systems and the users and operators of microwave radar. What can also be seen though is that the AREPS predictions at that level are smooth whereas the actual measurements show considerable fluctuation over height.

The figure below shows very good correlation between two sets of five-minute averages taken 30 minutes apart on the evening of measurement. This removes the possibility of the level fluctuations over height being a temporal anomaly.

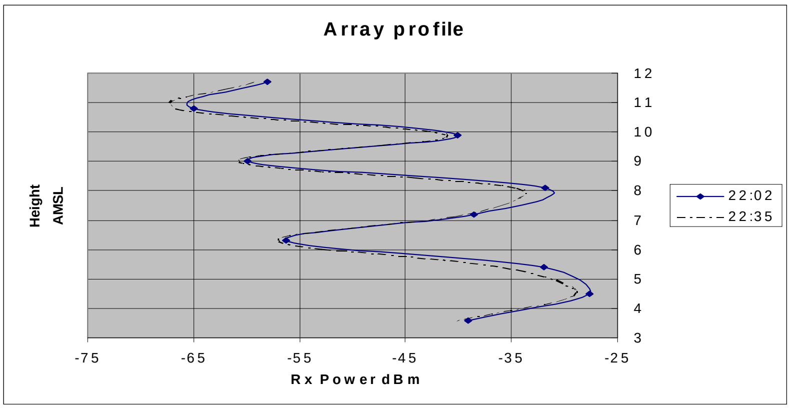

Figure 10.
Two sets of measurements, 30 minutes apart.

If these effects are not caused by the system but are not predicted by the AREPS program the question can be asked, what causes them? In Figure Eleven below, a series of duct height measurements taken in the same area in 1999 by Kerans and Kulessa[2] can be seen. The series shown was taken over a 100-minute period in the early afternoon using a series of atmospheric sensors on a tall spar-buoy anchored near Lucinda. The duct height can be seen to increase after midday, which is expected as the sea breeze intensifies, from 10 meters to nearly 25 meters in the space of an hour. These two duct heights correspond approximately to those simulated above. More rapid duct height fluctuations can also be seen with an amplitude of about 3 meters with a period of around ten minutes. A possible cause for these is local variation in wind speed. These are likely to cause variation in signal strength over this period however the readings in Figure Ten show little evidence of this. It would appear then that these differences in signal strength are caused by a relatively stationary effect.

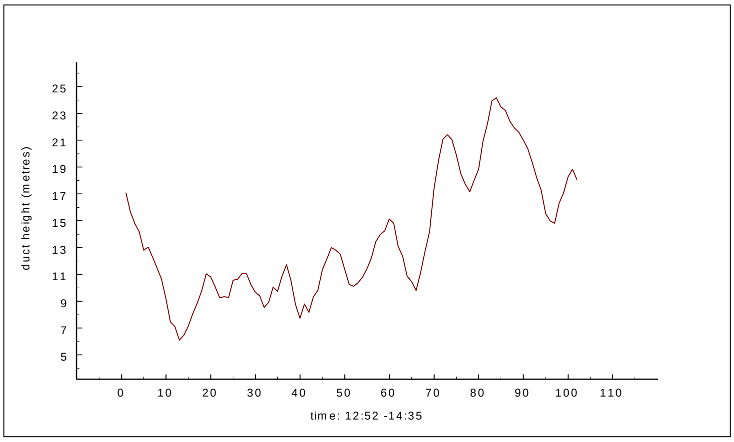

Figure 11.
Duct height variation with time, July 1999.

Looking for a causal effect for the semi-stationary interference pattern seen in the above readings the authors noted a fire on a nearby island. The smoke rose to about 250 meters and then spread indicating the possibility of coastal advection and thus the formation of an advection duct. The smoke from this fire can be seen in Figure Twelve below. In this photograph, the receiver array can be seen with Palm Island in the background. The smoke layering is obvious. Using the height of Palm Island as a reference this layer is calculated as around 250 meters.

Another AREPS environment profile was built using previously measured results for near surface atmospheric values and creating a trapping layer at around 250 meters. The results can be seen in Figures Thirteen and Fourteen below.

Figure 12.
The receiver array with Palm Island and smoke in the background.
The array is on the left and a mini-weather station on the right, photo taken from jetty.

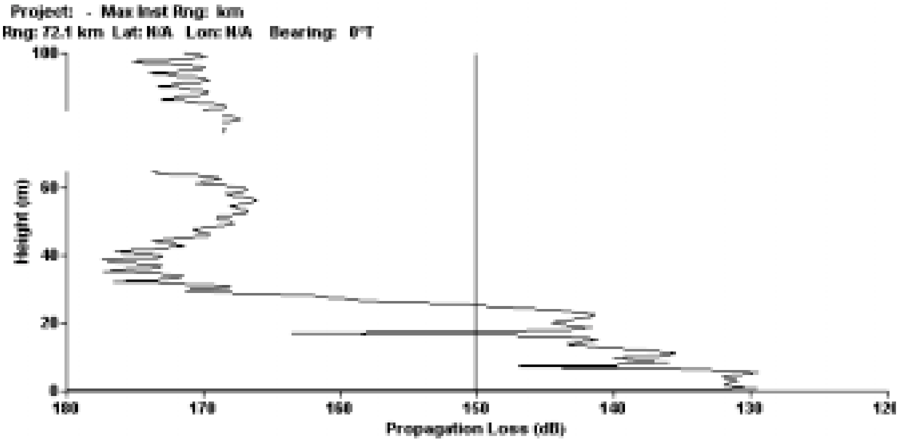

Figure 13.
AREPS prediction for the simulated atmosphere.
Vertical line is free space loss.

Comparing Figure Thirteen with its cousin, Figure Six, we see that the more complex, ‘double trapping’ atmosphere creates a more complex received signal strength in the first few meters of the atmosphere where our measurements were taken. Figure Fourteen is an approximation using the path losses above and the link budgets from the measurement system. While this is not an exact replication of the measured data, the similarity with the received levels in Figure Eight is obvious. Given that, in the absence of soundings, the upper air structure was ‘guestimated’ from visual observations this similarity is remarkable and points to the influence of complex atmospheric influences in such long paths.

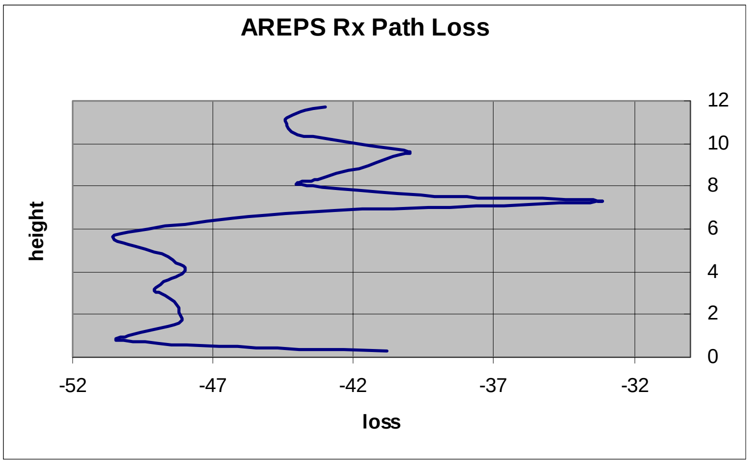

Figure 14.
AREPS received signal simulation using simulated ‘double trapping’ atmosphere.

Conclusions. This paper has presented the findings from a long distance propagation experiment inside the evaporation duct at 10.6 GHz. The ability to hold such a strong signal over 72.2 kilometres has indicated both potential uses and dangers of the evaporation duct in tropical regions. From one 24 hour measurement period it can be seen that the duct is capable of holding a communications link up with a C/N of at least 10 dB almost indefinitely.

The ability to hold open a communications link, or look beyond the horizon with radar also indicates a downfall of the evaporation duct. Traditional Australian microwave design uses RALI FX3[3] as the criteria for frequency coordination. When calculating protection, RALI FX3 does not cater for ducting of this strength. Individual systems designed to this standard could potentially suffer interference from each other in coastal regions even if many kilometres apart.

A complex pattern was measured over the link. It has been shown that there is a strong likelihood this is caused by a double trapping atmosphere, the evaporation duct combined with an advection duct around 250 meters. Comparisons between measured and simulated data favour this theory.

RSRG is currently completing the construction of a 16-element array, which will be capable of discriminating between the two duct structures via angle of arrival. This system will be deployed early in 2002. RSRG are also undertaking measurements of reflection from various sea surfaces with a view to incorporating this into later propagation models. Comparisons with various models will be made once this new data is available.

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[1] SPAWAR Advanced Refractive effects Prediction System (AREPS) program, see www.sunspot.spawar.navy.mil

[2] Evaporation Duct Statistics Around Australia and the West Pacific. A. Kerans, A. Kulessa, G. Woods, J. Hermann. Proceedings AP2000, Davos Switzerland April 2000.

[3] Radiocommunications Assignment and Licensing Instruction FX-3, see www.aca.gov.au