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EVALUATION OF JSAF EM PROPAGATION PREDICTION METHODS FOR NAVY CONTINUOUS TRAINING ENVIRONMENT / FLEET SYNTHETIC TRAINING,
RESULTS AND RECOMMENDATIONS:
PART I - EVALUATION OF
CURRENT JSAF EM PROPAGATION MODELING

by

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14. ABSTRACT
The EM propagation model currently used in JSAF is "FFACTR" which is a part of the Engineers Refractive Index Prediction System (EREPS) Tactical Decision Aid (TDA) developed by what is now SPAWARS SSC San Diego in 1988. This model is no longer supported by SPAWARS or any other group and has been replaced; it is obsolete. This model is able to represent some realistic features including: (1) decrease in signal strength (increase in propagation loss) with range, (2) more interference lobes for higher elevation and higher frequency transmitters, and (3) increased surface ranges for evaporation and surface ducts, and also with greater K-Factors. However the following deficiencies were noted:
1. Duct Strength (M value change) had no effect on the JSAF predictions. 2. The JSAF interference lobes caused by interaction between direct and surface-reflected radiation did not have the correct spacing..3. The effects of surface ducts were not realistically modeled. In reality, ducts create complex signal strength patterns and at the surface typically show "skip and hop" bands of increased and decreased signal strength. The JSAF predictions were unrealistically smooth and showed no skip patterns. 4. The far range (> 30 km) JSAF predictions appeared to have too strong signals and very simplified "flat" patterns. It appears that the JSAF EM model was not designed for these regions. 5. The standalone version used in this had no consideration for geographic location for predicting duct effects. Other versions do allow duct features to vary strongly over the Earth's surface. 6. The varying "leakage' of radiation above ducts was not captured by the JSAF predictions. 7. The radar "hole" that is usually present just above duct tops was not seen in the JSAF predictions.
It is clear that there are considerable and significant weaknesses in the JSAF EM propagation prediction model which result in unrealistic range predictions, particularly in situations when ducting is present.

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ABSTRACT

The EM propagation model currently used in JSAF is “FFACTR” which is a part of the Engineers Refractive Index Prediction System (EREPS) Tactical Decision Aid (TDA) developed by what is now SPAWARS SSC San Diego in 1988. This model is no longer supported by SPAWARS or any other group and has been replaced; it is obsolete. This model is able to represent some realistic features including: (1) decrease in signal strength (increase in propagation loss) with range, (2) more interference lobes for higher elevation and higher frequency transmitters, and (3) increased surface ranges for evaporation and surface ducts, and also with greater K-Factors. However the following deficiencies were noted:

1. Duct Strength (M value change) had no effect on the JSAF predictions.

2. The JSAF interference lobes caused by interaction between direct and surface-reflected radiation did not have the correct spacing.

3. The effects of surface ducts were not realistically modeled. In reality, ducts create complex signal strength patterns and at the surface typically show “skip and hop” bands of increased and decreased signal strength. The JSAF predictions were unrealistically smooth and showed no skip patterns.

4. The far range (> 30 km) JSAF predictions appeared to have too strong signals and very simplified “flat” patterns. It appears that the JSAF EM model was not designed for these regions.

5. The standalone version used for this evaluation had no consideration for geographic location for predicting duct effects. Other versions do allow duct features to vary.

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7. The radar “hole” that is usually present just above duct tops was not seen in the JSAF predictions.

It is clear that there are considerable and significant weaknesses in the JSAF EM propagation prediction model which result in unrealistic range predictions, particularly in situations when ducting is present.

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EVALUATION OF CURRENT JSAF EM PROPAGATION MODEL

A. INTRODUCTION

This report describes the results of a series of tests that were performed using a stand-alone version of JSAF that NWDC staff provided on a dedicated PC computer running in the LINUX operating system. This version of JSAF was modified so that for a particular transmission, the signal strength, propagation factor and range were written to a separate file which could then be archived for further processing. Most of this processing consisted of programming using MATLAB to display the results visually. The general scenario was that a vessel was transmitting a radar signal and an inbound aircraft was using ESM receivers to detect the radar transmission. The actual aircraft and vessels used and even the fact that these types of assets were used, were not important to the results because only relative propagation loss was analyzed, not probability of detection or absolute signal strength. The latter two parameters require knowledge of target, transmitter and receiver characteristics, which were not the focus of this study. For simplicity only one-way signal loss was examined, but these results are also valid for two-way propagation (radar), communications, electronic surveillance measures (ESM) or jamming. By using only propagation loss (which is relative measure) as the parameter under study, rather than the signal strength (which is an absolute measure), we were able to separate the environmental effects from the many system parameter effects such as transmission power, target radar cross section, receiver sensitivity, gains, noise etc. As a result, the only factors that affected the results were the atmospheric M-profiles, the heights of the transmitters and receivers, the frequency of transmission, the separation distance (i.e. range) and the antenna transmission pattern.

The tests were designed (1) to examine the general characteristics of the JSAF predictions, (2) to document how the various environmental inputs affect the predictions, (3) to compare with the Advanced Propagation Model (APM) and (4) to provide "baseline" case studies that can be compared with future implementations of the EM propagation model in JSAF. The case study tests examine how JSAF output varies for different ducting conditions, different frequencies, different duct "strengths", different K values (low level refractive index gradient), different surface refractivities and different geographical locations. Also, many of the same cases are compared with APM results.

A. RESULTS

1. Model runs – JSAF case studies

Due to all the different variables (degrees of freedom), it was not feasible to test all the combinations of the various environmental, frequency and height configurations. Therefore we specified a "standard case" (not to be confused with a standard atmosphere) with a specific rf frequency of 9.5 GHz, a transmitter (Tx) antenna height of 34 m, a receiver (Rx) antenna height of 5 m, a surface duct (when present) of 100 m depth and an evaporation duct height of 45 m. Generally, our tests involved using standard case specifications except that one variable was changed. Table 1 and 2 summarize the various case studies.

Table 1 – Original Case Study Summary

Case number	*Surface Duct height / strength*	*Evap Duct height/strength*	*Radar Frequency*	*Height of MH60 R Rx*	*Tx Antenna Height*	*Output filename*	*APM filename*
1	None	None	9500 MHz	5m	111 ft	case1.txt	standardatm.txt
				50m	111 ft		
2	100m / strong	none	9500	5 m	111 ft	case2.txt	APM_100m_Duct.txt
3	100m strong	None	9500	105m	111 ft	case3.txt	
4	None	None	9500	105m	111 ft	case4.txt	
5							
6	None	146.3 ft strong	9300	5 ft	100 ft	won't run	
7	None	146.3 ft strong	9300	15 ft	100 ft	case7.txt	
7weak	None	146.3 ft weak	9300	15 ft	100 ft	case7weak.txt	
8	none	146.3 ft strong	9300	30 ft	100 ft	case8.txt	
8weak	none	146.3 ft weak	9300	30 ft	100 ft	case8weak.txt	
9				5 ft			
10	none	146.3 ft	5100	15 ft			
11	none	146.3 ft	5100	30 ft			
12				5 ft			
13	none	146.3 ft strong	3700	15ft	60 ft	case13.txt	
13weak		146.3 ft weak	3700	15ft	60 ft	case13weak.txt	
14	none	146.3 ft strong	3700	30ft	60 ft	case14.txt	
14weak	none	146.3 ft weak	3700	30ft	60 ft	case14weak.txt	

Table 2 – "Newer" Case Study Summary

Case	Surface Duct height / strength	Evap Duct height / strength	Radar Frequency	Height of MH60 R	Antenna Height	Output filename	Notes or other parameters
1	None	None	9500 MHz	5m	111 ft	case1_new.txt	
2	100m	None	9500	5	111 (33.8m)	case2_med.txt	Test9 beam params
3	none	146.3 ft (44.6 m) / avg	9500	5	111	case3_med.txt	
4	100m /	146.3 ft /	9500	5	111	case4_med.txt	

	Avg	Avg					
5	100m / Avg	none	9500	5	111	refractivity_large	default is ~320. Made ~700.
6	None	none	"	5	111	K2_noduct	K = 2 (Default K ~ 1.3)
7	None	none	"	5	111	Ksmall_noduct	K=0.2 only detected to 60nm
8	100m / Extremely strong	none	"	5	111	xstrongduct	duct strength = extreme
9	100m/ weak	none	"	5	111	weaksfcduct	
10	100m / strong	none	"	5	111	strongsfcduct	
11	100m / avg	none	"	10	111		
12	None	none	"	5	111	headsouth headsouthagain	flies south (one degree N to one degree south of ship)
13	None	none	"	5	111	headnorth	flies north
14	none	none	"	5	111	headwest	flies east to west
15	none	none	"	5	111	headeast headeastagain	flies east to west
16	100m / avg	none	"	5	111	ductheadsouth	same as 12 but with a duct
17	100m / avg	none	"	5	111	ductheadnorth	same as 13 but with a duct
18	100m / avg	none	"	5	111	ductheadwest	same as 14 but with a duct
19	100m / avg	none	"	5	111	ductheadeast	same as 15 but with a duct
20	100m / avg	none	"	5	111	K2sfcduct	K=2 case
21	100m / avg	none	15000	5	111	avg15000	uses radar #7

22	100m / avg	none	5100	5	111	avg5100	uses radar #8
23	100m / avg	none	3700	5	111	avg3700	uses radar #10
24	100m / extreme	none	15000	5	111	extreme15000	uses radar #7
25	100m / extreme	none	5100	5	111	extreme5100	uses radar #8
26	100m / extreme	none	3700	5	111	extreme3700	uses radar #10
	None	none	9500	50m	111	stdatm	
	100m	none	800	5	111	case800ghz	uses “Test 6”; did “make” – use BPI=9 in JSAF

Different Types of Ducts. This case study test examined the effect of different duct specifications for the standard case (Figures 1 and 2). We see that there is little difference between the different environments except after ~35 km range, where the cases with surface ducts showed increased signal strengths. For the surface duct cases, there is a linear ramp up in strength from ~35 km range to ~44 km and then a gradual drop off after that Figure 1. The JSAF EM model simulates the “bounce” that happens to the signals that are refracted down to the surface at the greater ranges due to the duct. However the pattern appears to be quite artificial and not realistic looking. There is also no apparent effect of the evaporation duct at long ranges; this is not realistic.

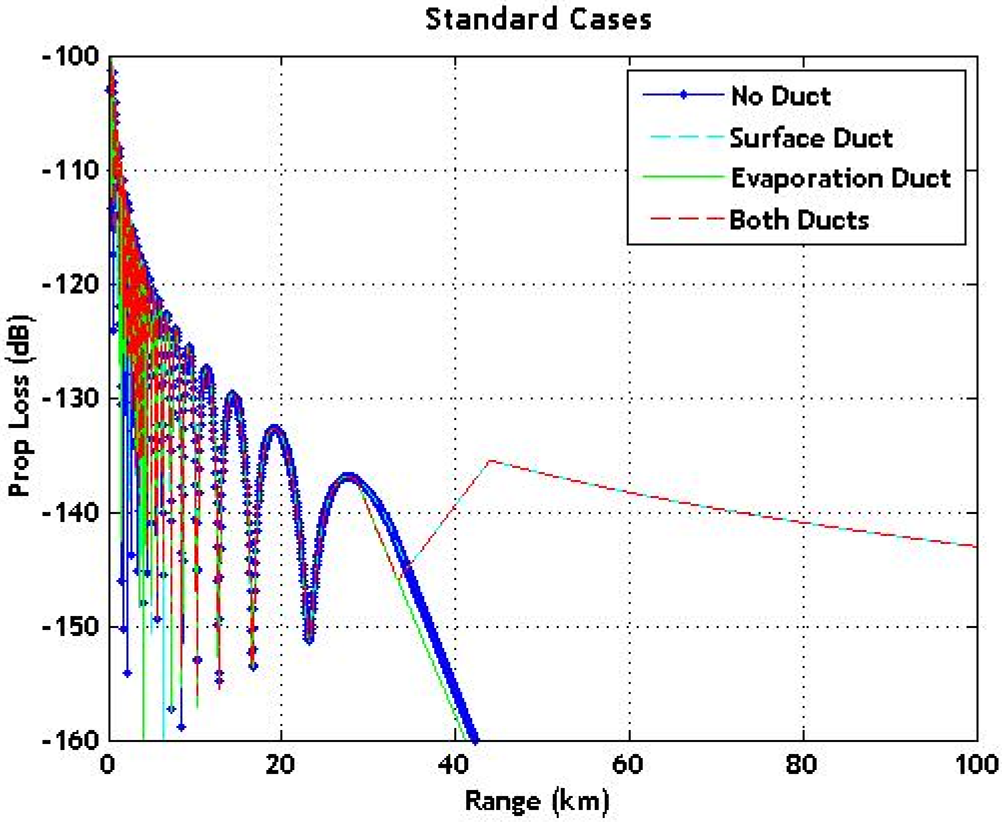

Figure 1. Effects of environmental conditions on JSAF-predicted signals. The vertical axis shows the negative of the propagation loss (dB). Therefore, points higher in the figure indicated stronger signal strength.

A closer range view of the same results (Figure 2) shows very little difference among all the cases. At these ranges, the effects of the surface duct would not be expected to be noticed, so the representation is realistic in this respect. However one would expect a more noticeable effect due to the evaporation duct which is a low level feature that should affect close-range signals.

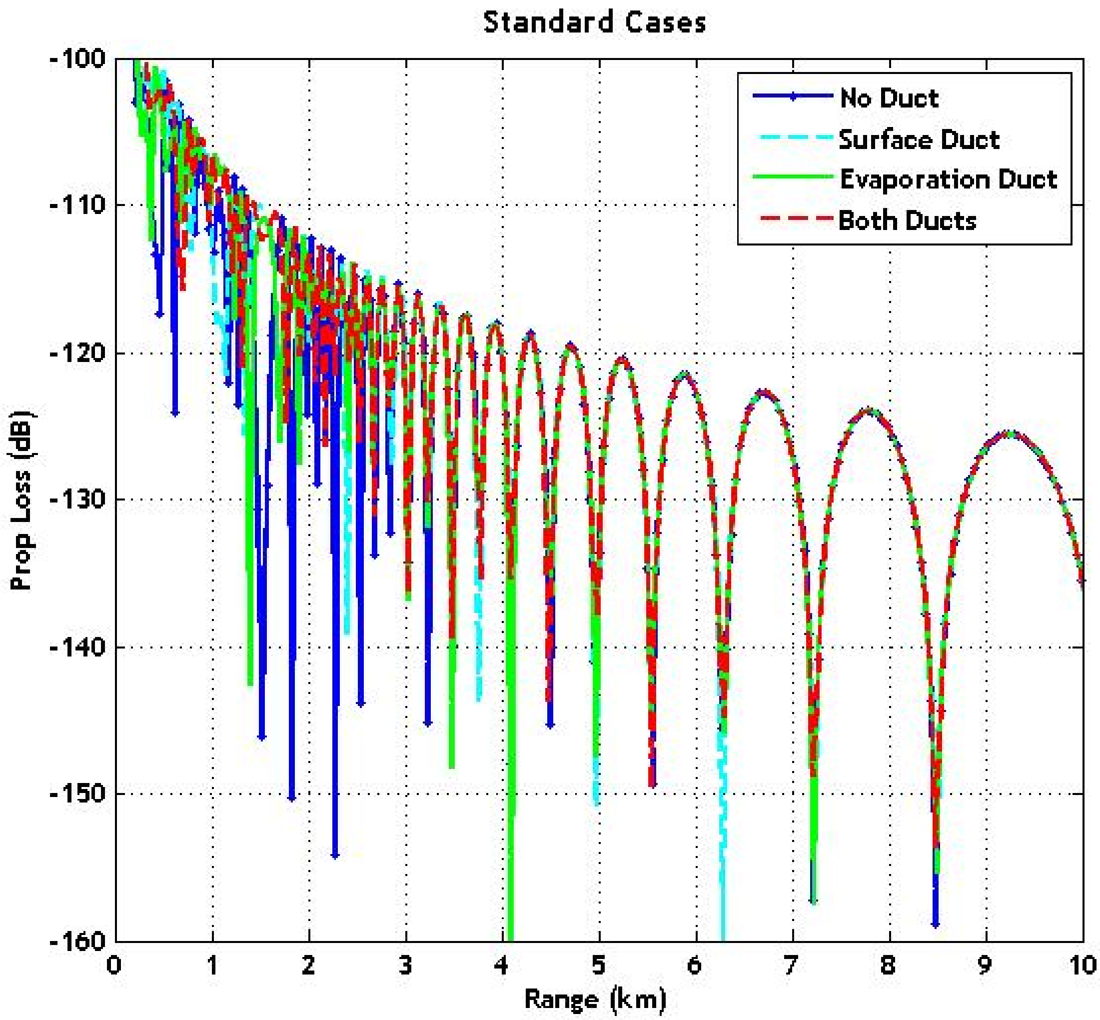

Figure 2. Same as Figure 1 but with the focus on shorter ranges.

Frequency and Duct "Strength" Effects. The next case study examines the effect of frequency and "duct strength" (Figures 3 and 4); the latter is a selectable parameter in the JSAF environmental editor. The propagation loss is lower (weaker signal) for the higher frequencies. This is a reasonable qualitative result. Also the interference lobe structure seen as a pulsating pattern (most obvious on Figure 4) shows more lobes for higher frequencies; again this is the expected result. The results in Figures 3 and 4 also show that the within each frequency, there is no difference in propagation predictions between "average" and "extreme" duct strength. Other chosen duct strengths show the same results: no effect. This is a clear deficiency with the JSAF EM model, duct strength should have a significant effect on the propagation pattern. We don't know whether this deficiency was due to the EM propagation model used with JSFAF, FFACTR, or the way that FFACTR was implemented within JSAF.

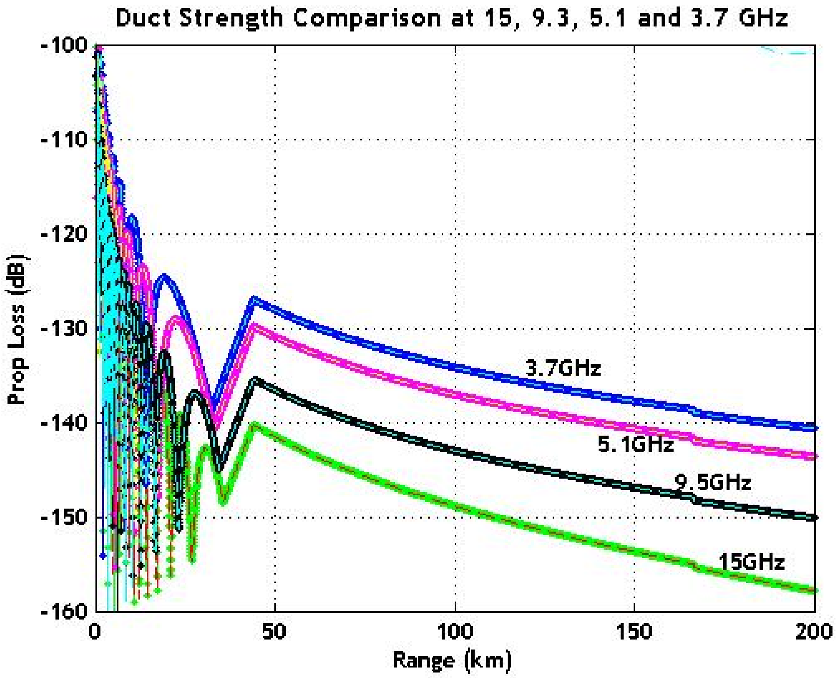

Figure 3. Results from using standard case parameters except for different frequencies. "Average" duct strength is indicated by solid thick lines while "Extreme" duct strength cases are shown as dashed thin lines. Note the dashed lines are exactly over the thicker lines, indicating input duct strength had no effect.

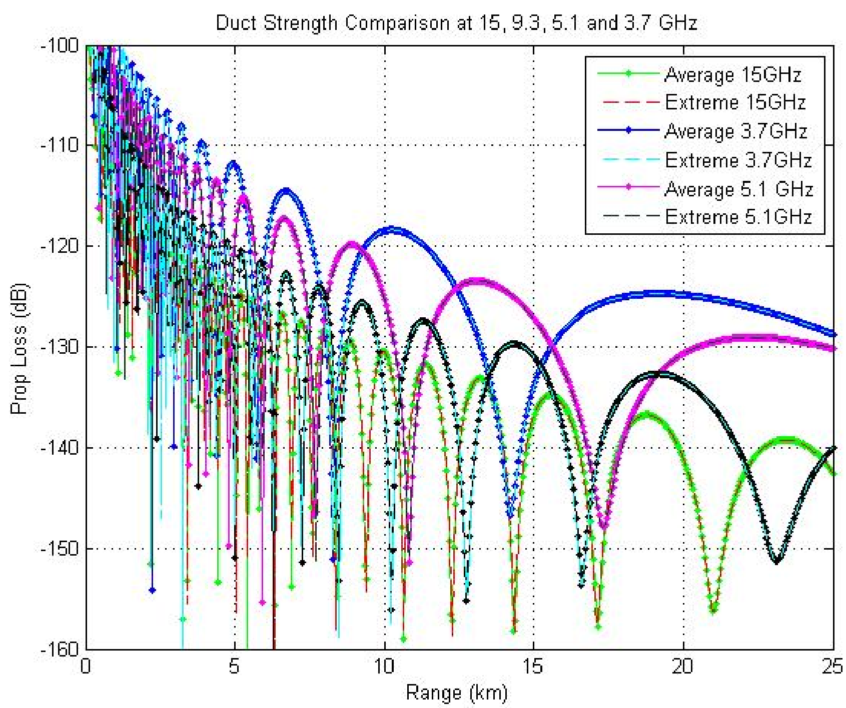

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Figure 4. Same as Figure 3 but with only shorter ranges shown.

Evaporation Duct Strength. In addition to having a choice of surface duct strength, the JSAF environmental editor also allows input of evaporation duct strength. However, similar to the results for surface ducts, we found that the strength input for evaporation duct had no effect on the resulting propagation loss predictions in our case studies (not shown in a figure).

UHF Communications Case. The next case study compares the JSAF EM model results for a standard case (9.5GHz) with a simulated UHF communication at 200 MHz. In this comparison, there were no ducts. As expected, the lower frequency case had more interference lobes and higher strength signals. This is qualitatively realistic. However the smoothness of the patterns, especially in at the greater ranges, indicates that the current JSAF model greatly simplifies the propagation predictions.

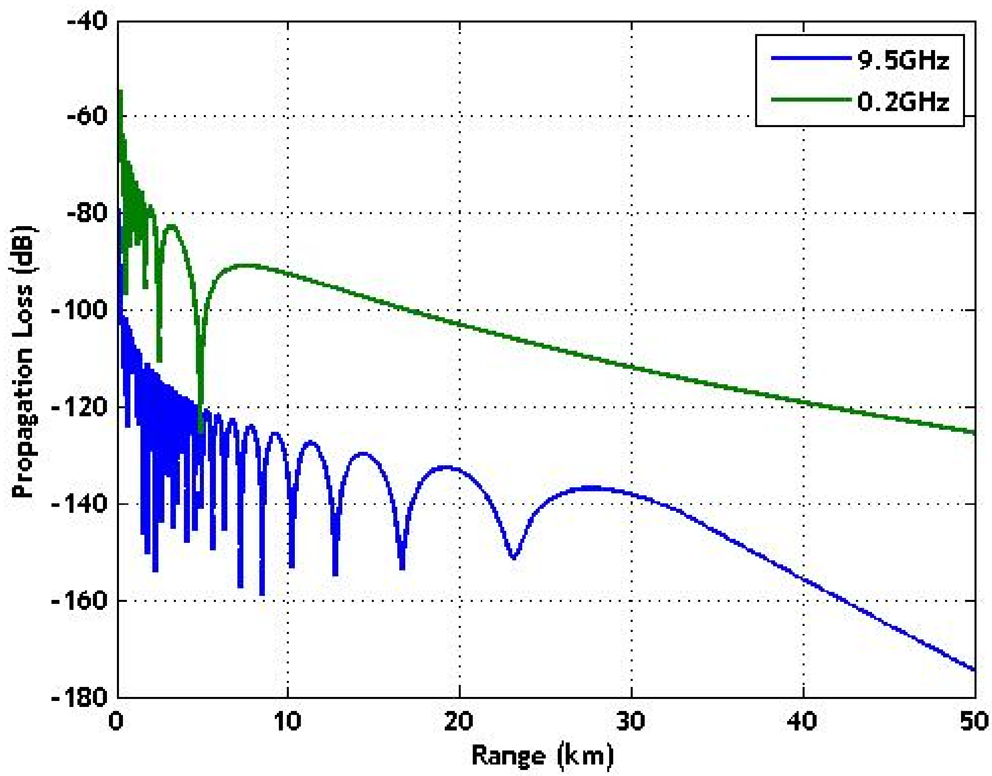

Figure 5. Comparison of JSAF predictions for propagation loss for a typical X band emitter (9.5 GHz vs. a typical UHF communication signal (0.2 GHz or 200 MHz).

K-Factor. The JSAF environmental editor allows for input of "K-Factor", which is defined as the ratio of the "effective" earth radius to the actual radius. Another way to interpret K-Factor is that it is a measure of the refractivity gradient in the lower atmosphere. If a duct is present, the inputted K-Factor is presumably a measure of the refractivity gradient below the duct, and perhaps above also. The lower atmosphere has on average a K-factor of 1.3. Values lower than this mean that rays bend toward the earth less than an average atmosphere while higher values indicate more bending or "super-refractive" conditions.

For the next test we examined the JSAF outputs for different K-factor values and also for ducting and no ducting cases. As expected, the test results show that lower K-values have decreased ranges (Figure 6). Also, the lower K-values have more closely spaced interference lobes at shorter ranges (Figure 7). This is qualitatively realistic because it would be expected that as the rays are bent downward less, the interference lobes at the receiver location would become more bunched. As before, the duct cases (these are surface ducts) show enhanced propagation strength at longer ranges. However, surprisingly, the duct cases are identical at these longer ranges, despite different K-values. This is not realistic and indicates that JSAF is not correctly modeling the effect of different K-values at longer ranges.

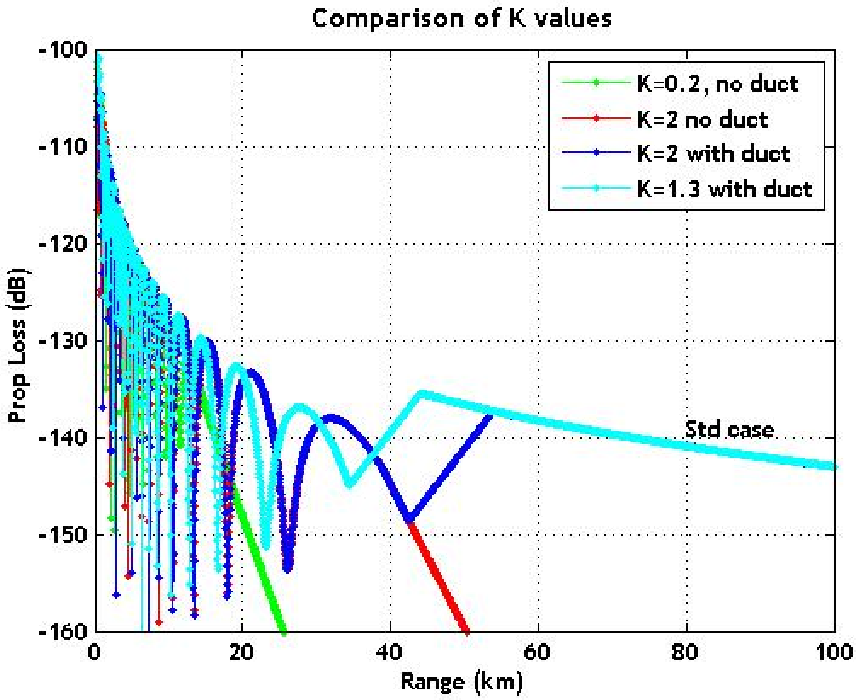

Figure 6. JSAF results for different K-Values and the presence or not of a surface duct. Note that most of the red and dark blue lines at longer ranges are not shown, because they are covered up by subsequently plotted lines.

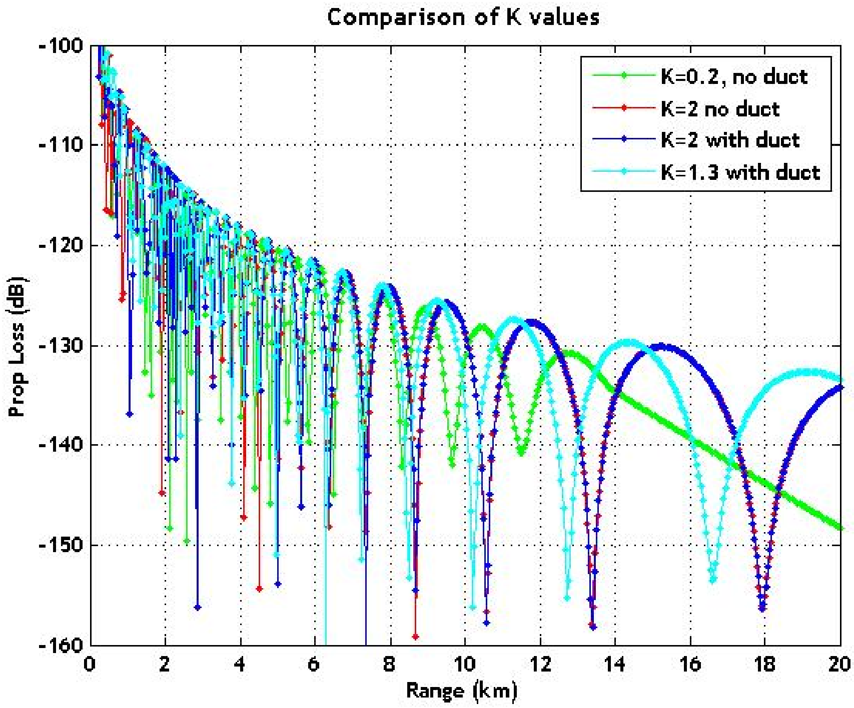

Figure 7. Same as Figure 6 but for closer ranges.

Surface Refractivity. The JSAF Environmental editor allows the input of different surface refractivity (M) values. Apparently the gradients remain the same below any trapping layers, so the effect of changing the surface refractivity is to shift the M values in the profile. We test the effect of changing the surface refractivity for a surface duct case (Figure 8). The results show that changing the surface refractivity has no effect on the results, at ranges less than 34 km, where the duct has no effect. At longer ranges, the higher surface refractivity cases had a longer "ramp-up" and higher signal strengths. This is the region where rays that have been bent downward by the duct are increasing the signal strength. The observed behavior is quite odd and indicates that the duct features may use fixed M-values so that increasing the surface refractivity effectively causes a stronger duct because the difference between the surface and the top of the duct M value is greater. This points out again some the problems JSAF has with regard to representing duct strength (which is a measure of the difference in M between the top of the duct and the surface).

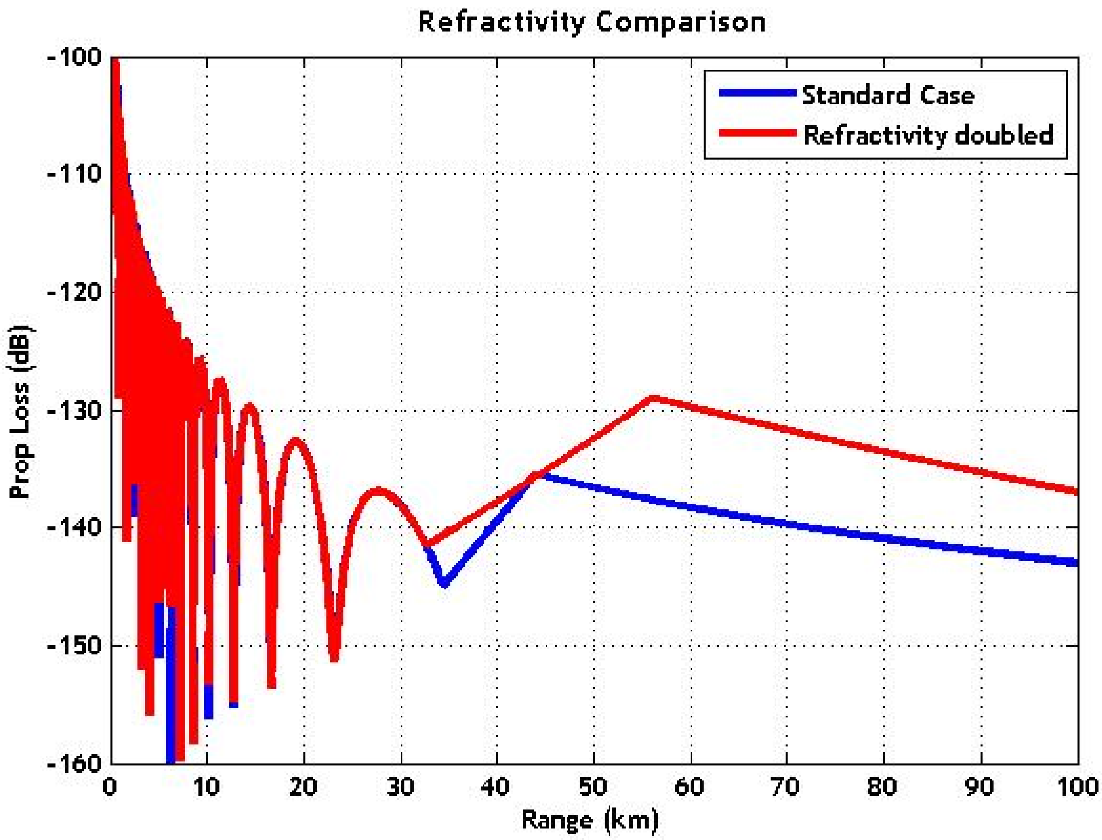

Figure 8. Comparison of cases with surface refractivity set to the standard case value (350 M units) vs a case with twice the surface refractivity (700 M-units). The results are only different at ranges greater than 34 km. The apparent differences at shorter ranges are not real; they are the result of sampling at slightly different ranges for the two comparisons, with infinite sample resolution the plots would be identical at the shorter ranges.

Geographic Location. The final JSAF alone case study shown here was to examine if there were any differences in predictions as a function of geographic location (Figure 9) for surface duct cases. There is no difference; the version of JSAF that evaluated does not use different inputs for different locations. This is an area for improvement because, in reality, there are large differences and the characteristics of typical ducts vary from one location to another. However, the JSAF documentation indicates that it does have the capability to account for changes in conditions in different geographical locations. JSAF does not allow for change along single propagation path.

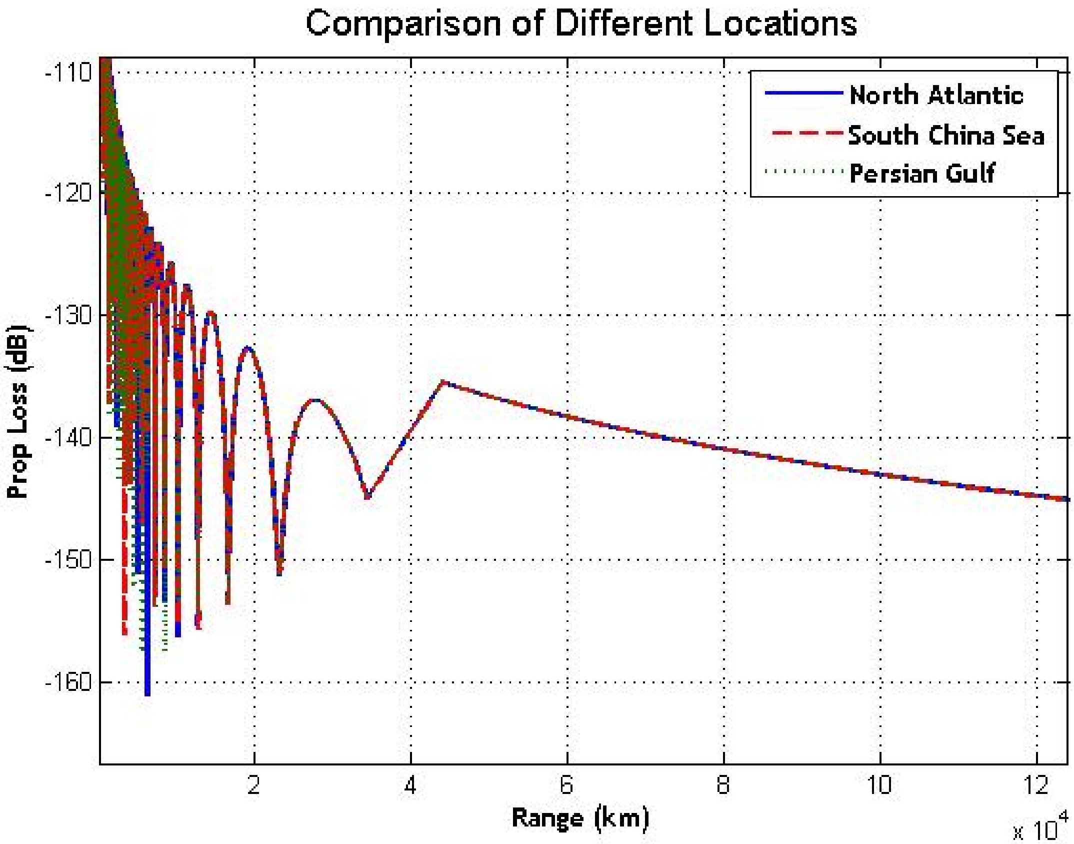

Figure 9. JSAF propagation results for a surface duct case at different geographic locations. All cases were identical; any plotted differences are due to sampling differences.

2. Model runs – JSAF vs. APM comparisons

In this section we compare JSAF predictions with APM predictions for the same inputs. We have attempted to match everything so that the inputs into each model are truly identical. We are certain that the transmission frequencies, ranges and vertical locations of transmitters and receivers are identical, but we cannot be certain this was true for the antenna patterns and some of the other transmitter characteristics. Therefore we pay more attention the "shapes" of the plots, rather than the absolute values.

Antenna Patterns and Initial Comparisons. Because of the uncertainty with respect to how JSAF models antenna patterns, our first test compared a single JSAF output with four APM outputs for different types of antennas (Figure 10). We focus first on the four APM results. These show that the propagation loss (or signal strength) does vary for the different antennas as specified in APM. However, in all but the "Sinc" case the magnitudes are very close and in all the APM cases the patterns of variation with range are identical. Therefore we have confidence that in our JSAF vs APM comparisons, the uncertainty in exactly how each model handles the different antenna type is not crucial, and makes no difference in the shape of the patterns.

The comparisons show significant differences in the EM propagation characteristics between JSAF and APM (Figures 10 and 11). We direct the reader to Figure 11, which shows only a single APM antenna result vs JSAF for what we believe is the same type of antenna (omni) for a no duct environment. We see that JSAF produced many more and more closely spaced interference lobes than APM. In addition, at ranges greater than 24 km JSAF predicted much higher signal strengths than APM.

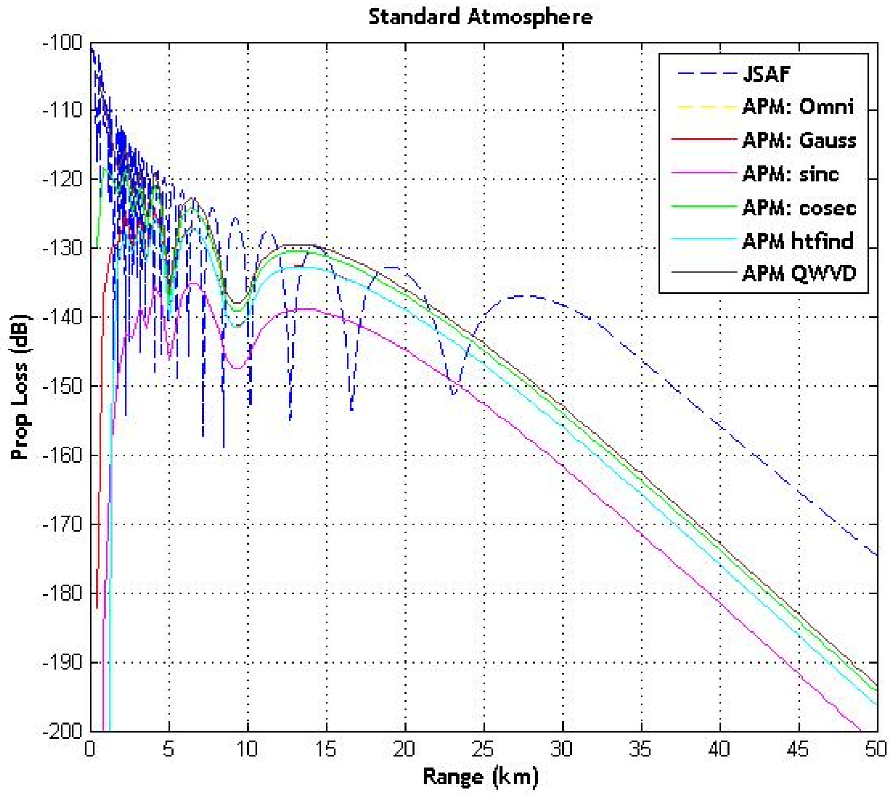

Figure 10. Comparison of JSAF with APM for a no duct case. Results using four different APM antenna types are plotted.

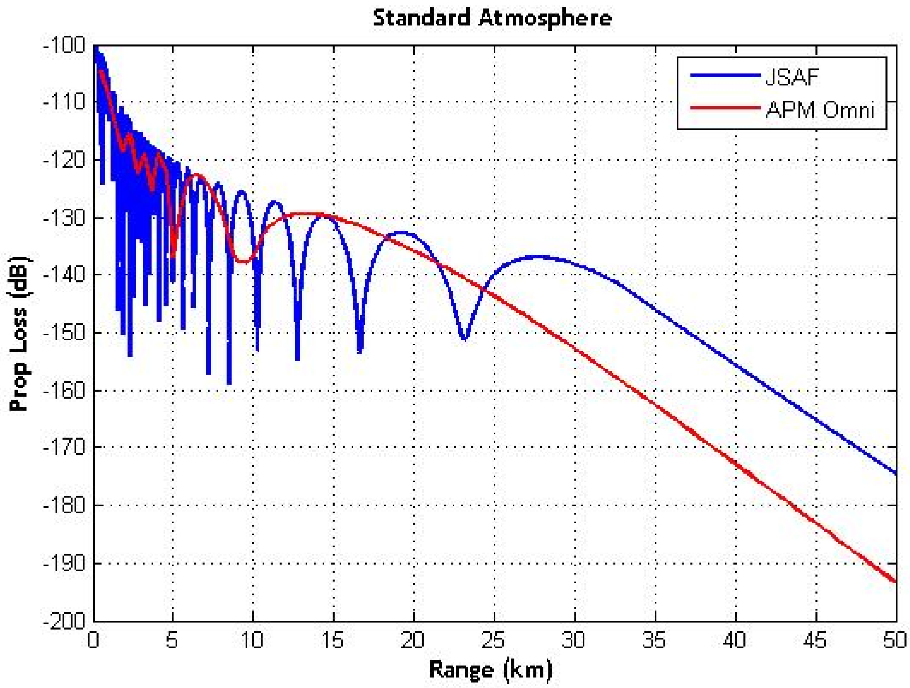

Figure 11. Same as Figure 10 but for only one type of APM antenna.

K Factor. This case compared JSAF vs. APM predictions for different K-Factor values (Figure 12). As expected, larger K Factors for both models produce increased ranges because the effective rf horizon was at a greater distance due to increased downward curvature of the rays. Also both models produced more closely-spaced interference lobes for the larger K-Factors, as expected. However, as noted previously, the JSAF predictions produced many more and more closely spaced interference lobes.

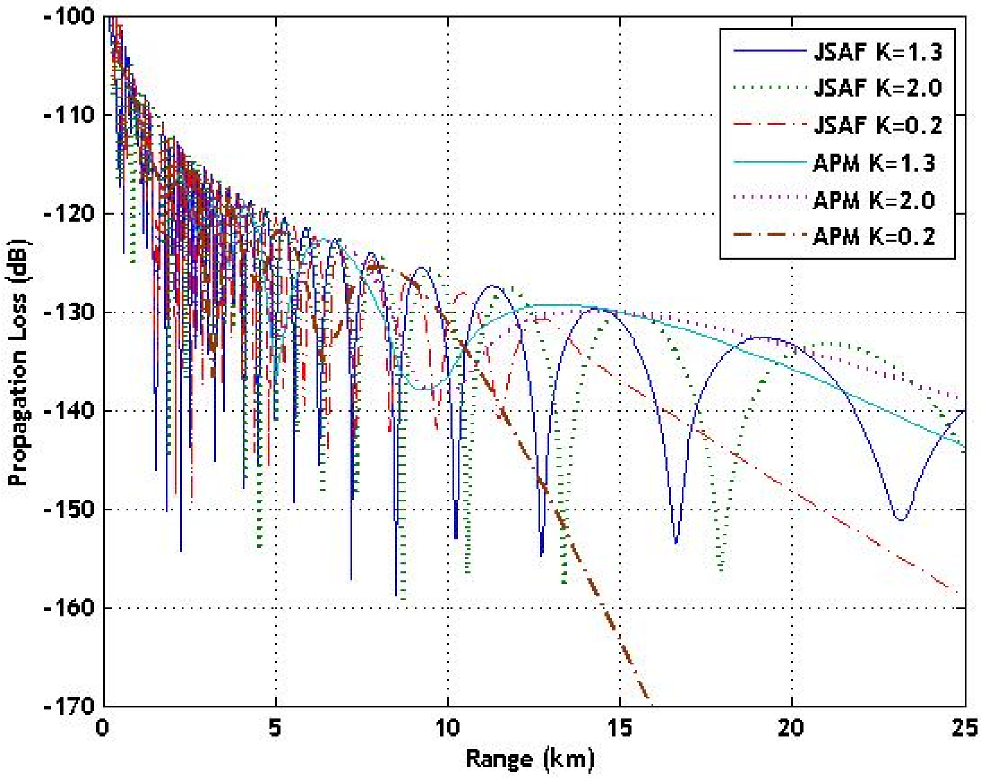

Figure 12. JASF vs. APM comparisons for different K-Factors.

We show the same case for longer ranges in Figure 13. We see extreme differences in the model results at the long ranges. The JSAF results at the long ranges are much smoother and have much stronger signals than the APM results. These low signals at long ranges are not relevant for radar because the signal levels are too low, but there may be some communication and ESM systems that could operate at these low signal levels. It is clear that JSAF "flat-line" propagation loss predictions are not realistic and were not designed for these long-range low-signal situations.

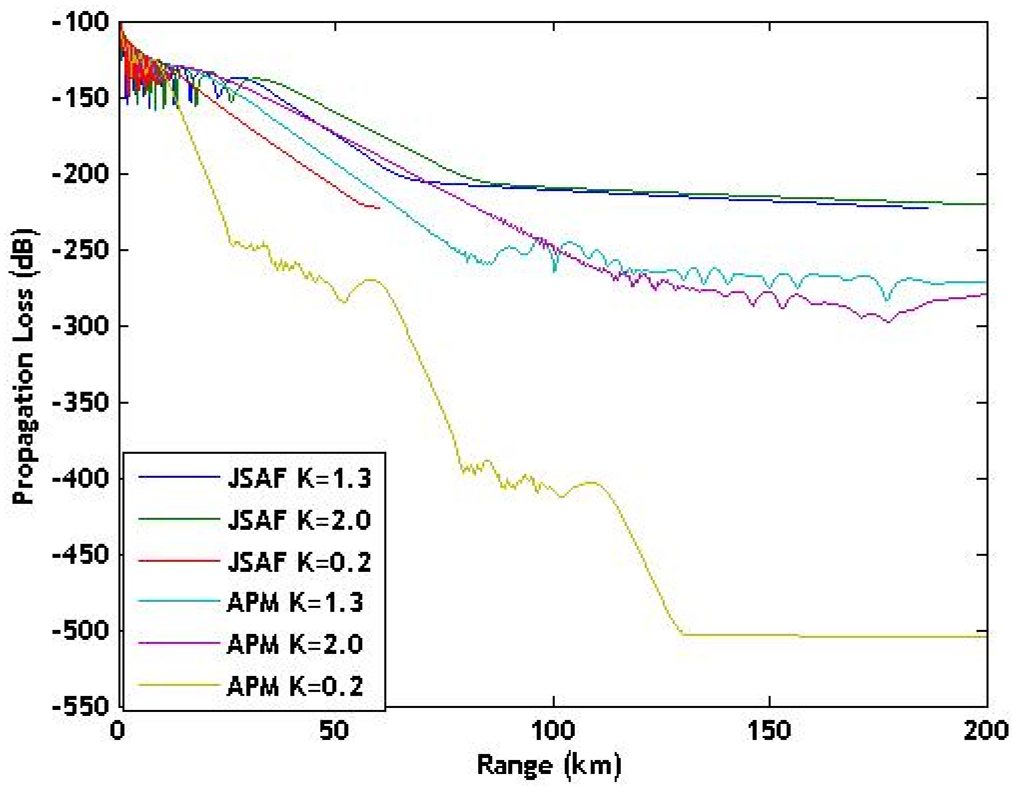

Figure 13. Same as Figure 12 but displaying longer ranges. The JSAF K=0.2 case did not produce data at ranges greater than ~60 km.

Coverage Diagrams. The above range vs. propagation loss plots displayed propagation loss as a function of range for one elevation; these are one-dimensional displays. Another way to display propagation is with a coverage diagram (Figures 14 - 21). A coverage diagram shows signal information in a two-dimensional "slice". As with the previous figures, the horizontal axis is range, but the vertical axis is now elevation, and propagation loss is displayed as color contours. Because much more information is displayed, coverage diagrams are useful for displaying the coverage patterns as a function of range and elevation.

Earlier we noted how the JSAF input on surface duct strength had no effect on the EM propagation predictions. All ducts are modeled the same (for the same duct heights and frequency) despite having an input option for different strengths. To demonstrate how this could create serious prediction deficiencies, we now show coverage diagrams from APM for the standard case (9.5 GHz) with weak, medium and strong ducting cases and compare these with a similar display for the JSAF ducting case. The APM coverage diagrams for these three duct strengths reveal complex patterns created by interference from ground reflections and refraction within the duct, which exists in the lower 100 m (Figures 14, 15 and 16). Note that there are fewer 'holes" (regions with low signals) near the surface for the stronger duct cases. This is because EM rays bend downward more sharply in strong ducts, which acts to fill in the holes.

We created a coverage diagram from the JSAF by simulating aircraft flights at 27 different vertical levels, which provided enough vertical points to construct a coverage diagram (Figure 17). Only one figure is shown because the JSAF-generated diagrams were identical for all duct strengths. It is apparent that the JSAF patterns are much different from the APM results. The EM energy is trapped within the duct but the energy fills the duct evenly, which is not realistic because actual EM radiation will be affected by interference patterns caused by reflections from the surface and refraction downward from the top region of the duct. The latter refraction usually creates bands of higher and lower strength radiation as seen with the APM cases. But this effect is totally missing from the JSAF case. Another effect not captured by JSAF is the "leakage" above the duct that shows complicated patterns that vary with duct strength. JSAF appears to have no leakage, just a gradual increase in propagation loss (i.e. decrease in signal strength) above the duct. Also, at closer ranges, the interference patterns are quite different between the APM and JSAF simulations.

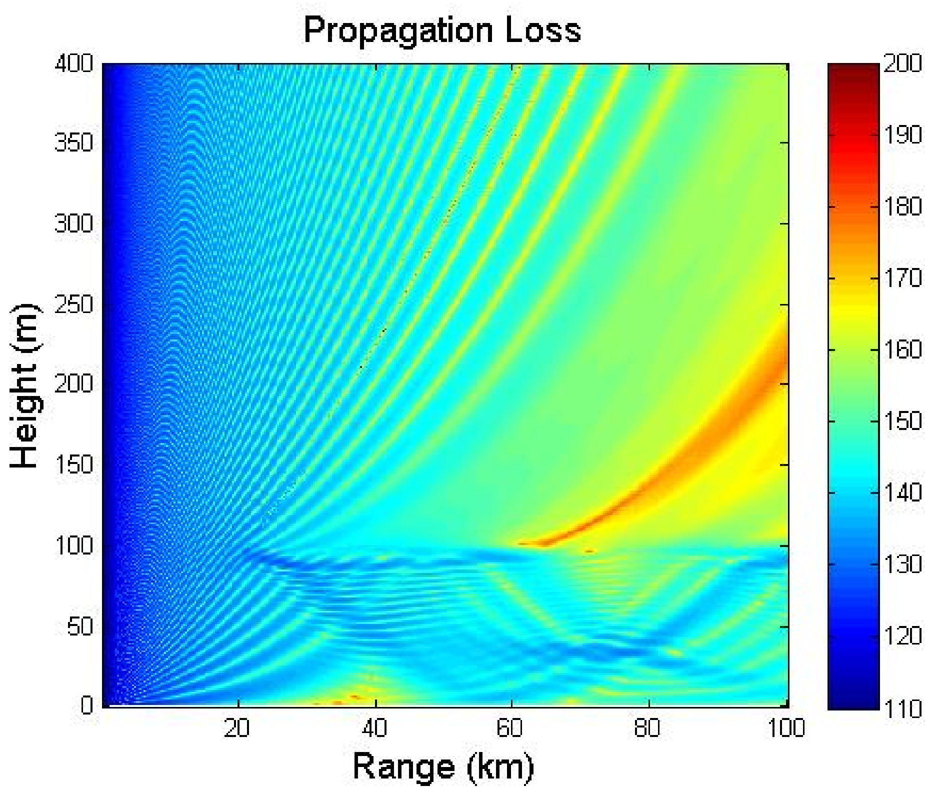

Figure 14. APM coverage diagram for the standard case (9.5 GHz) with a weak duct below 100 m. Blue colors indication less propagation loss, i.e. stronger signals, while the red colors indicate weak signals.

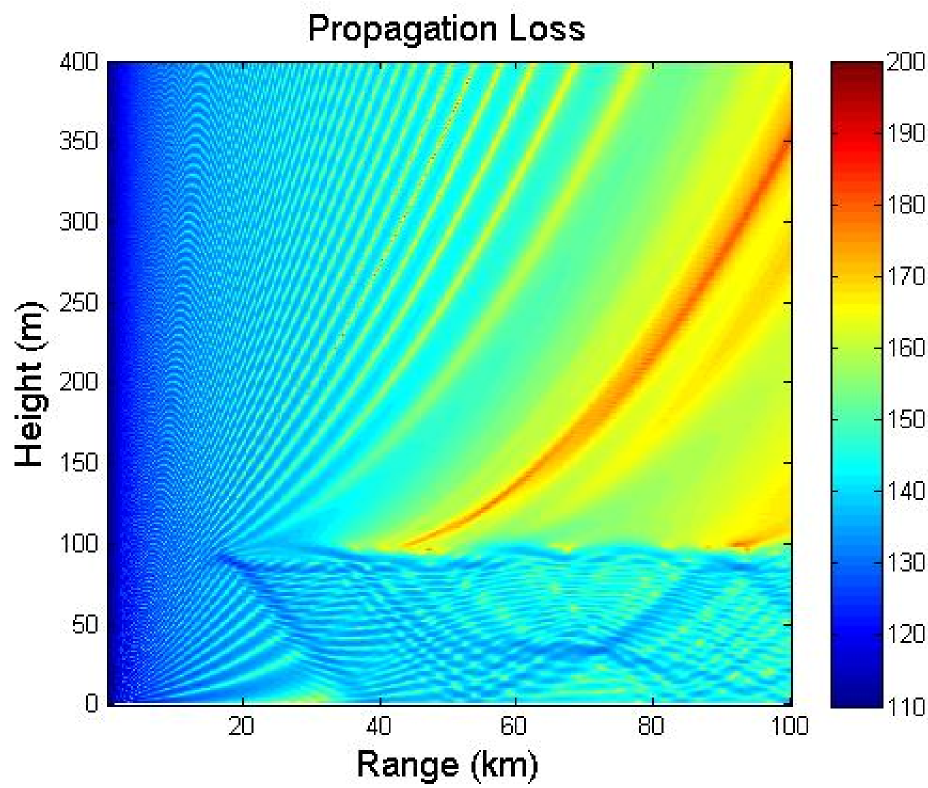

Figure 15. Same as Figure 14 but for a medium strength duct.

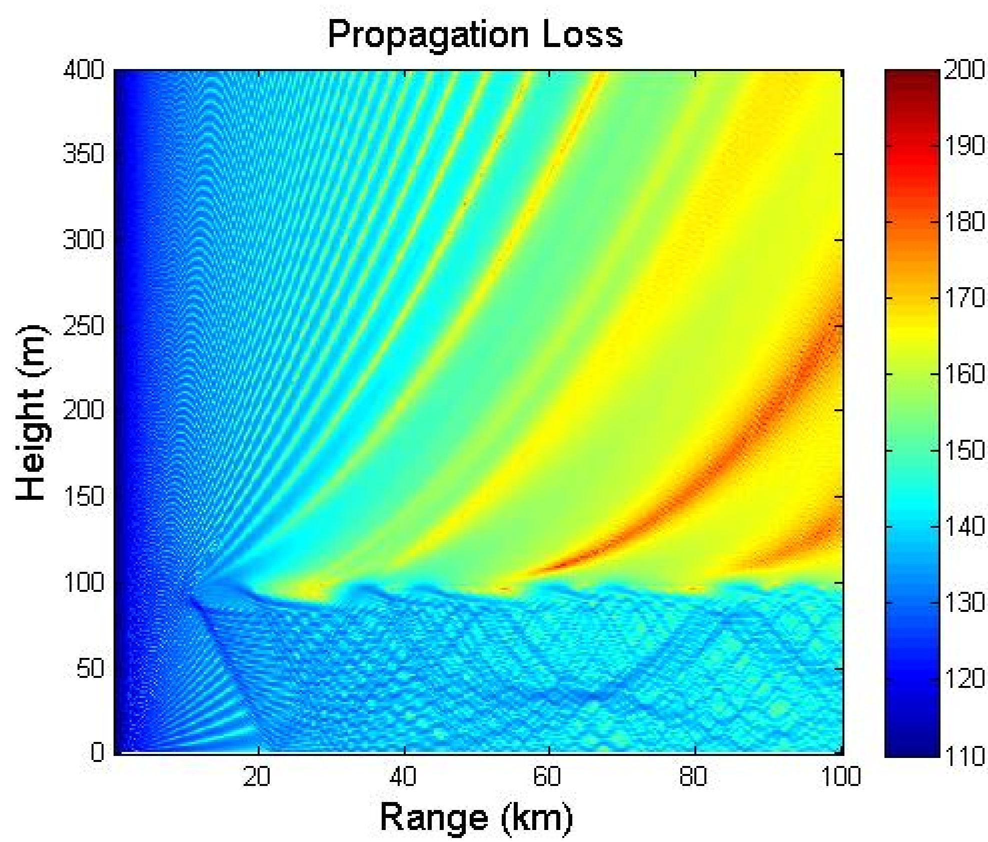

Figure 16. Same as Figure 14 but for a strong duct.

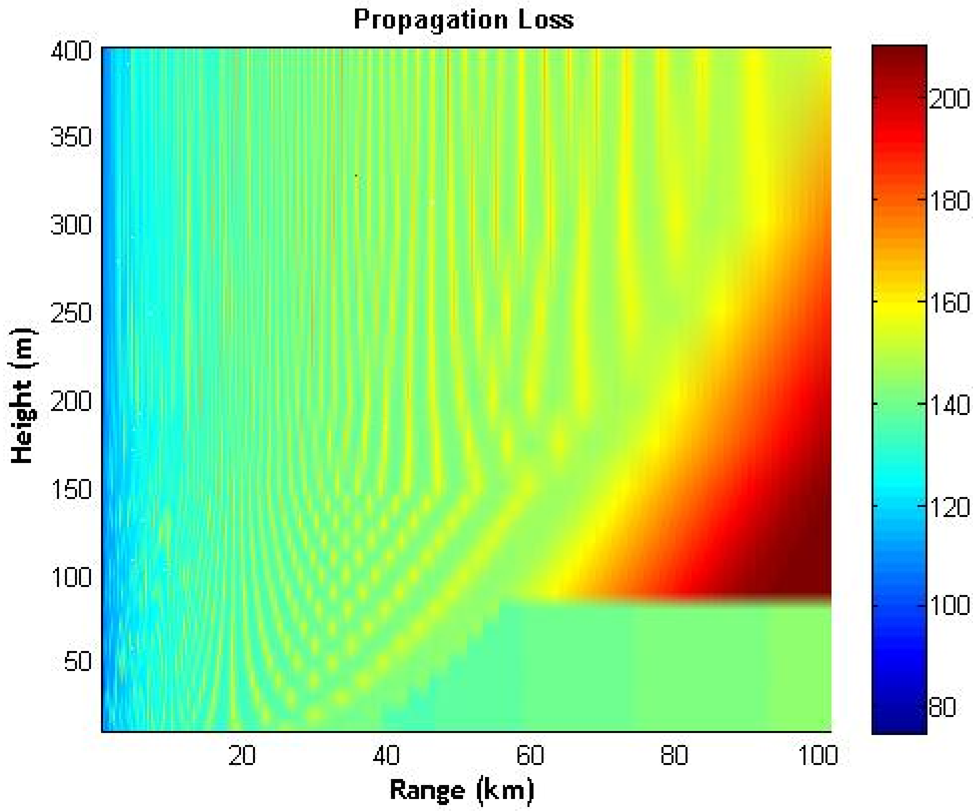

Figure 17. Similar to Figures 14-16 but derived from the JSAF output. This figure would be identical for all ducts strengths.

To further demonstrate the differences between APM and JSAF, we created similar coverage diagrams as above, but used a lower transmission frequency of 800 MHz (instead of 9.5 GHz), Figures 17-21. This comparison is perhaps more illustrative because at this lower frequency, the interference patterns are not so dominant as the previous cases. For example, note that at the surface the APM results show the “skip and hop” structure that exists in the signal strength, especially noticeable in Figure 20. This is a commonly-observed phenomenon that is not currently modeled in JSAF.

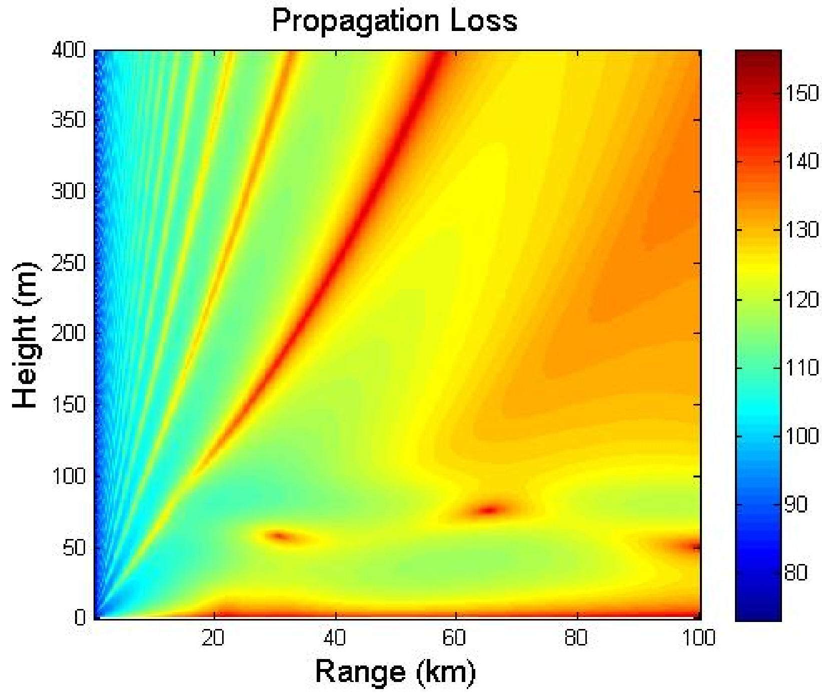

Figure 18. APM coverage diagram for an 800 MHz UHF transmission with a weak duct below 100 m. Blue colors indication less propagation loss, i.e. stronger signals, while the red colors indicate weak signals.

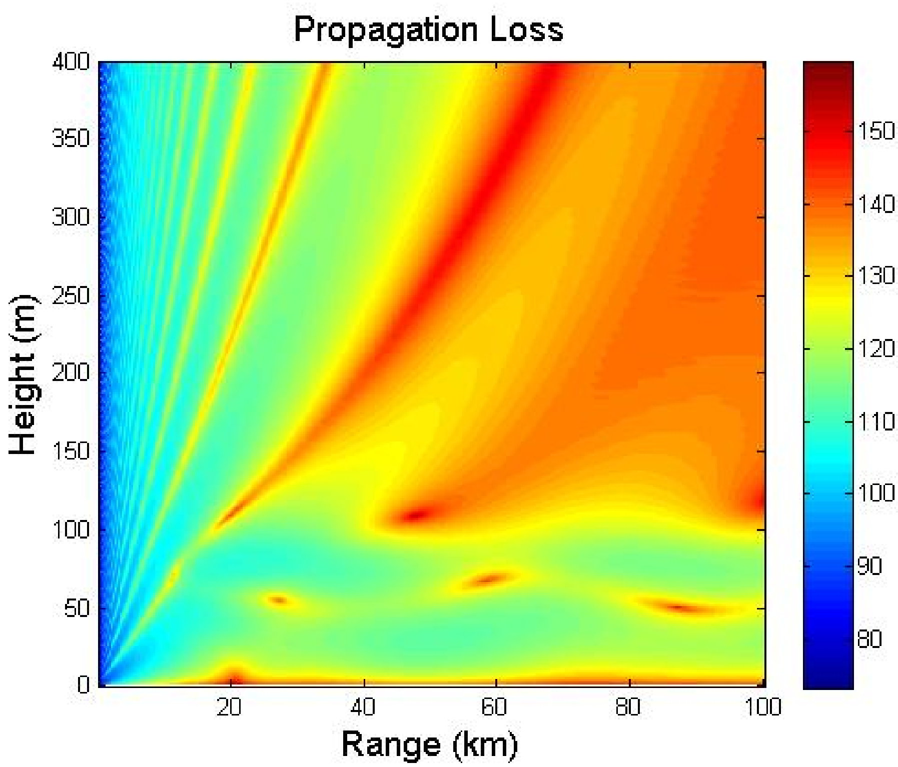

Figure 19. Same as Figure 18 but with a moderate strength duct.

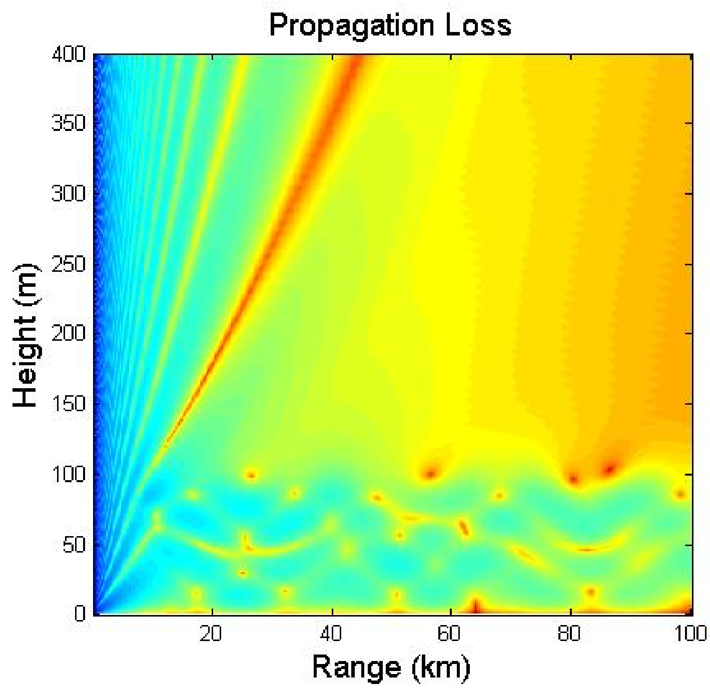

Figure 20. Same as Figure 18 but with a strong duct.

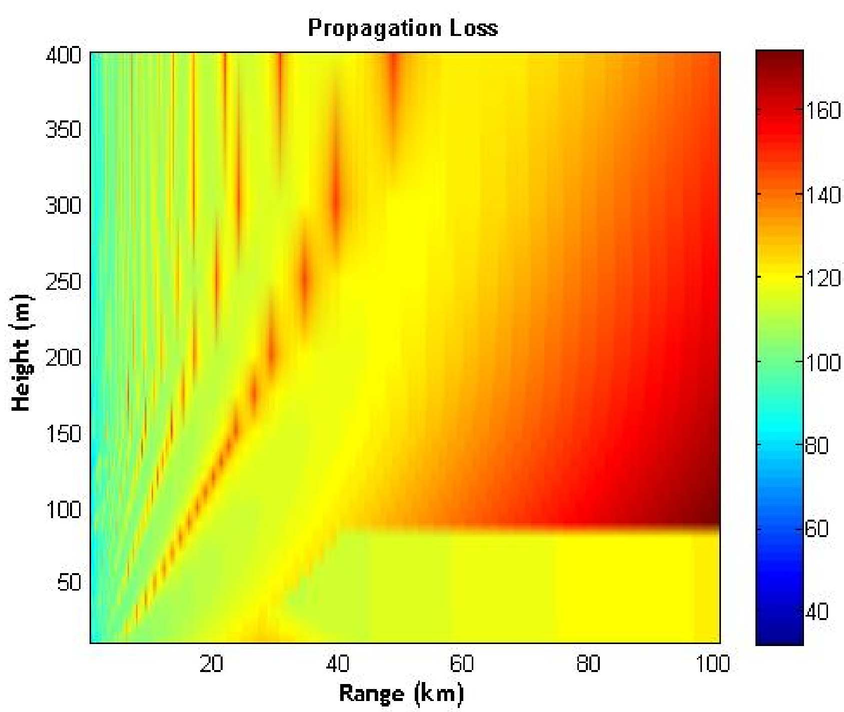

Figure 21. Similar to Figures 18-20 but derived from the JSAF output. The color scale is slightly different than for the previous AMP coverage diagrams.

B. JSAF EVALUATION CONCLUSIONS

The EM propagation model currently used in JSAF is “FFACTR” which is a part of the Engineers Refractive Index Prediction System (EREPS) Tactical Decision Aid (TDA) developed by what is now SPAWARS SSC San Diego in 1988. This model is no longer supported by SPAWARS or any other group and has been replaced; it is obsolete. This model is able to represent some realistic features including: (1) decrease in signal strength (increase in propagation loss) with range, (2) more interference lobes for higher elevation and higher frequency transmitters, and (3) increased surface ranges for evaporation and surface ducts, and also with greater K-Factors. However the following deficiencies were noted:

1. Duct Strength (M value change) had no effect on the JSAF predictions.

2. The JSAF interference lobes caused by interaction between direct and surface-reflected radiation did not have the correct spacing.

3. The effects of surface ducts were not realistically modeled. In reality, ducts create complex signal strength patterns and at the surface typically show “skip and hop” bands of increased and decreased signal strength. The JSAF predictions were unrealistically smooth and showed no skip patterns.

4. The far range (> 30 km) JSAF predictions appeared to have too strong signals and oversimplified “flat” patterns. It appears that the JSAF EM model was not designed for these regions.

5. The standalone version used for this evaluation had no consideration for geographic location for predicting duct effects. Other versions do allow duct features to vary.

6. The varying “leakage’ of radiation above ducts was not captured by the JSAF predictions.

7. The radar “hole” that is usually present just above duct tops was not seen in the JSAF predictions.

It is clear that there are considerable and significant weaknesses in the JSAF EM propagation prediction model which result in unrealistic range predictions, particularly in situations when ducting is present.

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