Modeling Environmental Effects on Radar Detection

32nd International Symposium on Military Operations Research

Kyle Kliewer
Senior Operations Analyst

LOCKHEED MARTIN

Missiles and Fire Control
Lockheed Martin, Orlando, Florida

Business Structure

Aeronautics

Information Systems & Global Solutions

Missiles and Fire Control

Mission Systems & Training

Space Systems

International

People

- 112,000 Employees
- 60,000 Scientists, Engineers and IT Professionals
- 500+ Facilities Across the US
- And Operating in 70 Countries with Over 7,000 Personnel

Lockheed Martin Operations Analysis (OA)

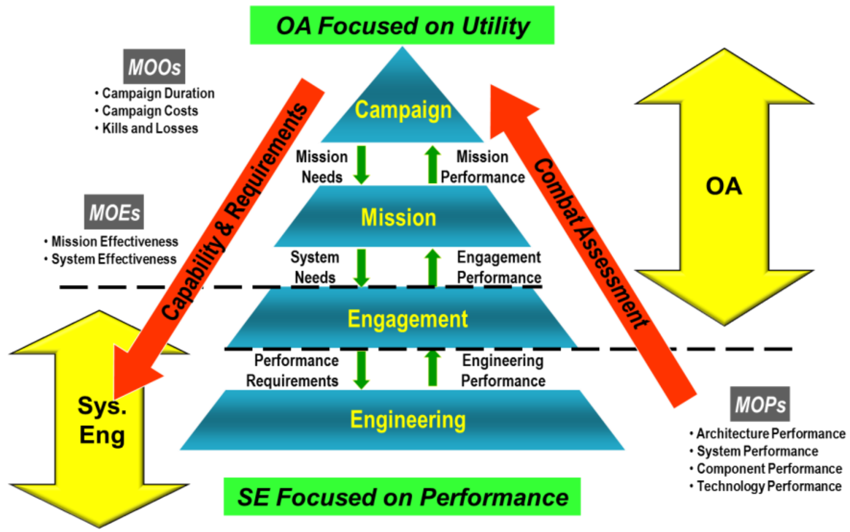
- **Studies activities and systems in operational contexts**
  - Uses an 8 step process as its framework
  - Supports a range of applications including product development and business strategy
- **Company strategic competency coordinated at the corporate level across the business areas**
- **Rigorous exploration performed in collaboration with customers and stakeholders**

OA Values

Ensure Customer Relevance	**Embrace Transparency**
Be the Honest Broker	**Provide Concise Documentation**
Present Clear Hypotheses	**Demonstrate Conclusions**
Follow Scientific Method	**Establish Assumptions**
Perform with Excellence	**Maintain Customer Intimacy**

The Need for Rapid Radar Modeling

- **Engineering development of various systems requires evaluation of detectability in increasing complex environments**
- **Current tools and models have two fundamental problems**
  - Using the standard radar equations requires estimates for many of the radar parameters



  - Few incorporate impact of the environment on radar detections

    Doing extensive physics computations in real time in most high level models slows computations and overall performance to unacceptable levels

- **Purpose of Study:**
  - Develop a quick, rapid method to predict radar performance that…
  - Incorporates the influence of persistent environmental conditions…
  - Suitable for evaluating mission effectiveness

Modeling Radar Detection (Basics)

- **Detection is a function of the signal excess bounced off the target, received and processed by the radar receiver.**

$$\begin{matrix} Signal \\ Excess \end{matrix} = [Transmit] \cdots [Reflect] \cdots [Receive] \cdots [Propagate] \cdots [Process]$$

- **Radar range equation derivation**

$$\begin{matrix} Signal \\ Excess \end{matrix} = \left[\frac{P_{AVG} G_T}{4\pi R^2}\right] \cdots \left[\frac{\sigma}{4\pi R^2}\right] \cdots \left[\frac{G_R \lambda}{4\pi}\right] \cdots [F^2 F^2] \cdots \left[\frac{t_{OT}}{L_S}\right]$$

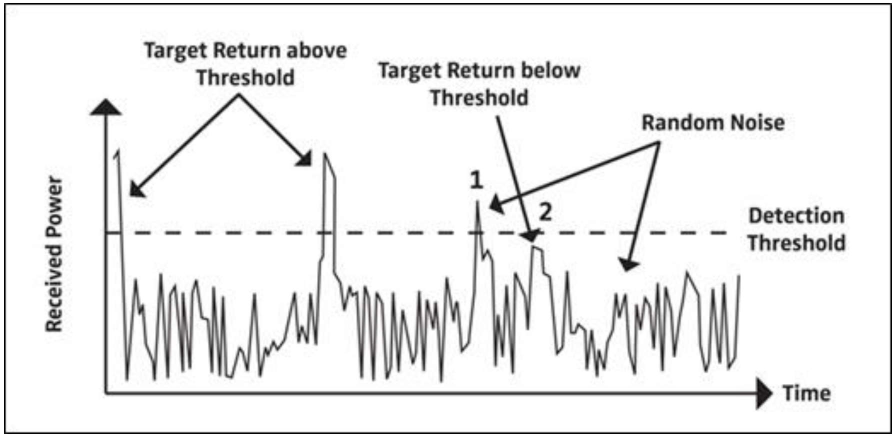
$$SE = \frac{P_{AVG} G_T \sigma G_R \lambda F^4 t_{OT}}{(4\pi)^3 R^4 L_S}$$

(Stimson, 1998)

- **Where**
  - R — Range
  - P_{AVG} — Average power produced by the radar
  - G_T — Gain from transmit antenna
  - σ — Radar cross section area of the target
  - G_R — Gain from the receive antenna (normally same as G_T in radars)
  - λ — Wavelength of carrier frequency
  - F — Propagation factor
  - L_S — Combined system losses that includes transmission, receiver, and noise losses
  - t_{OT} — Time on target – also called dwell time with results in pulse integration gains

Modeling Radar Detection

- **Define the "signal to noise" ratio to be a required threshold of signal excess needed to detect a target**



(Muro, 2008)

S/N is set to minimize false detections while ensuring enough signal is present to detect the target.

- **Incorporating the S/N value into the radar equation**

SE now has to be exceed S/N →

$$SE_{Detect} = \frac{P_{AVG} G_T \sigma G_R \lambda F^4 t_{OT}}{(4\pi)^3 R^4 L_S S/N}$$

- **Obtaining SE_{Detect} > 0 means the target can be detected**

Analysis of the Radar Equation

- **Parameters of the radar hard to estimate/know**

  Radar designers and intelligence organizations frequently use the term R_o, also called "*R naught*"

  - "Free space range at which a radar can detect a one square meter target (0 dBsm)"
  - Summarizes all the radar dependent parameters and constants into one term

- **Rearranging the radar equation…**

$$SE_{Detect} = \left(\frac{P_{AVG} G_T G_R \lambda t_{OT}}{(4\pi)^3 L_S S/N}\right) \frac{\sigma F^4}{R^4}$$

Let $\delta = \left(\frac{P_{AVG} G_T G_R \lambda t_{OT}}{(4\pi)^3 L_S S/N}\right)$

$$SE_{Detect} = \delta \frac{\sigma F^4}{R^4}$$ **and** $$\delta = SE_{Detect} \frac{R^4}{\sigma F^4}$$

- **These simplified forms provides greater flexibility in manipulating the radar detection problem**

Scaling to R_o

- **If we know a value of R_o for a radar…**

$$SE_{Detect\ 1m^2} = \delta \frac{\sigma_o {F_o}^4}{{R_o}^4}$$

- **By definition of R_o…**

σ_o = 1.0 (m^2)

F_o = 1.0 (free space range)

- **So…**

$$SE_{Detect\ 1m^2} = \frac{\delta}{{R_o}^4}$$ **and** $$\delta = SE_{Detect\ 1m^2} {R_o}^4$$

- **Since we defined *δ* as a collection of all constants…**

$$SE_{Detect} \frac{R^4}{\sigma F^4} = SE_{Detect\ 1m^2} {R_o}^4$$

$$\boldsymbol{R^4 = \sigma F^4 {R_o}^4}$$

Computation of detection range of a given RCS using a radar with known R_o and environmental propagation of F….

But what about "F"?

Atmospheric Propagation

- **Energy can be "ducted" if environmental conditions are correct**
- **Types of ducts:**
  - – Refractive Ducting (4/3 Earth)
  - – Layered Ducting:
    - Layers throughout the altitudes
    - Caused by temperature, humidity, wind, sand…
    - Very temporary - Prediction near impossible
  - – Evaporative Ducts (Surface Ducting)
    - Prevalent in maritime conditions
    - Influences 1.5 GHz to 18 GHz and beyond
    - Characterized by the "height" of the layer

Average Environmental Duct Heights

Area	**Duct Height (m)**
Northern Atlantic	5.3
Eastern Atlantic	7.4
Northern Pacific	7.8
California Coast	7.9
Mediterranean	11.8
Worldwide Average	13.1
Western Atlantic	14.1
Indian Ocean	15.9
Persian Gulf	16.1
Brazil	19.5

(Reilly ,1990)
(Yardim, 2008)

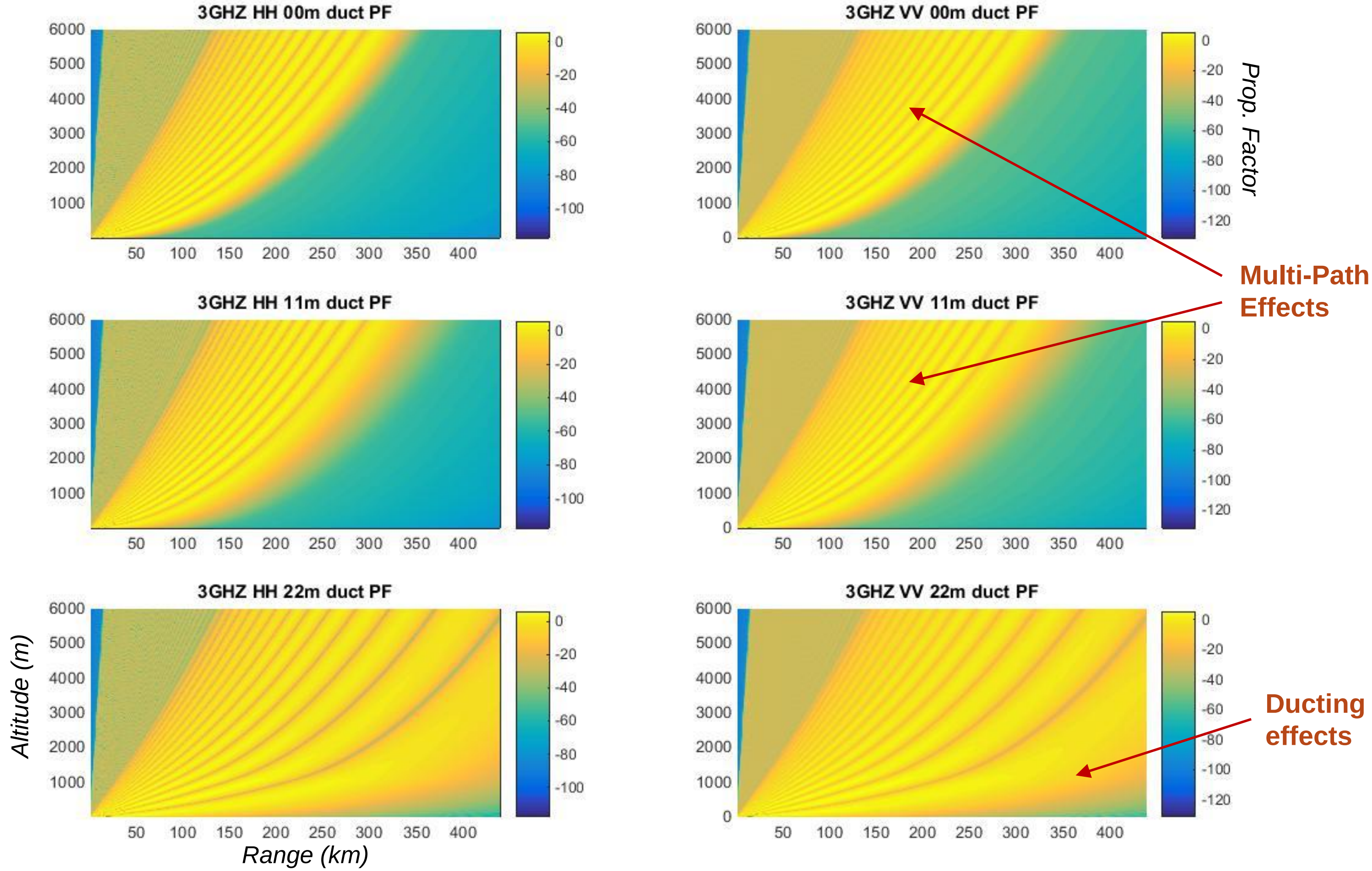
Propagation in a Ducted Environment

Height of evaporative ducting has dramatic influence on realized propagation patterns

No Duct

11m Duct

22m Duct



Propagation models must be used to predict to fully capture performance

** Charts computed using AREPS 3.6 data through MATLAB 2015b*

Modeling Propagation

- ***F*** **can be predicted as a function of range and height from radar**
- **Revising the simplified range equation…**

$$R^4 = \sigma F^4 {R_o}^4$$

Note: Two terms are a function of R

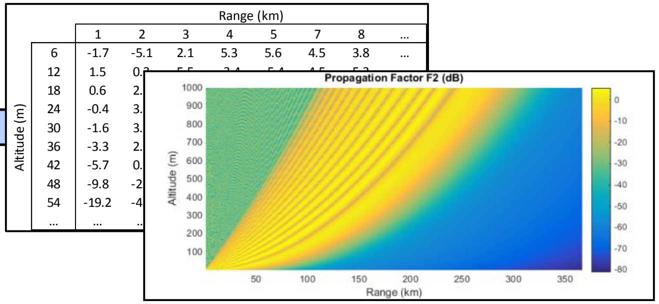
$$\sigma = 40Log_{10}R - 40Log_{10}R_o - 2F^2$$

Where $F^2 = f(R, Target\ Altitude)$

Propagation factor normally given as F^2 from models in dB

- **Equation computes σ (detectable RCS) at given range *R***

- **Using this Algorithm for determining range of detection**
  - Given:
    - Radar R_o (km)
    - Target RCS (dBsm)
    - Target Altitude (m)
  - Start at max range of table
    - Decrease range (R) incrementally
    - For each range value, determine F^2 from table and compute value for σ
    - If computed σ < target RCS = ***Detection occurs***
    - Otherwise pick next range (R)



Algorithm Usage

- **Physics Modeling**
  - Ability to examine detection analysis in various environmental conditions
  - Prediction of radar performance *(Example on next slide)*
  - RCS requirements analysis
- **Engagement Modeling**
  - Environmental effects on defensive systems
  - Verification of model detection computations
  - Determine survivability requirements and estimates
- **Mission**
  - Greatest influence in speed of modeling and simulation
  - Accurate detections to evaluate system of systems capabilities

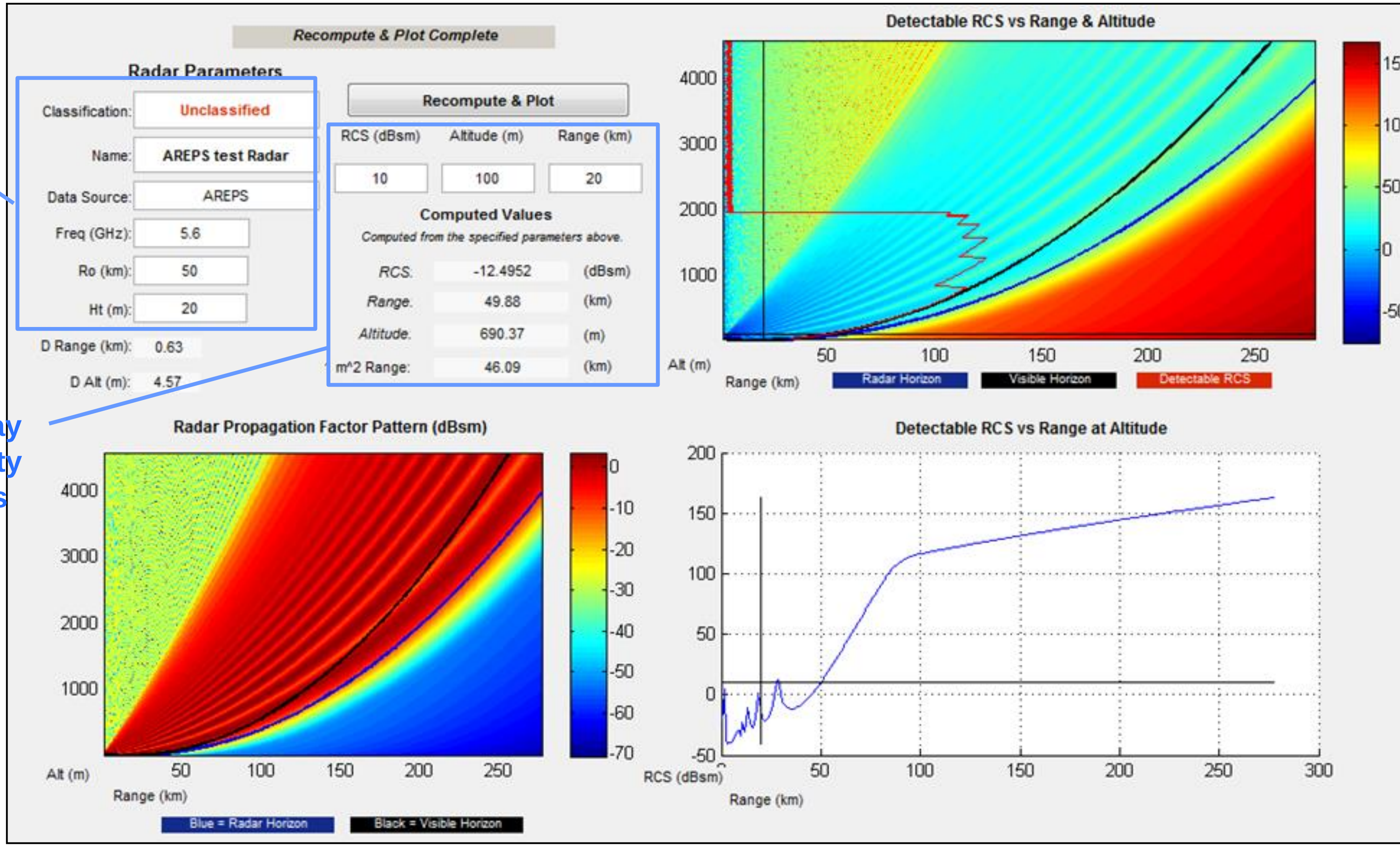
Questions and Comments?

Example: Radar Detection Prediction Tool

Purpose: Allows sensitivity analysis on detection problem

Radar Data

Three-way Sensitivity Analysis



Developed using MATLAB version 2013 with Guide©

Features:

- Importing tabular data for propagation factor (*F*)
- Radar data parameters for analysis and any classification level
- Ability to conduct sensitivity analysis of target RCS, Altitude and Range

Points to take Away

- **Comments and Assumptions**
  - Environment conditions vary
    - Atmospheric prediction tool needed to compute propagation factor
    - One environment at a time can be evaluated
  - R_o is a generalized estimate only
    - Computations are only as good as this estimate
    - Lack of estimate requires use of full radar equation
  - Target RCS will change with aspect of body
- **Computations shown are not new**
  - Scaling to R_o has been used by many modelers in past
  - Application of environmental propagation subject of numerous studies
- **What is new?**
  - Rapid method for use in higher level modeling and simulation

Questions and Comments?

Abstract

The radar range equation provides a deterministic, accurate method to predict detection of a target with a known signature as long as all factors/variables in the equation are understood and known. Items such as signatures and geometric situations are understood and can be predicted based on tactical presentation. What are unknown are the influences of the other variables in the radar range equation unique to the radar (noise loss, system loss, processor gains, etc.) which can be problematic to characterize individually, especially in modern dynamic adaptive radars. One particular parameter, the free space detection range of a one square meter target (also called the R_o), accounts for the collective estimates of all radar characteristics and would serve well to classify notional performance. Furthermore, to incorporate environmental conditions, which can vary in range, time, refractory conditions and other influences, extensive detailed models can predict these conditions and should be incorporated through estimates of propagation. Yet these models use time consuming calculations and thus are impractical for use in rapid OA modeling and simulation when used in process for each every detection calculation. Instead, tabulating output from the models can provide rapid accessing of the propagation values. Incorporation of both the R_o value and tabular results from the environmental models, the radar range equation can be reduced to a much simpler form for quicker and accurate detection range predictions for a target signature to be used in modeling and simulation.

References

- *Advanced Refractive effects Prediction System (*AREPS), version 3.6. Developed by Space and Naval Warfare Systems Center (SPAWAR), Atmospheric Propagation Branch, San Diego, CA.
- MATLAB, Version R2013b. The MathWorks, Inc. © 1994-2013
- Muro, Bob. Characterizing RADAR Interference Immunity. NoiseCom, ISO 9001-2008. Accessed 2013: http://noisecom.com/resource-library/articles/characterizing-radar
- Reilly, J.P. and Dockery,.D., (1990). "Influence of Evaporative Ducts on Radar Sea Return", *Radar and Signal Processing, IEE Proceedings,* Vol 137, Pt F (2). 80-88. ISSN 0856-375X.
- Stimson, G.W. (1998). *Introduction to Airborne Radar (2nd ed.)*. Raleigh, NC: Sci Tech Publishing Inc.
- Yardim, C., Gerstoft, P. and Hodgkiss, W. (2008) "Evaporative Duct Estimation from Clutter Using Meteorological Statistics", *Antennas and Propagation Society International Symposium, 2008*. 1-4: DOI: DOI: 10.1109/APS.2008.4619240 .