Modeling and Optimization of V/UHF RF Propagation in Maritime Environment

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Approval

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List of Abbreviation

EM	Electro magnetic
PE	Parabolic Equation
RF	Radio Frequency
M&S	Modeling and Simulation
VHF	Very High Frequency
UHF	Ultra High Frequency
PL	Propagation loss
SSFT	Split Step Fourier Transformation
DEM	Digital Evaluation Model
PF	Propagation Factor
ESM	Electronic Support Measure
FSPL	Free Space Path Loss

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Abstract

Very/Ultra High Frequency communication uses electromagnetic radio waves of frequency range, 30 MHz – 3.0 GHz (wavelength from 10m -1 mm) for voice/data communication and active/passive sensors. The electromagnetic waves experience propagation loss as they traverse in different mediums. The propagation loss is observed to be constant in vacuum but it dynamically changes with varying atmospheric conditions. The affect is more pronounced in maritime environment as compared to urban areas due to rapid variation in atmospheric/ climate parameters of oceanic weather environment. The variation in conditions cannot be predicted/ modeled through linear equations/ constant relationships. There is a need to develop a simulated environment to examine propagation losses in V/UHF spectrum for real time situational awareness. This will also give clear understanding of performance evaluation of V/UHF communication systems in the inhomogeneous maritime environmental conditions.

Different environmental conditions based on available archived data set will be modeled during the proposed research work. The conditions pertaining to Arabian Sea and adjacent coastal areas will be the target conditions for the study.

Keywords: *Modeling and Simulation, V/UHF Communication, Radio Wave Propagation, loss reduction*

Chapter 1 **Introduction**

This chapter provides information about the topic which is being studied. It describes the definitions and concepts of electromagnetic wave, tropospheric conditions and impact of environmental changes in EM wave propagation, simulation & Modeling domain and some preliminaries to get an understanding of this thesis

V/ UHF based communication systems are widely used in maritime domain for ship-ship, ship – shore communication. The communication comprises of real-time data protocols for voice, video and data communications. In modern navies different sensors and communication platforms uses Electromagnetic radio waves. These waves are affected by effects of atmosphere in propagation. Atmospheric refractive conditions above the sea surface play important role in electromagnetic wave propagation and allow the decision maker how to utilize the onboard sensors and system in a particular environment. Anomalous environmental conditions could misinterpret the information obtained from sensor and communication devices. The impact of atmospheric effect on electromagnetic wave propagation is not only affecting the use of communication systems but also on surveillance, Electronic Warfare systems, weapon guidance etc. It was reported in WW-II that radars operating in submarines were performing unpredicted targets. Aircrafts were receiving signals from transmitters that were too far away from defined range while some were reported no reception even within range. It was experienced in past that a radar detected a target beyond horizon, far beyond its ranges in anomalous atmospheric conditions while sometimes it is unable to detect a target which is optically visible.

Most of the propagation anomalies observed in past were came up over the oceans. The phenomenon of atmospheric ducting above the sea surface is more dominant and consistent as compared to land areas. As an example, availability of evaporation duct is found persistent over the waters. It has been observed that the variations in temperature and humidity in lower atmosphere yield significant variations in propagation of electromagnetic waves. These anomalies may produce improved or degraded signal strength of communication system. Therefore, consideration of weather and environmental parameters must be ensured while development of reliable prediction system which has impact on improved or degrade the range of system in maritime environmental conditions.

The signal propagation of microwave radios over the sea at low altitude is quite diverse than standard line of sight propagation. The presence of different vertical gradient profiles of humidity and temperature above the sea surface due to variation in atmospheric effects causes ducting to be developed near sea surface. The difference in refractivity profile converges the electromagnetic energy to bends towards earth surface instead of propagating in a straight line in vaccum. The propagation of electromagnetic wave within duct allow the signal to propagate over the horizon with low attenuation in signal power. Three main types of anomalous propagation are sub refraction, super refraction and trapping. Details of these is discussed in later chapters. The duct is formed due to trapping and is supposed to be present in lower atmosphere. It arises when cool and moist air is surrounded by warn and dry air resulting temperature inversion and sudden change in humidity. This phenomenon can be observed over the land but more prominent above the ocean and towards coastal areas.

Communication networks operating in V/UHF communication has high impact on performance of the systems. Due to dynamic environmental conditions in spatio temporal domain maritime environment, the behavior of system and its performance measure cannot be predicted. Domain of modeling and simulation is used to find out the environmental conditions and predict the path and propagation losses using real-time archived data.

This research will provide advantage over tactical level by utilizing the information of location and time of ducting phenomenon. The prediction model will suggest the availability of surface duct and propose extended coverage ranges with transmitter, receiver and antenna combinations. Other advantage is to make realistic estimation of communication link behavior and bandwidth and other tactical decision pertaining to ESM and counter detection ranges.

1.1 V/UHF Communication Systems

UHF communication uses electromagnetic radio waves for data communication. The frequency range of UHF is between 300 MHz – 3.0 GHz with wavelength from 1m to 1 dm. When radio wave propagates from one to another medium, the variation of refractive index between two mediums causes radio wave to bend towards higher refractive index value. Different environmental parameters cause changes in refractive indexes, some of are as follows:

a. Gasses in air at different Temperature and pressure.
b. Water vapors and their density.
c. Near Earth Surface with higher refractive index.
d. Selection of frequency spectrum and wavelength

Refractive index varies in troposphere at different height and temperature which will lead to positive and negative effects in UHF communication systems. If the change of refractive index is higher towards earth surface, it will have positive effect in increasing the range and signal quality. Whereas it can be negative if the higher refractive index is away from earth surface.

Another significant phenomenon which is observed in RF communication is atmospheric duct. An atmospheric duct is developed over a horizontal terrain in lower atmosphere with the vertical refractive index gradient are such that the RF signals are guided or ducted. The duct act as a dielectric wave guide and limits the spread of RF signals to horizontal dimension. The ducting cause long distance RF signal propagation.

1.2 Problem Domain

Electromagnetic wave observes anomalous propagation due to variation in atmospheric condition. The anomality in propagation causes un predictable results in terms of signal strength and ranges. To examine the anomalies in radio wave propagation, atmospheric and environmental conditions needs to be examined study the changes. It has been observed that radio wave propagation is affected more in lower atmospheric region. This is due to abrupt changes in refractive index in atmosphere. The gases and water vapour content in lower troposphere also plays vital role in variation of refractive index. Refractivity profiling over different vertical level creates ducting region. The duct is formed due to trapping and is supposed to be present in lower atmosphere. It arises when cool and moist air is surrounded by warn and dry air resulting temperature inversion and sudden change in humidity. This phenomenon can be observed over the land but more prominent above the ocean and towards coastal areas. The presence of different vertical gradient profiles of humidity and temperature above the sea surface due to variation in atmospheric effects causes ducting to be developed near sea surface. The difference in refractivity profile converges the electromagnetic energy to bends towards earth surface instead of propagating in a straight line in vaccum.

Land based communication systems observe different sets of problems in term of signal propagation. This includes, interference, reflection, diffraction through buildings, interference etc. Whereas, most of these problems are not affected in sea communication system. Maritime environmental conditions are very dynamic and unpredicted in nature in spatio temporal domain. These anomalies may produce improved or degraded signal strength of communication system. These conditions affect the performance of communication systems and other sensors operating in V/UHF frequency ranges. Therefore, consideration of weather and environmental parameters must be ensured while development of reliable prediction system which has impact on improved or degrade the range of system in maritime environmental conditions. To identify the near- real approximation of performance measures and analysis of factors which affects the performance, there is a need to study and model the environmental conditions of current area of interest with real time archived data in spatio temporal domain. Different environmental conditions based on available archived data set will be modeled during the proposed research work. The conditions pertaining to Arabian Sea and adjacent coastal areas will be the target conditions for the study.

1.3 Problem Statement

For highly reliable and efficient communication systems, all parameters pertaining to the performance and reliability needs to be addressed alongwith the environment. The aspects of environmental changes and propagation losses for communication system, there is a need to study the behavior of environmental changes pertaining to electromagnetic wave propagation which leads us to the formulation of our problem statement which is listed below:

"There is a requirement of Pakistan Navy to study the propagation losses due to change in environmental conditions in maritime domain in current PN Area of Operations for better situational awareness and performance analysis of V/UHF communication systems/sensors installed onboard ships and coastal areas".

1.4 Solution Domain

We give a brief overview of the solution to the above-mentioned problem in our thesis

1.4.1 Modeling and Simulation

Modeling and Simulation (M&S) is a technique for virtual representation of the real-world systems or scenarios. We can model real-world scenarios as we cannot afford to find the appropriate solution by testing with real-world objects and systems. It helps us to understand a complex system's behavior without doing practical experiments in the real world. Firstly, with the help of computers, a mathematical model which represents the physical parameters of the actual systems and then different conditions are applied to study the different scenarios [1].

1.4.2 Modeling of Environmental Conditions

To study the performance and propagation losses in EM wave spectrum, modeling of maritime environmental conditions with pseudo real scenarios based on real time archived data set will help to study the behavior of different sensors and systems in different environmental conditions.

1.5 Solution Statement

Modeling and simulation play an essential role in modeling this real-world scenario in a virtual world with some abstractions to analyze the environmental conditions of Arabian sea in spatio temporal domain that leads to affect the EM wave propagation over different levels of height, temperature, pressure and relative humidity. An Agent-Based modeling approach is used to develop a framework for analyzing environmental conditions and different phenomenon of tropospheric ducting. Modelling and simulation of the different scenarios can provide **Better understanding of impact of different weather parameters**, **Performance Analysis of Sensors / Systems** and decision **strategies** to manage communication systems and sensors installed onboard ships

1.5.1 Key Contributions

We propose maritime environmental modeling, simulation and analysis framework that encompasses (i) model environmental conditions of Arabian Sea (ii) model the tropospheric effects including presence of atmospheric duct (iii) model the propagation losses and path losses due to variation in environment (iv) abstraction of antenna and radio parameters including height and power of transmitter, receiver sensitivity, antenna gain (v) Environmental dataset to be used for simulation is discretized with the difference of 1 deg lat / long parameters in a girded environment.

1.6 Research Impact

Impact of atmospheric variations on electromagnetic wave propagation has been observed for quite long. Operational communication and sensors dealing with EM spectrum realize the importance of catering atmospheric effects. Reliable communication requires to cater all parameters which influence the propagation. UHF communication are highly influenced by environmental and refractive effects in maritime conditions. Our proposed framework will help to identify the impact of communication signals in current environmental conditions. This research will help Pakistan Navy, sister services and other national research groups better insights of planning in development of indigenous communication equipment for maritime environment with better performance in maritime domain

1.6.1 Academic Impact

This research will not only analyze the communication system over different environmental conditions but also develop an output structured dataset containing several parameters like duct availability, height, time, temperature variations, etc, which can be further analyzed using advanced data science techniques for future predictions and research.

1.6.2 Industrial Impact

This research will help communication equipment vendors to cater maritime conditions for better communication products. Moreover radars operating in 3-30

GHz band can also be calibrated. Furthermore, the model can be transformed into GUI based product for real-time analysis and situational awareness.

1.7 Thesis Organization

The organization of the thesis is as follows:

1.7.1 Chapter 2: Background

Chapter 2 provides a brief overview of maritime environmental conditions and profiles, its importance, factors that affect the change in profiles pertaining of EM wave propagation. Moreover, few environmental conditions profiles including ducting phenomenon and its impact of EM spectrum, models' preliminary concepts used in the methodology chapter have also been discussed.

1.7.2 Chapter 3: Literature Review

This chapter explains the related work done so far in the field of propagation losses in environmental models. The formulation of the thesis and the novelty of the thesis lie in identifying the research gap from the literature already published. The identification of the direction of research is also one of the sanctions of literature.

1.7.3 Chapter 4: Methodology

Our proposed simulation and analysis framework have been presented in this chapter Moreover, the tool used for the development of the framework and built-in libraries of the tool used for developing the model, are presented here Furthermore, the input parameters and archived dataset required to drive the framework are also presented in this section

1.7.4 Chapter 5: Simulation and Results

The functionality of our proposed framework is described in this section. The inputs which the framework requires and the output which our framework provides, the simulation of our framework and the visualizations which our framework provides are all presented in this chapter

1.7.5 Chapter 6: Conclusion and Future work

The tasks completed during the course of this thesis are presented in this chapter We will provide the conclusion of our work and propose the future work to be done for better advancements.

Chapter 2 **Background**

This chapter provides information about the topic which is being studied. It describes the definitions and concepts of Electromagnetic wave propagation, environmental effects with impact on EM wave some preliminaries to get an understanding of this thesis.

2.1 Electromagnetic Wave Propagation

When a charged particles travels, a magnetic field is created. The direction of magnetic field is dependent upon the direction of electron. A moving charged particle produces both magnetic and electric field. The acceleration of charged element formed Electromagnetic wave.

Figure 1 shows the creation of EM waves. Electromagnetic waves are formed by magnetic and electric field which are perpendicular to each other and also to the wave direction. The EM wave propagation is due to change in movement of particles thus change in electric and magnetic field. This change creates new another magnetic and electric field. This regeneration and collapsing of fields allow EM wave to propagate.

EM wave travels in straight line in vacuum or free space with static path loss but the direction of wave changes when it travels from one medium to another. Therefore the losses and directions are changing in different medium and environments. EM wave spectrum are widely used in communication technology as it carries energy, EM radiations are the foundation working principle of radars and other sensing devices. It is also used in medical sciences for treating and analyzing several diseases.

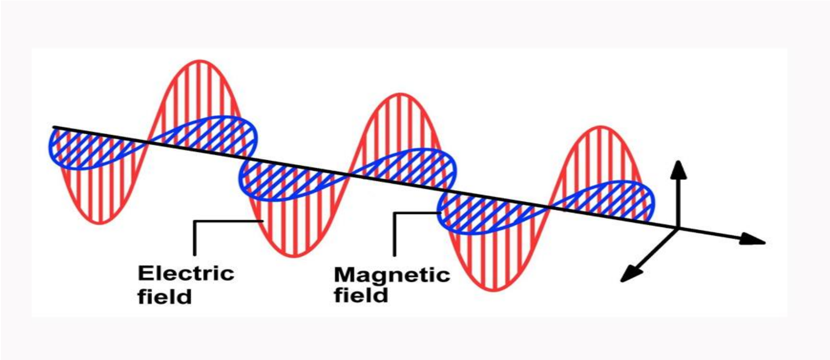

Figure 1 Generation of Electromagnetic (EM) Wave

2.2 EM Propagation Mechanism

It is highly beneficial to model the prevalent and imminent performance of communication systems under certain atmospheric conditions. It will not only increase the capability and usage of system but also beneficial in developing future marine based communication systems. To model the atmospheric changes with regard to EM wave propagation and calculation of path losses, it is necessary to develop the understanding what are the factors that could lead to affect the electromagnetic wave propagation under different conditions.

The impact of Electromagnetic wave propagation is observed more in near earth's surface – i.e. Troposphere. Different phenomenon like, reflection, refraction, spreading, divergence, interference, scattering and attenuation is observed when radio waves are propagating in environment. In this section we will briefly define some of the propagation mechanism which affects the propagation of EM waves in tropospheric environmental conditions.

2.3 Spherical Spreading

Most fundamental mechanism of EM energy is Spherical Spreading [2]. In a homogeneous and loss free environment also known as free space, the energy radiates from antenna spreads uniformly in every direction over spherical surface. The one-way spreading propagation loss is found to be inversely proportional to the square of the length between receiver and transmitting station. It is measured in decibels and is given by

$$L_f = 32.45 + 20\log(f_{MHz}) + 20\log(d_{km}) \quad [2]$$

2.4 Divergence

On a plane surface, when electromagnetic waves reflect, the incident angle is same as reflected angle but direction alters. However, on a spherical surface, the divergent beam reflects will diverge at a greater rate after reflection. The spreading loss will be added to spherical spreading after divergence

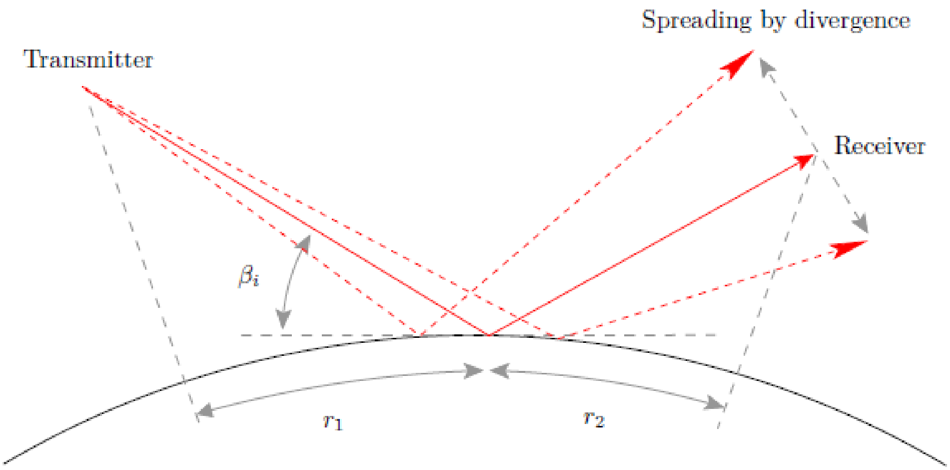

Figure 2: Illustration of Divergence under spherical surface

Divergence factor provides the degree of divergence and is defined as ratio of after reflection field strength from spherical surface to the reflection from plane surface. [21]. Considering divergence in elevation and small grazing angles (β < 5°), it is given by:

$$D = [1 + \frac{2r1r2}{kRe(r1 + r2)\tan\beta}]$$

Where: r1 is the range between Tx and reflection point

r2 is the range between reflection point to receiver

Re is earth radius

K is effective earth radius factor

2.5 Interference

When two or more electromagnetic waves collides each other and form a composite wave which may be greater or lower in amplitude. Interference is observed when multiple wave intersects with each other and may develop constructive or destructive interference. The phenomenon of interference is observed in areas where multiple transmitting equipment are operating. It is more imminent in dense populated areas where numerous radio waves are operating in the environment. Moreover, interference is also observed when direct and indirect reflected rays by reflected medium from same transmitter is intersected at a point in electric field strength and phase. Area of study is selected in this thesis may not be affected due to interference and hence the same can be made in abstraction.

2.6 Attenuation

Attenuation in electromagnetic energy is also observed in atmosphere due to interaction of EM waves with atmospheric gases molecular movement[3]. Electromagnetic wave energy is attenuated due to availability of metrological environmental conditions like rain, snow, hail and fog [26] The major impact of attenuation is due to presence of water vapour and oxygen[2,3,5] Studies shows that the impact of attenuation due to gasses operating below 20 GHz frequency spectrum are relatively small as compared to other phenomenon, however, frequencies operating above 20 GHz has considered impact on radio propagation over longer distances. Attenuation coefficient α is used to determine the degree of attenuation.

The attenuation due to water vaopur content and dry air can be computed by providing atmospheric pressure and relative humidity for upto 1Thz frequency spectrum. [5]. Figure shows attenuation at different frequencies with dry air and standard atmospheric conditions.

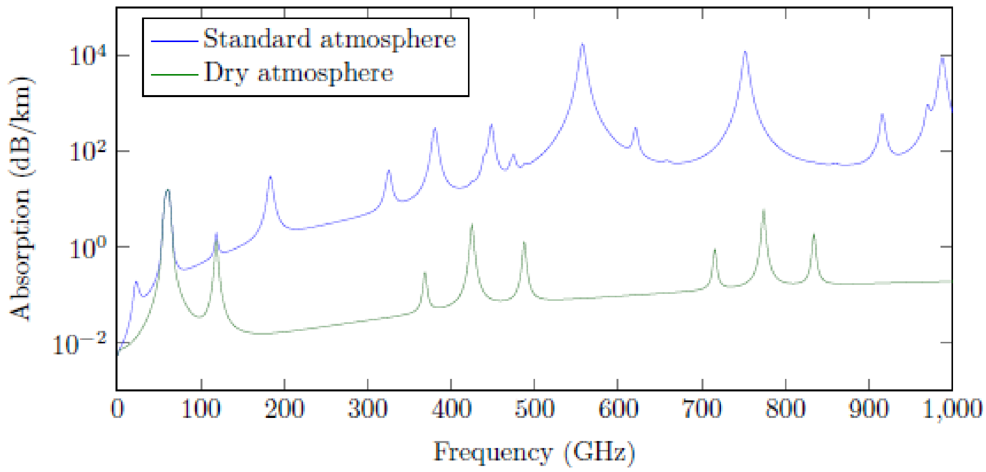

Figure 3: Graph Standard Vs Dry Atmosphere

The graph clearly depicts that dry environmental conditions has lower attenuation of signals as compared to humid environment at specific frequency domains.

Attenuation observed due to rain fade is dependent on the amount of rain and rain drop size [4]. Rain fade attenuation is estimated as a function of rain rate, polarization and frequency. To estimate the amount to all significant attenuation due to rain, snow, hail and fog, the sum of all must be integrated along the propagation path [2].

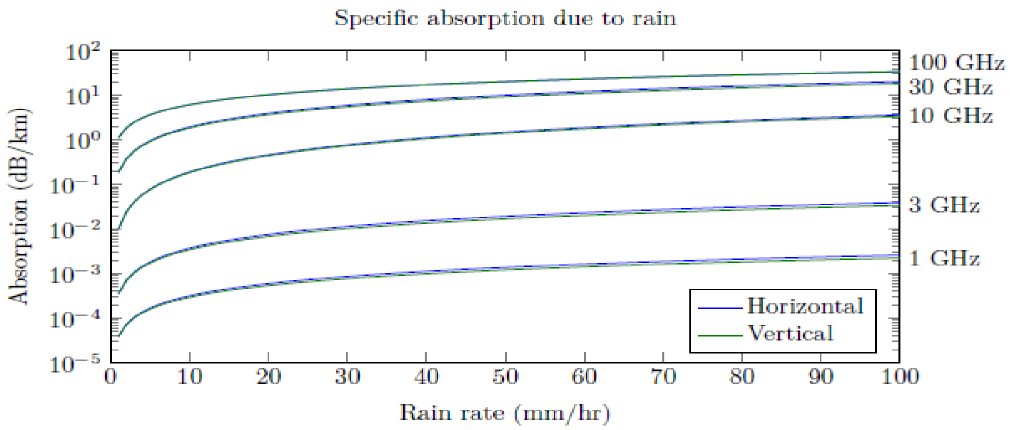

Figure 4:Graph Rain Vs Frequency

2.7 Troposcatering

Propagation of Electromagnetic waves beyond the horizon is achieved due to scattering of electromagnetic energy because of inhomogeneities in refractive index in the environment. Impact of Troposcattering is observed in communication systems. Several empirical models are presented for computing propagation losses in troposcatteric region, however, model presented by Yeh is simple and implementable [6]. As per the model, the propagation loss – including free space loss- in tropospheric region is given by

$$Ls = 57 + 10\theta s - 20\log(d) + 30\log(f\ Mhz) - 0.2(Ns - 310)$$

Where:

Ls= Propagation loss in dB

θs,= Scattering angle in degree

Ns= refractive Index Surface Refractivity

Figure depicts one-way propagation loss as a function of different regions of tropospheric scattering, interference and diffraction over operating frequency of 3.3GHz with distance of 37Kms between Tx and Rx and height of antenna is 20m above sea level.

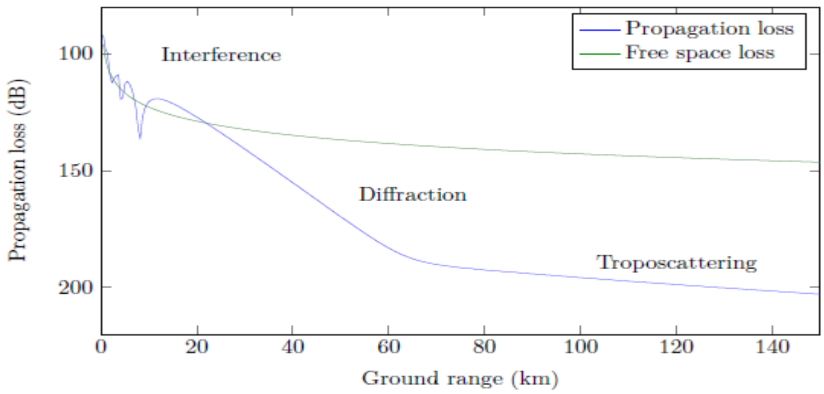

Figure 5 : Graph Range Vs Propagation loss

2.8 Reflection

Reflection is done when electromagnetic waves strikes over a surface, its energy is reflected back to the medium and propagation is continued along a new path [2]. If the surface is smooth like still water bodies, grazing angle of incident waves is equal to the grazing angle of reflected wave, also known as specular reflection.

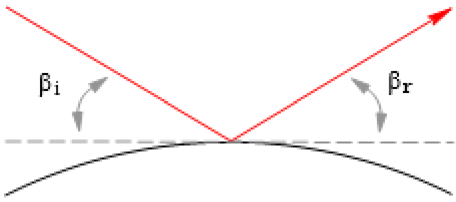

Figure 6 : Reflection

When reflection is observed, the energy in waves will reduce with change of phase. These effects are described in Fersnell's reflection coefficient. It will provide ratio of incident Ei and reflected Er electric field [7]. Fersnell's coefficient for horizontal and vertical polarization are defined as: [8]

$$RHS = \frac{Er}{Ei} = \frac{\sin\beta i - \sqrt{n^2 - \cos^2(\beta i)}}{\sin\beta i + \sqrt{n^2 - \cos^2(\beta i)}}$$

and;

$$RVS = \frac{Er}{Ei} = \frac{n^2 \sin\beta i - \sqrt{n^2 - \cos^2(\beta i)}}{n^2 \sin\beta i + \sqrt{n^2 - \cos^2(\beta i)}}$$

Where n is surface refractive index which is defined as:

$$n = \sqrt{\varepsilon r - i60\sigma\lambda}$$

Whereas:

εr is the relative permittivity of the surface,

σ is conductivity of surface and;

λ is wavelength of EM wave.

Electrical properties of ε and σ are defined as function of frequency and surface type. These properties and their impact in radio wave propagation will be elaborated in detail in subsequent paragraphs.

2.8.1 Conductivity of Reflected Medium

The surface used in reflecting electromagnetic waves plays important role in reflection. Materials with better conductivity like metals provides best reflection. The phenomenon is more imminent in HF communication ionospheric propagation where HF signals are reflected back from earth surface. The areas with good conductivity provides better as compared to less conducting surface. Chart below provides conductivity coefficient different surface areas.

Table 1: Surface and Conductivity

Surface	Conductivity
Dessert/ Dry Ground	0.001
Normal Ground	0.005
Fresh Water	0.01
Wet Ground	0.02
Sea Water	5

It is observed that sea surface provides better reflected signals whereas dessert or dry surface provides poor results.

2.8.2 Roughness of Surface

In case of rough surface, only some part of the wave are reflected back and most of the energy is scattered due to roughness of the surface. To determine the impact of roughness of the surface, the fersnell equation must be modified [6]. Miller & Brown presented a model to cater roughness of surface for reflection in specular directions and is derived from fresnell equation. It is given by :

$$RR = Rs \exp[-2(2\pi g)^2] Io\ [2(2\pi g)^2]$$

Where;

Rs = fersnell coefficient

g = Ocean roughness

Io= modified Bassel function [6, 3]

2.9 Refraction

Electromagnetic waves travels in straight line in vacumm or in free space as the there is no change in refractive index. Due to variation in refractive index in tropospheric environment, the electromagnetic waves bends. When the wave travels from one medium to another, it curves towards higher refractive index. Degree of refraction is to be determined by Snell's law [9]:

$$n1 \cos \beta 1 = n2 \cos \beta 2 = constant$$

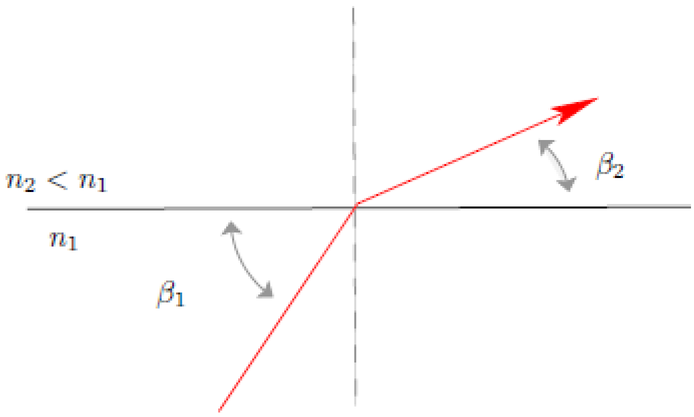

Figure 7 : Refraction

Where:

β1 & β2 are incident and refractive wave angle

n1 & n2 are refractive indexes of mediums

In troposphere, refractive index varies due to change in atmospheric pressure, water vaopur content in air, and temperature. To calculate refractive index in troposphere, empirical formula of Debye can be used.[10,11]

$$n = 1 + \frac{77.6}{T}\left[P + \frac{4810e}{T}\right] X\ 10^{-6}$$

Where P= Atmospheric pressure in millibar

T = temperature in Deg Kelven

e= partial water vapour pressure in millibar

2.9.1 **Refractivity**

The variation of Refractive index in troposphere lies between 1.00025 - .1000400 units [2]. Since the number are extremely small, scientist have found to alleviate the usage of these digits by introducing a parameter refractivity (N). Studies pertaining to radio wave propagation, refractive index is not convenient to use, instead refractivity N is used. Refractivity N is ascended version of refractive index and is related as N= (n-1) x 10^6 and the values on N lies between 250 – 400 N units in troposphere. The empirical formula for computing the refractivity N is given by

$$N = 77.6\left[\frac{P}{T}\right] - 5.6\left[\frac{e}{T}\right] + 3.73\ X\ 10^5\ \left[\frac{e}{T^2}\right]$$

It is assumed that refractivity varies linearly with height in atmospheric layer. Moreover, it is more convenient to represent electromagnetic wave in term of ray energy which is drawn perpendicular to every wave. EM rays propagation path can be determined easily using Snell's law.

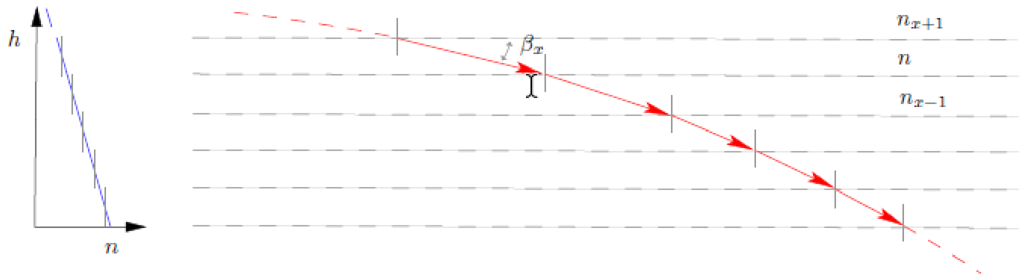

Figure 8 : Rays Propagation in Normal Atmosphere

Figure shows the illustration of rays propagating under normal atmospheric conditions where refractivity varies linearly with height propagates alongwith curvature radius. It has been observed that under standard atmosphere, the variation in refractivity with respect to height is 39 N units per KMs. However, atmospheric conditions varies with time and space which affect the propagation path of EM rays.

2.10 **Impedance of Wave**

Impedance of electromagnetic wave is defined as the ratio of electric field strength and magnetic field strength. It is denoted by Greek letter η (ETA) as a physical constant relating to magnetic and electric field in free space and is expressed as:

$$\eta = \frac{Eo(x)}{Ho(x)}$$

Where:

Eo= Electric field strength

Ho= Magnetic field strength

The wave impedance can also be expressed as:

$$Z = \eta = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{i\omega\mu}{\sigma + i\omega\varepsilon}}$$

Where:

μ = Magnetic permeability

ε= Electric permittivity

i= imaginary unit

ω= angular frequency

σ= electrical conductivity of material

In free space these values are $4\pi \times 10^{-7}$ H/m (henries per meter) and ($1/36\pi$) F/m (farads per meter) which gives the impedance value of 377 Ohms. However, in dielectric materials, the value of wave impedance will become 377/n. where n is the refractive index of the material.

2.10.1 **Magnetic Permeability μ**

The property of a material to support magnetic field development is defined Magnetic permeability. A constant μ defines ratio between magnetic induction and field intensity. The greater the μ the higher the conductivity of magnetic lines of force. μ in vaccum and in air is very poor however, it is affected by many external factors like temperature, medium used, humidity and strength of magnetic field in environment. μr is the relative permeability and is defined as the ratio between μ of material to μ in free space (μo).

$$\mu r = \frac{\mu}{\mu o}$$

Since air is a paramagnetic medium, it has mere effect due to change in temperature as it observed in significantly in metals like iron. μr of Air is observed to be 1.00000037 [12]

2.10.2 Electric permittivity ε

A constant of proportionality exists between electric field intensity and electric displacement is defined as Electric permittivity

$$\varepsilon r = \frac{\varepsilon}{\varepsilon o}$$

εr -also called di electric constant, of air at room temperature (25 C) is 1.00059

2.11 **Tropospheric Propagation**

Tropospheric propagation refers to the propagation of electromagnetic waves due to e environmental parameters and atmospheric conditions affecting the electromagnetic rays propagation and path losses. We will discuss about standard and anomalous atmosphere based on weather parameters and impact on propagation which is referred as normal and anomalous propagation.

2.11.1 Standard Atmosphere & Normal Propagation

The atmosphere is formed by collection of gases alongwith the particles of liquids and solids. Troposphere is the lowest portion of the atmosphere with an altitude of upto 8 to 10 KMs from earth surface[13]. The values of refractivity in tropospheric region is dependent upon weather conditions which includes atmospheric temperature, pressure and water vapour content in the air. It is assumed on a global scale that in troposphere, horizontal layer of weather parameters (temperature, water vapour content and pressure) changes with height [14]. Pressure is exponentially decreases with height with a fraction of 1/e from the surface till the height of about 8 Kms[14]. Further, the avg temperature also decreases with height at 6.5 deg C per Kms [13,15].

Water vapour content also decreases rapidely with height as the water content in air becomes half at altitude of 1.5 Km from surface[13].

The impact of variation in temperature, pressure and water vapour content with respect to height results the refractivity profile to decrease exponentially with increase of height. The decrease of refractivity in observed linear with avg gradient of dN/dh = -39 N units per Km for lower altitudes upto 1 Km [13,16,10,14]. 'International commission of Aeronavigation' declared Standard Atmosphere as Atmosphere with refractivity gradient of -39 N units in year 1925 [3].

In standard atmospheric conditions, propagation of EM waves are observed in linear fashion and termed as standard or normal propagation. It is generally occurred when refractivity gradients observed between 0 to -79 N units/ Km [2,13].

2.11.2 Anomalous Propagation

Non standard atmospheric conditions affect the characteristics of EM wave propagation resulting anomalous wave propagation. The anomalous propagation are significantly different in term of normal propagation. It is observed due to change in vertical atmospheric profile which is significantly different from standard atmospheric profile. The impact of anomalous propagation is mostly due to variation in refractivity in vertical profiles. Based on difference in refractivity gradients, following conditions pertaining to anomalous propagation is characterized as per following table [13]:

Table 2 : Condition of Anomalous Propagation

Condition	**dN / dz (N-unit / km)**	**dM / dz (M-unit / km)**
Sub refraction	Greater than 0	Greater than 157
Normal refraction	Between -79 to 0	Between 79 to 157
Super refraction	Between −157 to −79	Between 0 to 79
Trapping	Less than −157	Less than 0

The conditions pertaining to sub refraction, super refraction and trapping will be discussed in detail in following paragraphs.

2.12 Modified Refractivity

The table shows another field of modified refractivity gradient. Modified refractivity is also a scaled version of refractive index which has taken an account of height. It is used to determine the bending of EM rays relative to the curvature of earth. The areas the value of M gradient is negative, it is more likely the presence of duct. The electromagnetic energy is trapped in duct resulting better propagation ranges than expected in normal conditions. The modified refractivity M profile can be described as :

$$M = N + \frac{h}{Re} = N + 0.157h$$

Where:

N= Refractivity

Re= Radius of Earth =6.370 x 10^6 m

H= height above the surface of earth.

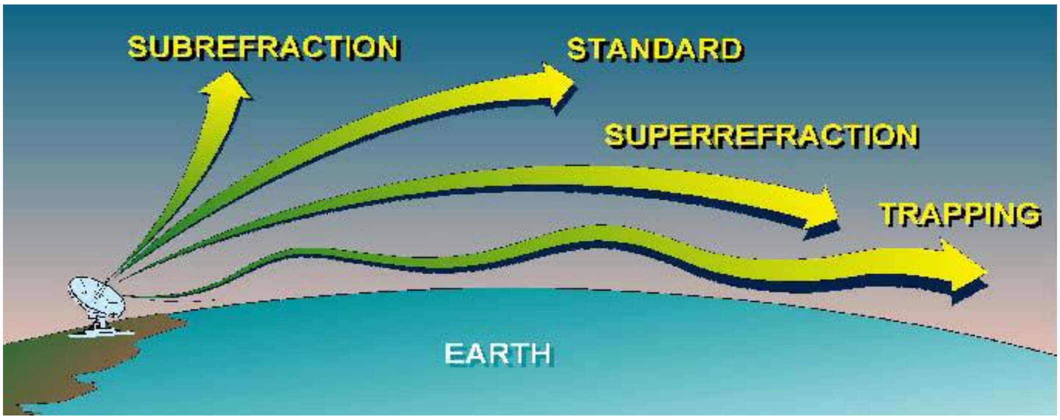

Figure 9 : Conditions of Refraction

2.12.1 Sub Refraction

In normal conditions, refractivity gradient decreases with height, however, in certain conditions, amount of water vapour content and temperature in atmosphere with respect to height resulting the increase in refractivity [13]. In this scenario, the electromagnetic waves bent upwards away from the curvature of earth. This bending of electromagnetic rays due to increase in refractivity M with height called sub refraction, resulting decrease in range.

2.12.2 Super Refraction

The phenomenon of super refraction is observed where content of water vapour in air decreases rapidly with height as compared to normal conditions with the presence of temperature inversion. This will decrease the refractive index more than the normal conditions resulting to curve electromagnetic waves towards earth curvature. Hence, the range of propagating signals will increase. It is observed that when refractivity gradient is found between -157 to -79 N units or M- gradient between 0 to 79 M units.

2.12.3 Trapping / Ducting

Ducting phenomenon is occurred in similar environment like super refraction but decrease of water vapour content and temperature inversion is of more imminent. The

EM wave propagation is observed with a curvature radius of smaller or equal to radius of earth [2,15].

Under this condition, the electromagnetic rays are stuck in a atmospheric layer which act like a waveguide. The phenomenon can be defined as an atmospheric layer having refractivity N gradient of less than -157 N units or negative M refractivity gradient.

This phenomenon of ducting is the most significant refraction mechanism which can alter the maximum ranges of electromagnetic wave propagation beyond horizon. The operating frequencies between 1- 20 GHz are mostly affected by this ducting mechanism [17].

Three types of ducts can be formed in marine environmental conditions: Evaporation ducts, Elevated ducts and surface ducts. The details of types are further elaborated in next section.

2.13 Evaporation Ducts

Evaporation ducts are very common and persistent in oceanic environment and other large water bodies [2,13] . The value of Relative humidity just above the sea surface is found to be approximately 100%. The high humidity of near sea surface rapidly decreases with height till it reaches to ambient values. This will result in creating a trapping duct just above the sea surface due to rapid decrease in refractive index. Temperature inversion is not required for development of Evaporation duct. Height of Evaporation duct varies a meter or two in the areas of northern latitudes in winter season to 40 meters near equator in summers. Average height of the duct is approximately 13 meters above the sea surface. Average height of evaporation duct in Arabian sea is 14.8 meters. The strength of evaporation duct is weaker than surface based duct as the ability to trap the energy is relaying on the wavelength of used frequency spectrum. Frequencies above 3000 MHz can be affected by evaporation ducts. The more affected frequency spectrum by evaporation duct is 18 GHz.

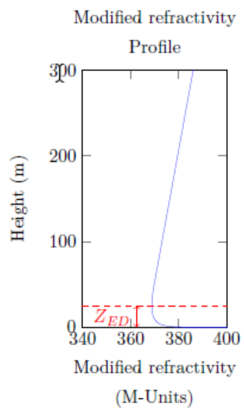

Figure 10 : Evaporation Duct

2.14 Surface Ducts

Surface ducts are not formed very commonly like evaporation ducts in oceanic environment. They are mostly developed in coastal areas, seas surrounded by dry and warm areas like Gulf [14]. The availability of surface ducts in Indian ocean is found to be 13.4% with average duct height of 110 meters. These ducts are not frequency sensitive as it can trap the lower frequency spectrum of 20 MHz. These ducts will increase the communication ranges extremely beyond the horizon[16]. It is observed due to temperature inversion [18]. Under the conditions more rapid decrease in refractivity is observed due to temperature inversion. Vertical airflow is suppressed because of temperature inversion resulting strong layer to trap electromagnetic energy near earth surface [10].

The development of surface ducts is observed due to transmission of heat due to interaction of low- and high-pressure system of land area warm and dry air and comparatively cold water. Strong trapping layer is formed due to rapid decrease of water vapour content and temperature inversion because of the interaction between warm air with moist and cold air above sea surface [14].

2.14.1 Standard Surface Ducts

Standard surface duct is formed adjacent to the surface of sea due to decrease in refractivity profile with respect to height starring just above the sea surface. Normally, standard surface ducts are of 200 m height.

2.14.2 Surface Based Ducts

Surface-based duct is formed hundreds meters above the sea surface. Modified refractivity profile increases with certain height and then surface-based duct is formed as an elevated trapping layer. Generally surface based ducts have an average height of 300 meters but can go upto 1000 meters under some conditions [15].

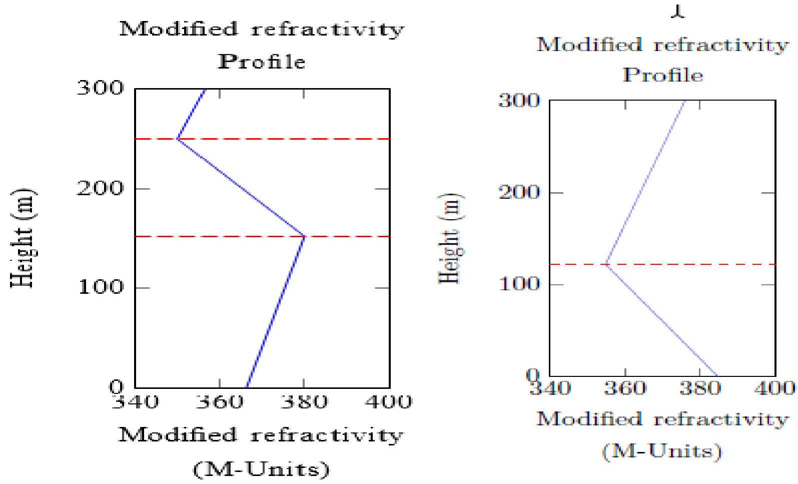

Figure 11 : Surface & Surface based Ducts

2.15 Elevated Ducts

The trapping layer of elevated duct is also as the name predicts, like surface based duct. Modified refractivity profile value at the top of the layer must be greater than the values of modified refractivity at some height lower than the duct layer [2]. The thickness of the duct extends from top to bottom till Modified refractivity value of top of the layer is equal to the modified refractivity values of the bottom of the layer. Elevated duct thickness is measured from zero to hundreds of meters with altitude of upto 6 Kms but mostly found within 3 Kms. Elevated ducts are not sensitive to frequencies and signals of above 100 MHz of frequency can be trapped in elevated duct layer. Similar phenomenon like surface -based duct creates Elevated duct. They are formed due to dropping of high pressure systems and moist and cooler air above the sea surface.

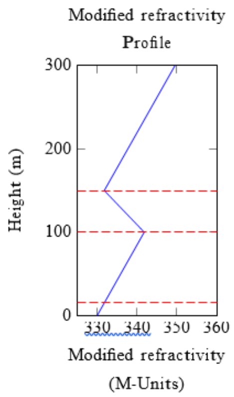

Figure 12 : Evaporation Duct

2.16 Environmental Conditions Modeling

Modeling of atmospheric and environmental conditions pertaining to the electromagnetic wave propagation is challenging and difficult task. This requires composite dataset of environmental conditions for proposed geographical area of study and then transform it to system modeling. Java NetBeans & MATLAB are used to model the empirical equations & conditions and for computing propagation factor and path loss over spatio temporal domain. MySQL is also used as database for datasets and storage of results.

2.17 Propagation and Path Loss Modeling

After setting up the environmental modeling, there is a requirement to develop model for computing propagation factor and path loss in spatio temporal grid dataset. 'Parabolic Equation Modeling' approach is used for computing the propagation losses. Split Step Fourier Transform is modeled to compute the results.

Chapter 3 **Literature Review**

This chapter explains how related is our work with that of others Moreover, it also contributes to the understanding and development of the area of research

Table 3 summarizes different research clusters of the literature reviewed during the course of the literature reviewed.

Table 3: Literature Review

Author (s)	Category	Paper Description	Key Features
[19]	**Electromagnetic Wave Propagation**	The chapters of the book describes the theory of electromagnetism also known Mexwell theory. Further it describes the formation of electromagnetic waves and their propagation phenomenon.	The Maxwell theory verifies that the magnetic and electric field variation will affect the presence of other and will constitute a field called electromagnetic filed. The electromagnetic wave travels in vaccum with the speed to light, however, the propagation is affected by atmospheric conditions. The EM waves contains energy which helps them to travel over a long terrain. The impact in propagation of EM wave due to various dynamic environmental conditions were also discussed covering reflection, diffraction, interference and diffusion.

Author (s)	Category	Paper Description	Key Features
[20]	**Electromagnetic Wave Propagation**	The chapters of the book describes the propagation of electromagnetic waves with scattering of EM energy from random rough surfaces focusing Kirchhoff-tangent plane approximation.	The author describes classical method for estimating the EM energy scattered by random rough surface using Kirchhoff and small perturbation method. Further, some specific cases of scattering of electromagnetic energy from sea surface is also discussed and presented the theoretical asymptotic models for validity using comparison with numerical methods and excremental data. Finally, the expressions of random rough surface is derived using statistical calculation and assuming ergodic random process.
[21]	Atmospheric effects	The paper present the survey article based on different propagation models used to analyze propagation factors in maritime environment. The analysis of antenna characteristics, mobility and multipath propagation is considered for analysis of path loss at receiver end.	The reliable communication link over sea environment is quit difficult to develop due to dynamic nature of the sea. This study will compare and analyze the simulation results of different communication links over the oceanic environment as no single universal model to predict path loss in maritime

Author (s)	Category	Paper Description	Key Features
			communication is available. Different models considers different significant factors affecting EM wave communication in maritime domain. This paper provides following: • Identification of factors of maritime environment causing path loss •Categorization of propagation loss factors • Critical analysis of the study methodology and path loss factors adopted by the existing works
[22]	Refractivity Profile	This paper presented the impact of change in refractivity profile in propagation of electromagnetic waves using Very High Frequency band. Different atmospheric conditions have variations in refractivity which has severe impact on communication links.	Refractivity profiles under different atmospheric state like fog, rain, cloud is discussed with the impact on signal strength on VHF frequency band. An experimental based setup of a communication link of 50 Km over a sea surface was conducted to analyze the variations in value recommended by ITU-R and standard profiles.

Author (s)	Category	Paper Description	Key Features
			The setup has gathered reading for over a year at 240MHz link with different observed refractivity profiles and its impact on propagation losses. During the study it was found that the evaporation duct is available upto 10 m height.
[1]	Atmospheric Effects	This paper discussed the methods for determination of Evaporation Duct height using standard meteorological data. Four models are analyzed to evaluate the duct height using atmospheric pressure, water vapour content and air temperature. The results are then verified using measured duct height at Atlantic and equatorial zone of Indian ocean.	This paper presents most common techniques and theories for evaluating vertical refractivity profile using atmospheric data. The refractivity profiles are used to formulate evaporation duct heights. The experimental results are then compared with calculated figures. Four models were presented in this paper namely Monin–Oboukhov Similarity Theory, Liu–Katsaros–Businger Model, RSHMU Model and COARE Model. It has been found that under unstable conditions, the height of evaporation duct is 5-20m using Monin-Oboukhov theory with error of 2.5 meters. The error will be

Author (s)	Category	Paper Description	Key Features
			about 3.5 meter in case of stable condition. The LKB and COARE have small rms deviation whereas RSHMU and ECMWF have higher deviation. All the models provides over estimation of smaller duct heights and under estimation of larger duct heights.
[24]	Atmospheric Effects	The study is based on impact of propagation losses due to variable troposphere parameters on UHF communication signals. In this paper experimental, theoretical and statistical approaches in the study.	The main focus of the study is based on impact of propagation loss in UHF frequency band due to liquid water density of clouds, relative humidity and air temperature The results show that air temperature, relative humidity and Liquid Water Density Clouds have significant influence on UHF signal propagation. Experimental setup was demonstrated using UHF antenna of 900-950 MHZ. The setup continuously monitor the received signal strengths alongwith the variations in atmospheric conditions.

Author (s)	Category	Paper Description	Key Features
[25]	Frequency Variations	This paper presented the effects of oxygen content and water vapour content on GHz frequency band. The oxygen content and water vapours are strong absorbtant of radio signal especially for the frequency in 10s of GHz.	The study defines the absorption and attenuation constant α for oxygen and water vapour content as defined by ITU-R recommendations. Attenuation by rain can computed by using empirical formula for attenuation constant for rain which is defined as $Ar = kR^{\alpha}$ where R is the rain rate and α is the constant of frequency and temperature. The results presented in paper classifies the attenuation by rain with respect to change in frequency as rain attenuation is a function of frequency, rain rate and polarization.
[26]	Frequency Variations	The paper discussed VHF based digital communication channels used in aeronautical communication. It discussed the affect of tropospheric refraction over propagation channel over VHF communication band used for aeronautical communication. The impact of refraction may lead to over	Spatial and temporal variation in troposphere is observed in medium scale in between 100m to 100 KM ground field. Scattering and other variation in radio waves are observed in small scale of less than 100 m due to turbulent mixing. The ducting effect is assumed to be efficient by combination

Author (s)	Category	Paper Description	Key Features
		the horizon communication due to ducting and provide better signal level Ducting conditions are discussed in this paper which may lead to design the VHF communication links in future.	of conditions with respect to gradient of N and minimum height of duct. The ducting condition over VHF frequency is also shown in tabular form in the paper. It shows that with ducting height of 200m and gradient of N is 400 may produce co channel interference in VHF band. Higher power level of interference is obtained closer to the ground and is decreasing with hight but at very low pace. It identifies that elevated altitude planes approaching also experienced the interference. This phenomenon is less imminent in VHF band as compared to higher frequencies.
[2]	Atmospheric Effects	The study presented in this paper is based on excremental setup to conduct the analysis of UHF radio signal over water channel at Nigeria. 24 hrs readings were conducted alogwith meteorological parameters like, air temperature,	The experimental study was conducted at cross river state broadcasting co-operation (CRBC) at 519 MHz UHF radio band. Atmospheric temperature, pressure, humidity and wind speed and direction with signal strength were measured with half hrs

Author (s)	Category	Paper Description	Key Features
		pressure, water vapour content ,wind speed etc. This study is focused on the impact of humidity in signal strength	interval over a period of 24 Hrs. This study is focused on the impact of humidity in signal strength. The results show that signal strength is inversely proportional to the relative humidity. Other weather parameters: atmospheric temperature and pressure were observed to be constant in this study.
[3]	Parabolic Equation Modeling	The study is conducted to model the fractal sea surface and simulate one dimensional rough sea surface model for analysis of behavior of electromagnetic wave propagation using Parabolic Equation Method. Finite Differential algorithm is used to compute the results and compare the numerical results with other models like Miller-Brown and Elfouhaily spectrum inversion model. The results show that FD model caters more the effects of sea surface structure compared to other models.	This paper concern the sea surface, its structure and influence of wind speed on the roughness and structure of sea surface and analyze the influence of these parameters over EM wave propagation. The influence increases with higher frequency and wind speed. Finite differential model of parabolic equation modeling is used and compare with other models. It indicates that proposed models has detailed information of sea surface to cater in the model which lead to more closer to actual sea states. This model can also be used in combination with other

Author (s)	Category	Paper Description	Key Features
			models for simulation of different sea conditions, thus producing near to real results.
[4]	Refractivity Profile	The paper presented the study and analysis of vertical refractivity profile and its impact on electromagnetic wave propagation and performance of communication links. Experimental setup was formulated over a specific area to analyse the impact of refractivity profile on EM wave propagation.	This paper addressed impact of vertical variation of refractivity in troposphere. Variations in vertical refractivity profiles depends upon atmospheric parameters – Temperature, humidity and atmospheric pressure. This will produce huge impact on communication links performance in tropospheric environment. The results show that different tropospheric duct is formed resulting better range and higher received signals due to duct formation.
[5]	Atmospheric Effects	This paper discussed two types of attenuation factors in troposphere region; Atmospheric Gaseous absorption; and Rain attenuation. Both of the factor is more imminent in microwave frequency spectrum of range 3- 30 GHz. The paper discussed the empirical formulas for	The paper is addressing transmission power loss in microwave frequency ranges due to variation in transmission frequency. Frequency and transmission loss is directly proportional as higher frequency is more prone to atmospheric dense environmental conditions. The impact of dense

Author (s)	Category	Paper Description	Key Features
		getting attenuation constant for gasses and water vapour content.	atmospheric absorption is more immanent within 3- 30 GHz spectrum but not negligible in 1.4 – 2.4 GHz.
[29]	EM wave Propagation	This paper discussed the EM wave propagation over irregular terrain. To model the electromagnetic wave propagation over irregular terrain, Parabolic Equation modeling using Digital Evolution Model based approached is used. Further, DEM-based modeling approach is compared with the shift map for validating the accuracy.	To model the electromagnetic wave propagation over irregular terrain, Digital Evaluation model is introduced. Split Step fourier transform is another analytical method used to model complex atmospheric environment. DEM is a 3D cartesian coordinate method. This paper analyzed and evaluated the effects of DEM resolution on prediction of propagation.
[30]	Frequency Variations	The paper discussed the impact of evaporation duct based on VHF and UHF communication signals. The effect of evaporation duct on VHF signals are more prominent as compared to UHF communication signals. Moreover, the effect of variations in refractivity is not severe for the long path at VHF.	The study is based on practical experimentation to investigate the effect of variations in refractivity for oversea UHF (2015MHz) and VHF (240MHz) propagation at different heights and time. The study is Focus on region where evaporation duct is more dominant. The analysis shows that trapping of a signal in a duct depends not only on the frequency of the

Author (s)	Category	Paper Description	Key Features
			propagating wave but also on the incidence angle of wave.
[31]	Parabolic Equation	Study is based on live communication link over a specific frequency band to examine the sensitivity of radar i-e 3- 15 GHz in range. Some vital readings were not available due to malfunctioning/ failure of link	The paper examines the sensitivity of Radar (3- 15 GHz) at Vertical & Horizontal Polarization. A Global sensitivity Analysis method is used to do modelling of PE for propagation. The results show that the impact of frequency is more significant than polarization. Furthermore, thickness of Atmospheric mixed layer is more significant in result
[5]	Atmospheric Effects	Experimental setup was made under NEP-6 program near Panama City Limited dataset of sensor readings and RF components are available working at specific frequency band	This thesis is focusing the analysis of propagation losses of near-earth surface. Main focus on a novel technique takes advantage of tidal sea level variation to continuously vary antenna height above the surface. It concludes that strong dependence of propagation loss on antenna height

3.1 Electromagnetic Wave Propagation

The electromagnetic wave propagation is defined in Maxwell theory which verifies that the magnetic and electric field variation will affect the presence of another field and will constitute a field called electromagnetic filed. The electromagnetic wave travels in vaccum with the speed to light, however, the propagation is affected by atmospheric conditions. The EM waves contains energy which helps them to travel over a long terrain.

The impact in propagation of EM wave due to various dynamic environmental conditions were also discussed covering reflection, diffraction, interference and diffusion. Classical method for estimating the EM energy scattered by random rough surface using Kirchhoff and small perturbation method.

Further, some specific cases of scattering of electromagnetic energy from sea surface is also discussed and presented the theoretical asymptotic models for validity using comparison with numerical methods and excremental data. Finally, the expressions of random rough surface is derived using statistical calculation and assuming ergodic random process.

3.2 Tropospheric / Atmospheric Impacts on Propagation

The reliable communication link over sea environment is quit difficult to develop due to dynamic nature of the sea. The studies compare and analyze the simulation results generated by different models and some experimental setups of different communication links over the oceanic environment as no single universal model to predict path loss in maritime communication is available. Different models considers different significant factors affecting EM wave communication in maritime domain.

- Identification of factors of maritime environment causing path loss
- Categorization of propagation loss factors
- Critical analysis of the study methodology and path loss factors adopted by the existing works

In tropospheric environment, different types of ducting phenomena is also present which will enhance the signal strength and will produce beyond horizon communication. Four different types of models are analyzed in an study to evaluate the duct height using atmospheric pressure, water vapour content and air temperature.

The results are then verified using measured duct height at Atlantic and equatorial zone of Indian ocean.

Some studies are focusing the analysis of propagation losses of near-earth surface. Main focus on a novel technique takes advantage of tidal sea level variation to continuously vary antenna height above the surface. To examine the variations, eexperimental setup was made under NEP-6 program near Panama City with limited dataset of sensor readings and RF components available over at specific frequency band. The result concludes that strong dependence of propagation loss on antenna height.

The main impact of tropospheric variations on EM wave propagation is highly dependent on change in refractive index. Since change in refractive index is quite small due to atmospheric conditions, therefore, refractivity N is being used instead of refractive index in most of the studies. The section further elaborates the impact in detail.

3.2.1 **Refractivity Profile**

Analysis of vertical refractivity profile and its impact on electromagnetic wave propagation and performance of communication links are discussed. Experimental setup was formulated over a specific area to analyse the impact of refractivity profile on EM wave propagation. The impact of vertical variation of refractivity in troposphere depends upon atmospheric parameters – Temperature, humidity and atmospheric pressure. This will produce huge impact on communication links performance in tropospheric environment. The results show that different tropospheric duct is formed resulting better range and higher received signals due to duct formation.

3.2.2 **Frequency Variations**

It has been found that the transmission power loss in microwave frequency ranges due to variation in transmission frequency. Frequency and transmission loss is directly proportional as higher frequency is more prone to atmospheric dense environmental conditions. The impact of dense atmospheric absorption is more immanent within 3-30 GHz spectrum but not negligible in 1.4 – 2.4 GHz. Water vapour content in environment paly important role in attenuating the signal strength at higher frequencies. It has been observed that communication links utilizing higher frequency spectrum are more prone to rain and foggy conditions where water vapour content in air are dense compared to low frequency communication links.

3.3 Parabolic Equation Modeling

Parabolic equation modeling is the most effective way to model propagation loss and path loss in different environmental conditions. Different models were formulated based on different conditions like irregular terrain, fractal sea surface smooth conducting surface etc. Study is conducted to model the fractal sea surface and simulate one dimensional rough sea surface model for analysis of behavior of electromagnetic wave propagation using Parabolic Equation Method. Different approaches of Parabolic equation methods are used to simulate different condition modeling and computing path losses. Split – Step Fourier transform was firstly used in underwater acoustic wave analysis. Mixed fourier transform and descrete mixed fourier transform method were also proposed. Three most commonly used Parabolic Equation algorithms used are; Split Step Fourier Transform (SSFT),finite Element Method (FEM) and finite differential method (FDM). FDM and FEM are numerical method while SSFT is analytical way to solve the problem. For large scale, low elevation and long distance tropospheric propagation, SSFT is suited more over FDM.

Chapter 4 **Methodology**

In this chapter, we propose an Modeling and Simulation approach in developing the proposed framework using real archived dataset and generate processed dataset for further analysis

4.1 Modeling and Simulation

Performance analysis of various communication systems in different environmental conditions is a very challenging task. Synthetic environmental modeling using computer simulation is the solution for analyzing various sensors in dynamic environment. The dynamics of simulation and modeling will help you to understand the performance analysis of sensors regardless of physical testing at location which may not be conducted under several geographical locations at different time and space. In contrary to simulation, real experimentation will require following pre requisites before conducting the tests.

- Under which environmental conditions test is to be conducted
- How to conduct the experiments in limited budget and time
- How to specify the conditions etc

To obtain realistic results from the model, the inclusion of randomness is necessary for realistic communication model. Stochastic modeling and simulation will provide realistic generation of environmental conditions for modeling propagation path and losses. A good understanding of physical and statistical behavior of EM wave propagation is essentially required for development of good realistic model. Furthermore, input data modeling is also very crucial task to provide realistic environmental condition and developing realistic results.

4.2 Input Data Modeling

For development of environmental conditions at different geographical location and time, following environmental data duly validated by international bodies is required:

- Temperature
- Relative Humidity
- Pressure w.r.t Height

The archived data set of year 2018 for area under the study is obtained from Copernicus Climate Data Store [33] has been gathered with the temporal coverage of **01 day** and spatial coverage of **01 deg lat/long**. The dataset is available is NETCDF format widely used represent weather model data. The data is provided by "ECMWF - European Centre for Medium-Range Weather Forecasts"[33]. Since the dataset is in NETCDF format which is not readable by our framework program, the same needs to be rendered and transformed into MySQL database. This task has been done using NETCDF to Excel plugin and converting it into desired data structure by programing macros. MySQL database server is used to handle input and output data. The database schema has been prepared by which main simulation model gets input parameters of desired location at designated time and main program compute the output results accordingly and save it into database. Figure 13 shows the schema of database.

id	time	lat	lng	temp_h1	temp_h2	temp_h3	rh_h1	rh_h2	rh_h3
1	1	12.000000	45.000000	272.199982	267.759979	263.309998	86.519997	86.519997	86.519997
2	1	12.000000	46.000000	272.019989	267.600006	263.179993	86.970001	86.970001	86.970001
3	1	12.000000	47.000000	271.820007	267.419983	263.019989	87.939995	87.939995	87.939995
4	1	12.000000	48.000000	271.989990	267.559998	263.139984	87.080002	87.080002	87.080002
5	1	12.000000	49.000000	272.009979	267.579987	263.160004	85.759995	85.759995	85.759995
6	1	12.000000	50.000000	271.489990	267.190002	262.899994	82.820000	82.820000	82.820000
7	1	12.000000	51.000000	270.869995	266.750000	262.619995	80.709999	80.709999	80.709999
8	1	12.000000	52.000000	270.820007	266.779999	262.729980	79.309998	79.309998	79.309998
9	1	12.000000	53.000000	270.809998	266.820007	262.820007	79.769997	79.769997	79.769997
10	1	12.000000	54.000000	270.790009	266.839996	262.889984	78.790001	78.790001	78.790001
11	1	12.000000	55.000000	270.669983	266.750000	262.829987	78.320000	78.320000	78.320000
12	1	12.000000	56.000000	270.500000	266.600006	262.709991	78.080002	78.080002	78.080002
13	1	12.000000	57.000000	270.100006	266.259979	262.410004	78.470001	78.470001	78.470001
14	1	12.000000	58.000000	269.869995	266.049988	262.239990	77.849998	77.849998	77.849998
15	1	12.000000	59.000000	269.509979	265.759979	262.010010	77.900002	77.900002	77.900002
16	1	12.000000	60.000000	269.229980	265.540009	261.859985	77.040001	77.040001	77.040001
17	1	12.000000	61.000000	268.970001	265.339996	261.720001	76.430000	76.430000	76.430000
18	1	12.000000	62.000000	268.889984	265.309998	261.720001	74.930000	74.930000	74.930000
19	1	12.000000	63.000000	268.570007	265.059998	261.540009	75.189995	75.189995	75.189995
20	1	12.000000	64.000000	268.139984	264.729980	261.320007	75.699997	75.699997	75.699997
21	1	12.000000	65.000000	267.589996	264.299988	261.010010	76.930000	76.930000	76.930000

Figure 13 : Database Schema

4.3 **Proposed Framework**

The framework which is proposed in this thesis is based on stochastic and mathematical modeling & simulation of maritime environmental conditions which has the major impact on Electromagnetic wave propagation and path losses in V/UHF communication systems and sensors. The framework is distributed into three main tasks, which are (i) Environmental modeling, (ii) Tropospheric ducting conditions modeling, (iii) Path loss and propagation modeling using Parabolic Equation modeling framework.

While considering the environmental parameters, earth's effect, inhomogeneous terrain and other important parameter discussed in earlier chapters also contribute the propagation of EM waves. To make the model simple and effective, it is assumed that all the experiments are to be done with smooth sea surface and assumed as conducting surface.

4.3.1 Environmental Modeling

Synthetic generation of environment using computer simulation is the desired solution for performance analysis of communication systems and sensors operating in V/UHF communication frequency spectrum. To scrutinized, the proposed environmental model is expected to produce realistic profiles of modified refractivity. As discussed earlier that refractivity and modified refractivity profile plays a key role in impact of environmental effects on electromagnetic radio wave propagation and path loss.

4.3.2 Modeling Refractivity Profile

Mathematical modeling of refractivity in troposphere with reliance of atmospheric parameters on pressure, temperature and relative humidity is taken into account. With the help of these parameters, necessary inputs parameters essentially required for defining modified refractivity profile are derived through these input parameters.

In tropospheric environmental conditions which are inhomogeneous in nature, the electromgnetic rays do not travel in a straight line but to refract. Therefore, understanding the values and variation of refractive index in tropospheric conditions will help to develop synthetic environmental model and simulations. Since the variation in refractive index is very minimal therefore refractivity N is used instead of refractive index as refractivity is an scaled version of refractive index n which is defined as [34]

$$N = (n-1) \times 10^{-6} = \frac{77.6\,p}{T} - 6\frac{e}{T} + 3.75\,X\,10^{5}\,\frac{e}{T^2} \qquad \text{5-1}$$

Where:

T is the Temperature recorded in deg Kelvin

P is the atmospheric pressure in mbar

e is partial pressure of water in mbar

Partial pressure of water is defined as the product of saturation vapour pressure and relative humidity [28]

$$e = es \; X \; Rh \qquad 5\text{-}2$$

Satutation vapour pressure can be computed using Clausis- Clapeyron equation [28]

$$es = 6.11 \exp[17.26 \frac{(T-273.16)}{(T-35.87)}] \qquad 5\text{-}3$$

By using equation 5-3 & 5-2, Refractivity profile N is be computed using equation 5-1 by providing input data of temperature, atmospheric pressure and relative humidity. The data set is provided in temporal and spatial domain. Screen shots of java code for computing above equations are placed as Appendix I

4.3.3 Modified Refractivity

Modified refractivity M profile is also a scalar version of refractivity profile N by considering height into an account. M profile is used to determine the bending of EM rays relative to the curvature of earth. Modified refractivity is used to determine the availability of tropospheric duct in horizontal area. If the value of M gradient is negative, it is more likely the presence of duct. The electromagnetic energy is trapped in duct resulting better propagation ranges than expected in normal conditions. The modified refractivity M profile can be described as:

$$M = N + \frac{h}{Re} = N + \; 0.157h \qquad 5\text{-}4$$

Where:

N= Refractivity

Re= Radius of Earth =6.370 x 10^6 m

H= height above the surface of earth.

4.3.4 Determining Height above Earth Surface

The parameter of height is not available with input data set however, the same can be computed by using atmospheric pressure and temperature. Hypsometric formula is used to compute altitude height in meters by providing sea level pressure, atmospheric pressure at vertical profile and temperature [35].

$$h = \frac{\left(\left(\frac{po}{p}\right)^{\frac{1}{5.257}} - 1\right) X\, T}{0.0065}$$

The hypsometric formula is being used in main model to compute the height by providing vertical input profile of Temperature in kelvin and pressure in hpa.

4.3.5 Modeling Atmospheric Refractive Conditions

As discussed in chapter 3, refractivity plays an important role in electromagnetic wave propagation. Different conditions are also discussed in detail which affect the EM wave propagation. The conditions can be simulated with the help of refractivity gradient and M gradient. Electromagnetic wave energy propagation in the atmosphere is determined by vertical gradient of N in relation to the horizontal plane. If the value of N gradient (dN/dz) is positive the EM rays bends upward(sub refraction) whereas of the value becomes negative it bends towards earth curvature. The trapping conditions can be identified by using M profile in relation with height z above the surface. If the value of dM/dz= 0 the curve of rays is equal to the curvature of earth computationally it is done when N gradient is -157 units per KMs. In standard atmospheric conditions, value of M increases with height however, to identify the existence of duct profile, dM/dz must be negative[36].

Table 4 shows numerical comparison of M and N profiles with atmospheric conditions.

Table 4: Conditions of refraction

Conditions	**dN/dz(N- units/ Km)**	**dM/dz M- units/Km)**	**Distance**
Sub – refraction	0<dN/dz	157<dM/dz	Reduced
Normal	-79 < dN/dz <= 0	79 < dM/dz <= 157	Standard
Super- refraction	−157 < dN/dz<= −79	0 < dM/dz<= 79	Increased
Trapping	dN/dz <=-157	dM/dz <=0	Greatly Increased

The proposed model computes M and N profiles with vertical gradients of M and N over different heights and stores the results of horizontal grid also known as area under observation in structured database. MySQL sever is used. Furthermore, use cases with respect to above mentioned properties are compared to identify the trapping conditions.

Furthermore, the program also computes the ducting characteristic like duct top duct middle and duct bottom height profiles, local maxima and local minima of M, can be computed by switching the sign of dM/dz. The value of M same as the duct top and duct bottom. The same can be computed using simple geometry by drawing straight line between duct top and duct bottom. Height of duct bottom can be computed by following equation [37] .

$$Z* = Z2 - \frac{M2-M*}{M2-M1}(Z2-Z1) \qquad 5\text{-}5$$

4.3.6 Parabolic Equation Modeling

Parabolic equation (PE) modeling is widely used to find out the electromagnetic wave propagation in a inhomogeneous and complex atmospheric environments. The method was firstly proposed in 1946 by Leontovich and Fock[38] . Later, Split Step Fourier transform (SSFT) is defined by Hardin and Tappert [39] and used in underwater acoustic project.

Many variants of PE model have been developed till date; however, Split Step Fourier transform – SSPE-FT method is considered to be most efficient with respect to problem domain presented in this thesis. This algorithm is also widely implemented in several applications [40,41,42]. Parabolic Equation modeling considering earth curvature is obtained from Helmholtz equation [43] and is defined as:

$$\frac{\partial^2 u(x,z)}{\partial z^2} + 2jk\frac{\partial u(x,z)}{\partial x} + k^2\left(n^2 - 1 + \frac{2z}{R}\right)u(x,z) = 0 \qquad 5\text{-}6$$

Where;

k= 2π/λ (Free Space wave)

x= Range in horizontal distance

z= altitude / height

R= radius of earth (6.378×10^6 m)

It is assumed that variation in horizontal plane is quit slow and partial derivative $\partial u(x, z)/\partial x$ can be analyzed to partial variations. Therefore for extremely small range steps, equation 5-6 can be derived as

$$\frac{\partial^2 u(x,z)}{\partial z^2} + \left[\frac{2jk}{\delta x} + k^2\left(n^2 - 1 + \frac{2z}{R}\right)\right] u(x,z) = \frac{2jk}{\delta x}\, u(x - \delta x, z) \qquad 5\text{-}7$$

Assuming x= δ x then, $u(x - \delta x, z) = u(0, z)$ which is treated as the start field. One dimensional parabolic equation is defined in equation 5-7 which is being used in a recursive fashion. The equation can be used to directly solve individual range step using finite element modeling and results become the input to the equation of next step.

4.3.7 SSPE Tool For Propagation Analysis

In real world problem, the refractive index n can be a function of range and height. The method of split step is feasible as very small range step is used to solve the equation such that refractive index is assumed to be constant within range at horizontal axis. The mathematical solution of SSPE for m= 1, 2, 3, …M can be defined as [44]:

$$u(xo + m\Delta x, z) = \exp\left[i\frac{ko}{2}\,(n^2 - 1)\Delta x\right] F^{-1}\left\{\exp\left[-i\,\frac{kz^2\Delta x}{2ko}\right] F\,\{u(xo + (m-1)\Delta x, z)\}\right\} \qquad 5\text{-}8$$

The above equation 5-8 is used to compute u(x,z) along horizontal axis with split steps of Δx, provided initial field distribution u(xo,z). Transverse field profiles of Nz for vertical points and Nx for range can be stored in array list. After applying fourier transformation, Path loss and propagation factor in dBs can be computed using following equations respectively:

$$PL = -20\log|u| + 20\log(4\pi) + 10logx - 30\log\lambda \qquad 5\text{-}9$$

$$PF = -20\log|u| + 10logx - 20\log\lambda \qquad 5\text{-}10$$

MATLAB based implementation code developed [44,45] Ozlim Ozgun, Gokhan APAYDIN and Levent SEVG˙ et al which is the implementation of SSPE Fourier transform by taking inputs of environmental and ducting parameters from main program alongwith the standard antenna parameters. Furthermore, MATLAB code is also been integrated with main Java based code using Java APIs which helps to compute the results in an efficient manner and store it in structured database like mySQL.

4.3.8 Antenna and Other Parameters

Some constant and derived input parameters of antenna system and receiver system is used as static entity in this thesis as antenna patterns and other factors which may have impact on propagation is beyond the scope of this thesis. Standard values of these parameters are used in a program for computing propagation losses.

Chapter 5 **Simulation and Results**

In this chapter, we describe the functionality of our proposed framework. We simulate the developed model using dataset of several months of year 2018, to findout the availablity of different types of ducts and propagation and path losses in spatio temporal domain.

5.1 **Simulation**

The proposed model is implemented in Java Netbeans IDE 8.2 using mathworks, JDBC and Mystic JDBC libraries. In order to compute refractivity profile N, refractivity M profile, Gradients of M and N profiles, Saturated water pressure, dew point, height over a spatio temporal domain; several functions are developed and called on main program. The database is also developed in MySQL same is integrated with main program for input and output data analysis. Month wise input dataset is used to compute the output. For UI based analysis in temporal domain over GIS grid, Arc GIS 10.4 is used. The output of main program is exported to Arc Map 10.4 and displayed it on GIS grid along with temporal analysis. Parabolic Equation toolbox developed in MATLAB is also used for analysis of propagation and path losses by taking input of standard atmosphere and modified refractivity profiles of ducting scenarios to compare and analyze the path and propagation losses in standard environment and ducting environment.

The MATLAB program can be integrated with Java program using Mathworks library. This code is used to implement Split Step Fourier Transformation for finding out the propagation loss and path loss by taking input from output dataset computed by main program.

5.2 **Data Analysis**

The Output results for 30 days contains 16740 rows. Due to heavy data and high computational cost , data analysis for selected months of year 2018 are presented. It may also be noted that the framework has no limitation of data size, high resolution data can also be computed using same framework if required. For UI based analysis over GIS grid system, Arc GIS 10.4 platform is used.

5.2.1 Input Data Modeling

The desired area of interest for subject study is quit large covering Arabian sea, coastal areas and part of Indian ocean. To make the study conclusive, discrete values of Latitude and Longitude is considered. The area of interest is grid on a GIS map with 1 deg spatial resolution. The same depicts in Figure 18.

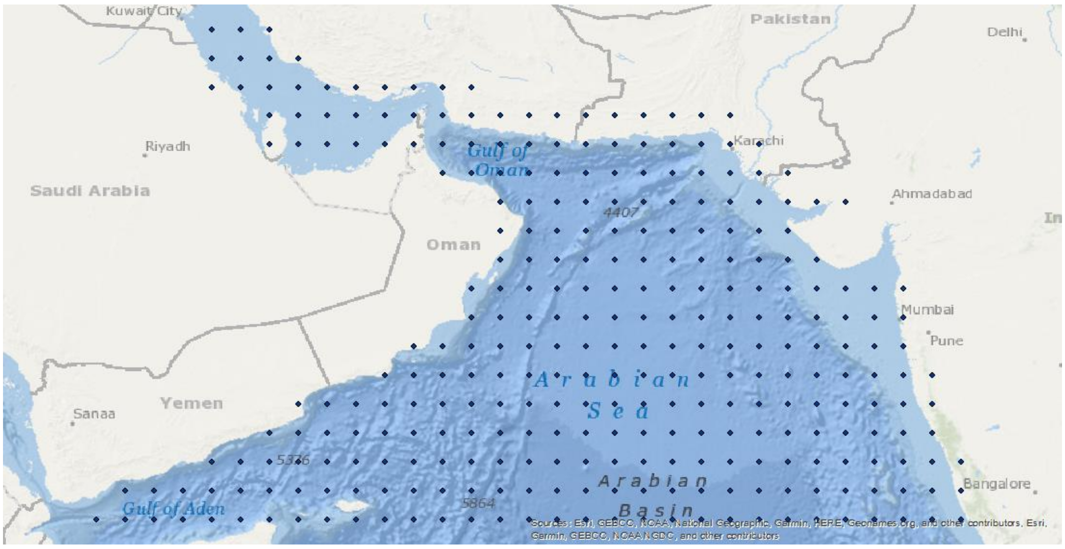

Figure 14 : GIS Grid of Area of Interest

Dataset is obtained for selected months in NETCDF format having following information and values:

- Temperature at different levels
- Relative Humidity at different levels
- Selection of different pressure levels for height analysis

The levels are defined by pressure values, in our study, data set with pressure level of 1000, 9750 and 950 Hpa is selected. This will give the approximate levels of 0 meters, 230 meters, and 460 meters. The average height of surface duct in Indian ocean is above 100 meters. The available input datasets are likely to produce more realistic results. Monthly Data set contains the value of all variables for each day at 1200 hrs. The program will select each row of input containing values of temperature and relative humidity at all three levels and compute the results over spatial grid at different time intervals.

5.2.2 **Output Data Analysis**

Results for the month of March, June, August, October and December is computed for analysis. It has been observed that input available data set consist of temporal resolution of 01 reading per day with spatial resolution of 01 deg latitude and longitude with readings of specific available altitudes. The computational results generated from the proposed framework also depicts this limitation. However, the framework will compute results from higher resolution input data which may depicts near to actual results. The atmosphere of areas of Arabian sea and coastal belts is classified in 04x transition seasons as per table 5:

Table 5: Arabian Sea Season Transition

SNO	SEASON	MONTHS
1.	Winter Monsoon or North-East	Dec – Mar
2.	Spring Transition	Apr- May
3.	Summer Monsoon or South-West	Jun- Sept
4.	Fall or Autumn Transition	Oct- Nov

Relative Humidity over the Indian ocean and Arabian Sea is found to be unfluctuating and shows a very little dissimilarity all the year. Relative humidity chart of Jan, March, Aug and June is compared in figure 21.

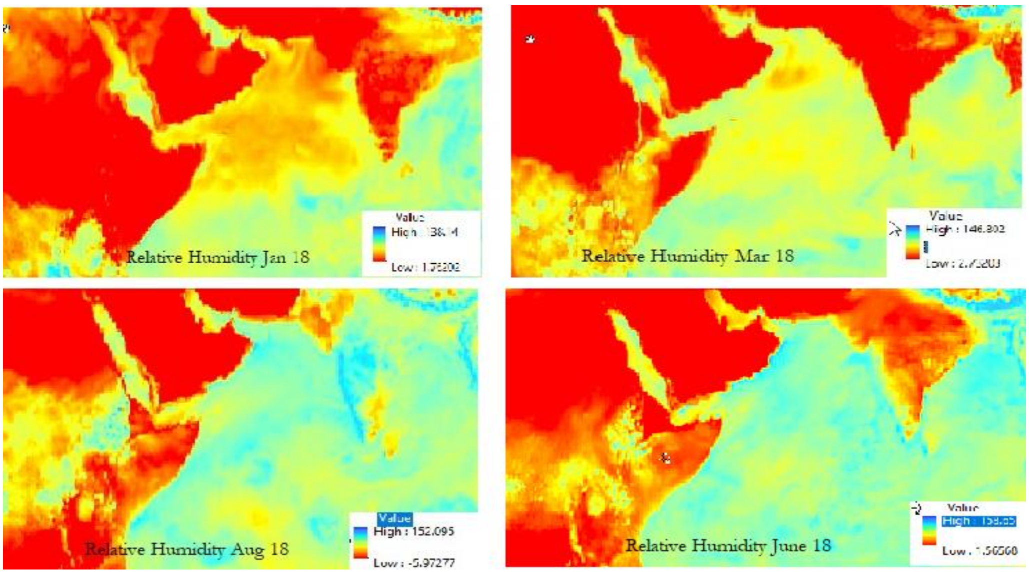

Figure 15: Relative Humidity 2018

The results clearly depict that the value of relative humidity in autumn and winter season is found to be low however, it is higher in monsoon and summers at sea region.

This also shows that presence of duct in monsoon and summers are more imminent than dray weather conditions.

Similarly, temperature analysis is also described. The analysis shows that temperature is evenly distributed with very mere change in overall temperature.

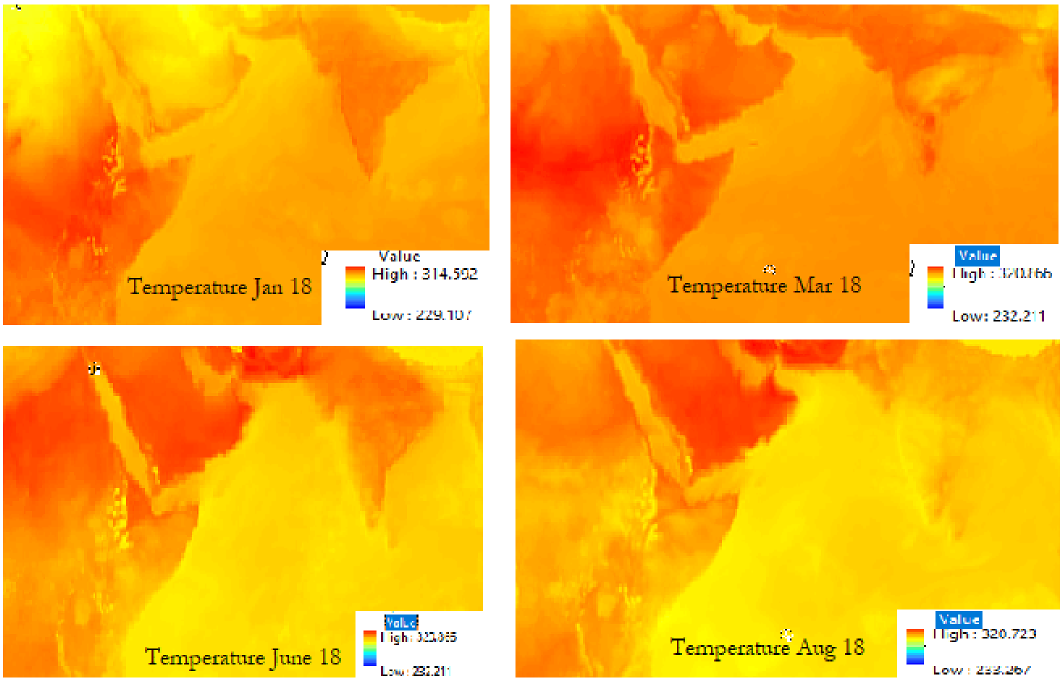

Figure 16: Temperature 2018

The results also show that the land areas have higher temperature in summers while oceans are colder, whereas land masses in winters are comparatively colder w.r.t ocean environment.

5.2.3 **Presence of Ducting Condition**

The modelled framework program predicts the presence of ducting conditions including the thickness and height of available duct. Moreover, the program also computes the M profiles at different heights which are used to predict propagation factor and path loss analysis using Parabolic Equation modelling. Different monthly dataset of daily resolution is simulated over the framework to compute the presence of ducting conditions alongwith other relevant outputs. Some of the scenarios are discussed here for analysis.

Results of monthly dataset for the month of March, August and December 18 is computed using proposed framework program. It is shown that ducting conditions are available for the month of March & August however, no duct presence is found for the month of December. The results also shows that avg duct height is around 108 meter above the sea surface which satisfies the result of V. K. Ivanov et al. [23].

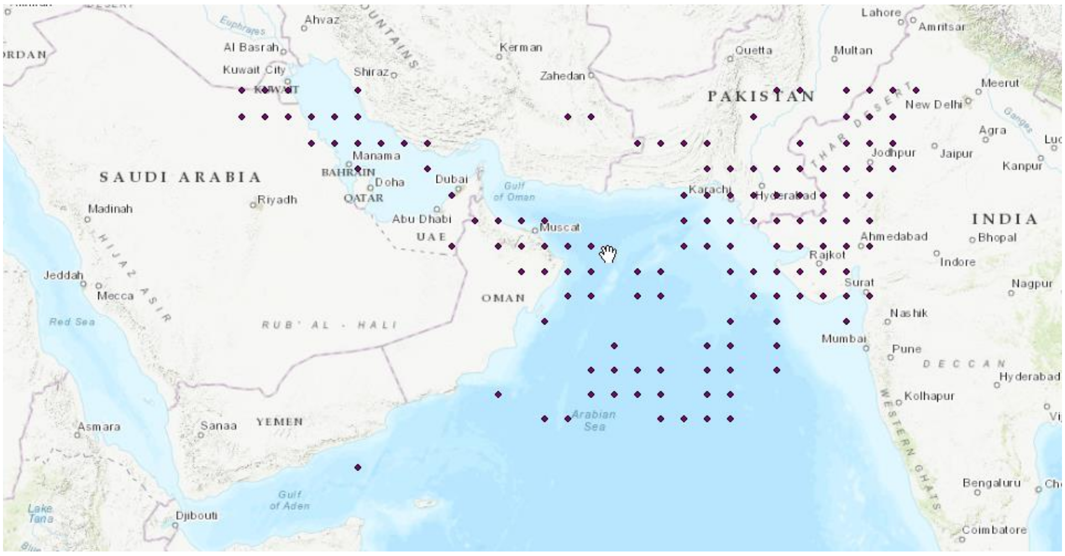

Figure 17: Availability of Duct in month of March 18

Furthermore, it is also evident that the duct is more densely populated in creek and coastal areas near Karachi and less populated at deep sea of Indian ocean. Presence of duct is also found in Gulf of Oman region in the month of march.

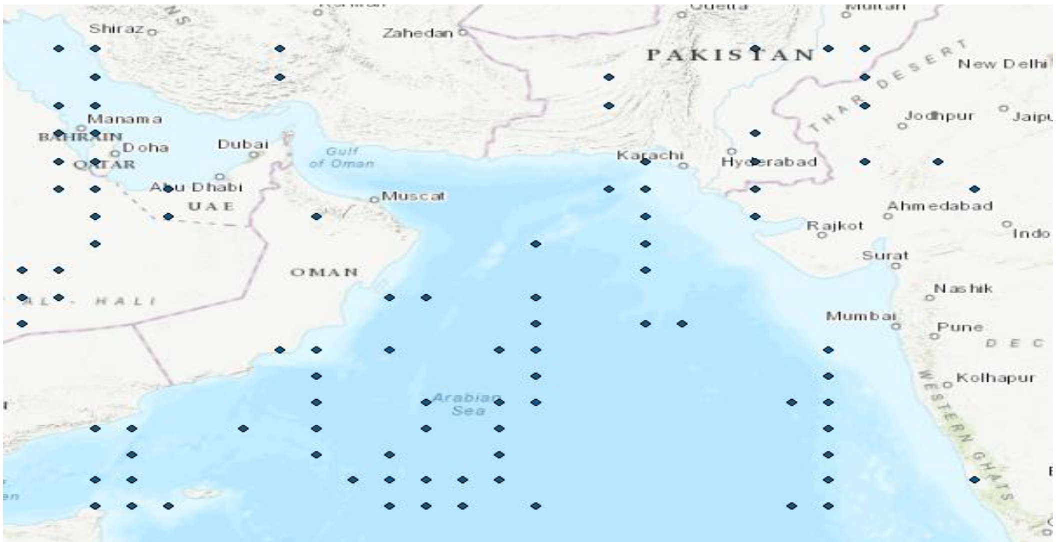

Figure 18: Availability of Duct in month of Aug18

By analyzing the statistics of august, it is found that ducting is dispersed all along the area, more specifically in the region of deep sea of Indian ocean.

Figure 19: Availability of Duct in month of Dec 18

No duct is found to be available for the month of December. This is due to the fact that these months dry with less humidity due to wind is blowing from land area towards sea and temperature variation on vertical profiles are also not prominent in the month of Dec, Jan and mid of Feb. The results also validated the facts that normally ducting conditions are not available during winter season in Arabian sea.

5.2.4 **Propagation factor and Path loss With Duct & Without Duct**

Ducting conditions has a great influence in radio wave propagation and path losses. The conditions have greatly increases the ranges and carries the signals beyond horizon. To ascertain the difference on impact of ducting conditions and standard atmospheric conditions, parabolic equation modeling toolbox is used. This uses split step fourier transform method for modeling wave propagation. Standard antenna parameters with antenna height of 30 meters is used along with frequency selection of 3 GHz. Figures 19 - 22 below shows the results of path losses and in standard atmospheric conditions and ducting conditions respectively.

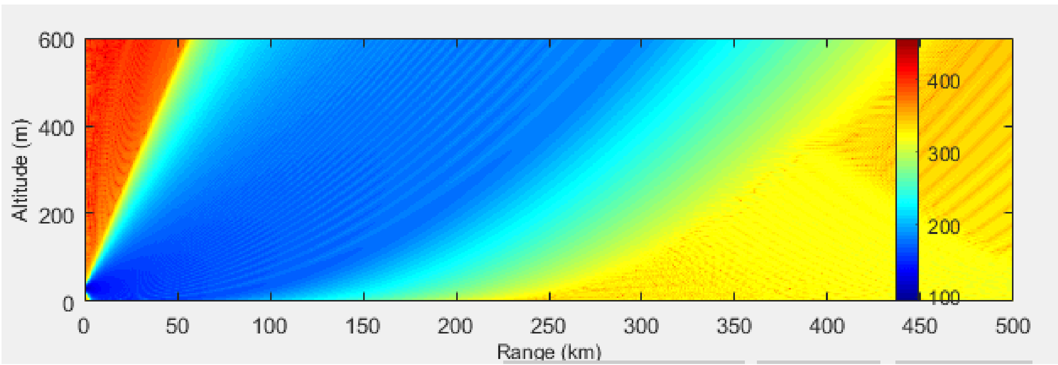

Figure 20 : Path loss with Standard Atmospheric Conditions

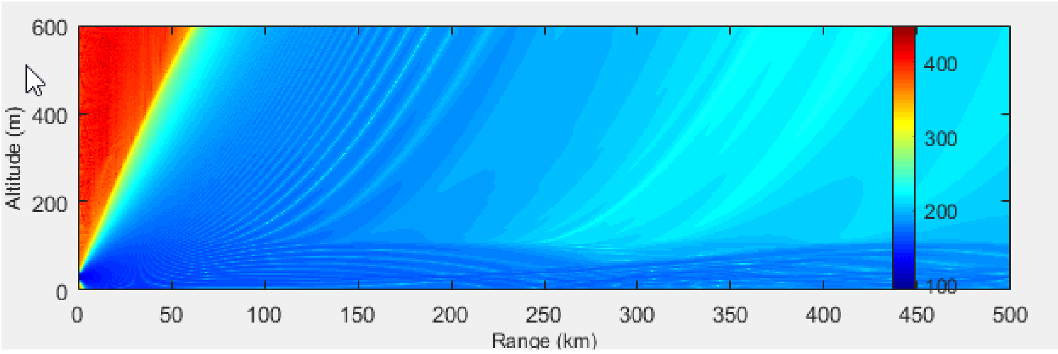

Figure 21 Path loss with Ducting Conditions

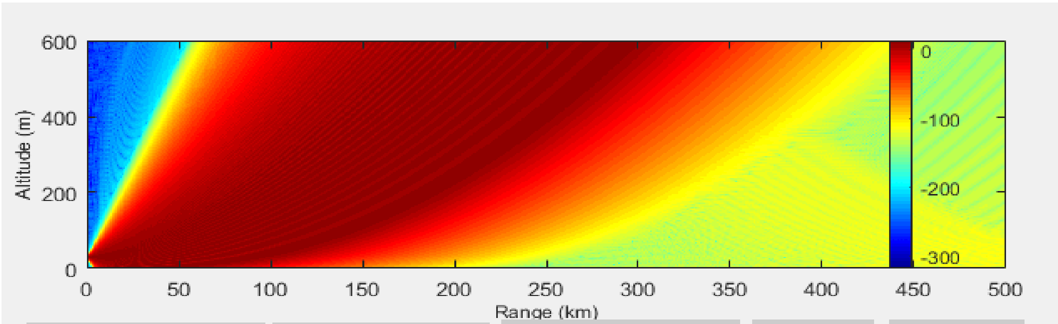

Figure 22: Propagation Factor with Standard Conditions

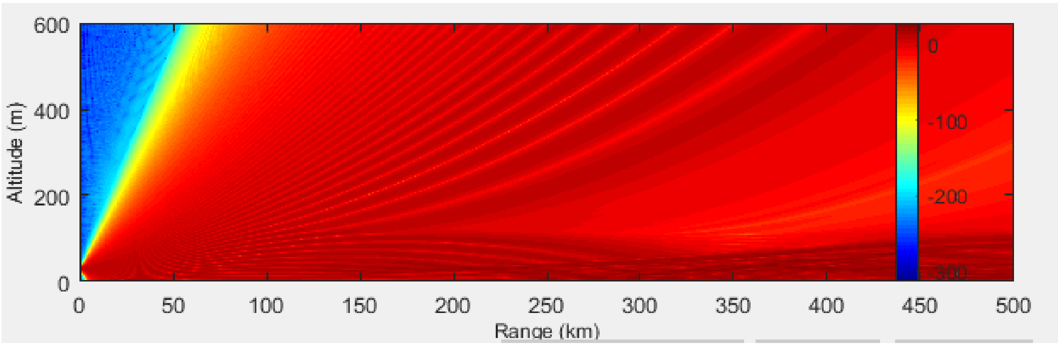

Figure 23: Propagation Factor with Surface Ducting Conditions

The results clearly depicts that in standard conditions for the month of march 2018, the radio waves are travelling towards the sky, thus reducing the range in between 100 - 125 Kms, whereas; in figure 20 shows the radio wave propagation in surface duct. The duct height was found to be 108 meters (Results of March 2018). It is found that the radio waves are trapped in a duct and bends toward earth curvature, thus increasing the range for around 500 Kms. Further analysis reveals that the path loss is found to be minimum at altitude of duct height. Path loss is the function of range and transmitting frequency. PL decrease with distance in standard conditions. Similarly, the variation in path loss is a function of transmitting frequency. PL is found to be increasing linearly with marginal increase in free space over a certain frequency. The free space path loss is derived from Friis transmission formula which is given below:

$$FSPL\ (dB) = 20\log10(d) + 20\ \log10(f) + 20\ log10\ \left(\frac{4\pi}{c}\right) \qquad 5\text{-}1$$

Where d= distance in meter

f= frequency in hertz

c= speed of light

Figure 24 shows the comparison between free space path loss and standard conditions over 3 GHz frequency. The graph shows that the attenuation is increased after 150 Kms to more than 350 db which depicts no communication could be possible after certain threshold limit.

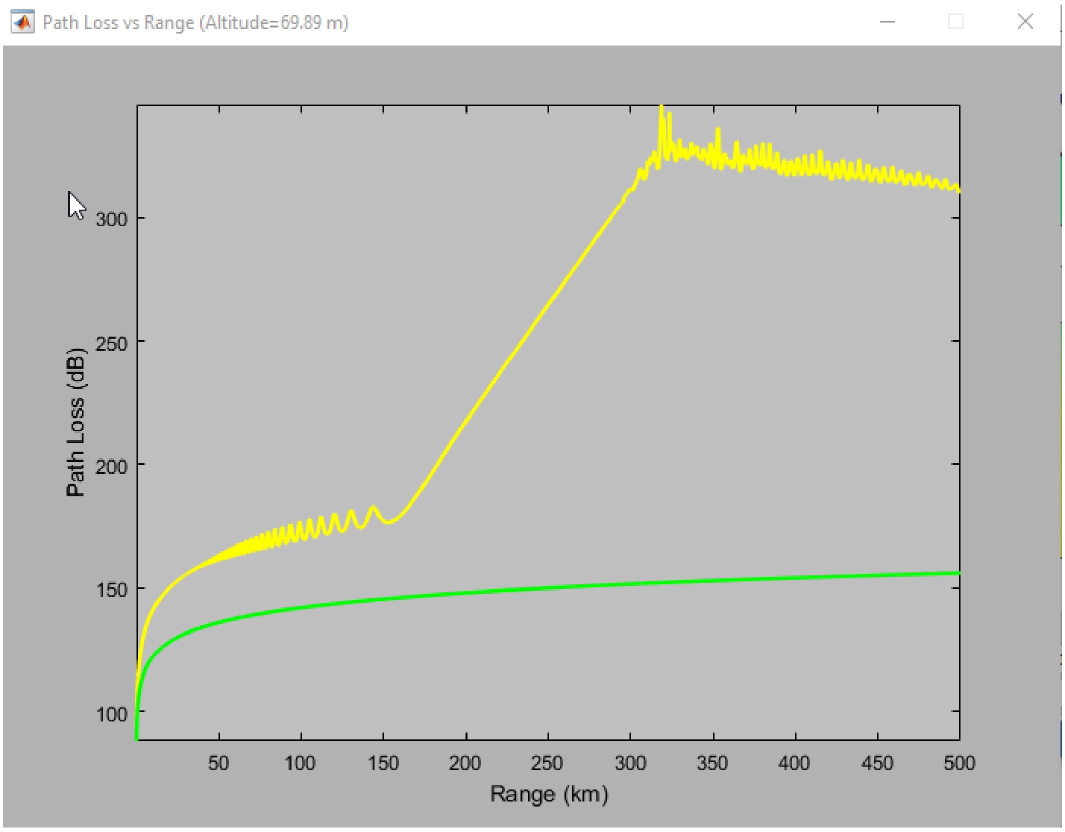

Figure 24 : Standard Condition Path Loss & FSPL Vs Range

Whereas, path loss in ducting / trapping conditions gradually increases and found to be within communication limits as shown in figure 25.

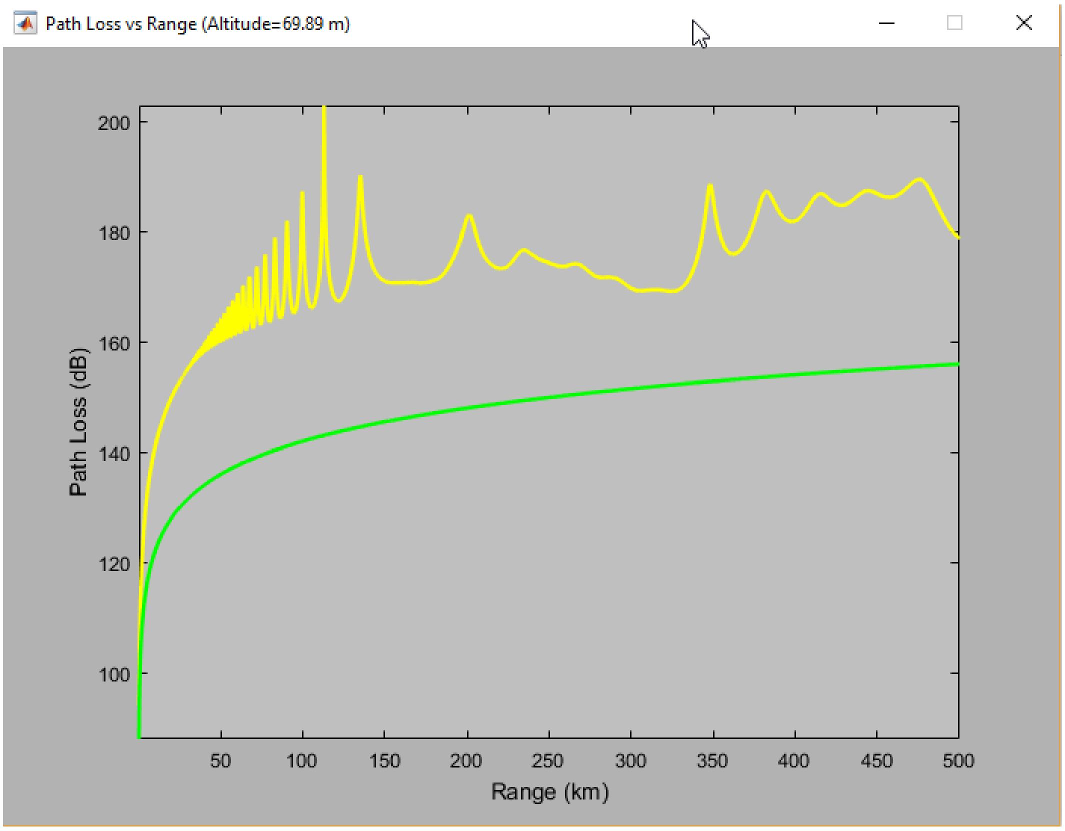

Figure 25: Ducting condition Path Loss Vs FSPL

5.3 Results and Discussions

The model framework presented in this thesis generates results based on provided input data. As a case study, we have selected monthly dataset of area under observation containing values of relative humidity and temperature at three different pressure heights. The program generates refractivity profiles, M profiles, its gradients, presence of duct, duct heights w.r.t top, bottom and middle of the duct, temperature, pressure and dew points values. These values will be used for further analysis. It may be noted that the output for 01 month (30 Days) for input data parameters contains 16740 rows. Due to bulk of data, results of few months are presented in this thesis, however, the framework is smart enough to provide output data set for whole year. It may also be noted that to compute records of a month with 03 vertical profile values on selected area, it took more than 10 mins on core i7 processor. If high resolution dataset with multiple vertical profile variable data set is required to be computed, computational cost would increase.

The results also help the viewer to identify the conditions by analyzing input data modeling and relate it with environmental changes. For example, dry weather with no temperature inversion over vertical profile would predict non-existence of surface duct. Similarly, for surface duct to be formed, temperature inversion and high relative humidity in the troposphere favors the existence of tropospheric duct. Some of the results may not be compared with actual results, this might be due to non-availability of high-resolution data set and of usage available low resolution data set. Furthermore, available dataset for weather and atmospheric conditions are available in GRIB and NETCDF format which is required to be render as per schema of database. It is done using NETCDF excel reader macro then transform the values as per data structure schema by programing queries in SQL.

The main framework produces structured database containing values for indepth analysis and further research. The output dataset computed for whole year contains various information for indepth analysis and can also be used as input dataset for future predicting models using modeling & simulation or AI & machine learning paradigm.

Chapter 6 **Conclusion and Future Work**

This chapter provides information about the conclusion and future work of the thesis.

6.1 **Conclusion**

The performance and coverage of V/UHF communication system has significant influence of propagation medium. Refraction due to variation of refractive index between tropospheric layers has great impact on electromagnetic wave energy, resulting better coverage and signal strength. Under certain weather conditions, the propagation of electromagnetic waves is expressively differing from standard conditions like ducting etc. Ignorance of these effects on propagation of signals may cause confusion and uncertainty which may lead to wrong decision making.

After successful development of mature propagation models, there is a need to obtain reliable and accurate atmospheric data with desired resolution as input data parameter for propagation model. The prediction model accuracy and validity is highly dependent on validity and accuracy of input atmospheric data. Furthermore, it is erroneous to assume that atmosphere is horizontally homogeneous can have serious operational limitation in communication environment. Electromagnetic wave propagation and its behavior due to change in refractivity profiles is discussed as sub refractive conditions cause radio wave to bends toward the sky causing decrease in range while super refraction mechanism cause radio waves to propagate towards earth curvature, resulting higher ranges and low path loss. The atmospheric conditions of desired Area of interest is analyzed and modelled and proposed a framework to predict environmental conditions in spatial-temporal domain. Reliable prediction system for such conditions can help commander at sea in taking decisions like selecting frequency and transmitter power etc.

6.2 **Future Work**

In the future, we are planning to convert the model framework into a product with highly enrich GUI interface. At present we are using ARCMAP 10.4 to display input and output data on GIS by manually exporting it from main program import on Arc Map. There is a requirement of integrated UI based solution covering all aspects of analysis and can also integrate parabolic equation modeling tools with main program to compute and plot ray tracing of propagation factor and path losses in spatio temporal environment.

Furthermore, the model validation is beyond the scope of this thesis, the same can be validated by gathering experimental data using live sensors and satellite readings. Simulated and actual results can be compared using same dataset. Our proposed framework is scale-able and can be configured for a sizeable number of dataset, but requires high performance distributed simulation platforms. We also aim to extend our framework for other sectors including commercial, industrial and military sectors for better utilization of the research.

References

[1] "R. E. Marshall, W. D. Thornton, G. Lefurjah, and T. S. Casey, "Modeling and simulation of notional future radar in non/standard propagation environment facilitated by mesoscale numerical weather prediction modeling," *Naval engineers journal*, vol. 120, pp. 55–66, 2008".

[2] "H. V. Hitney, "Refractive effects from VHF to EHF - part A: propagation mechanisms,"*Advisory Group for Aerospace Research & Development*, vol. LS-196, pp. 4A–1 – 4A–13,1994".

[3] "A. G. Huizing and A. Theil, "*Computer-Aided Radar Performance Evaluation Tool (CAR- PET) version 2.0 manual"*. Netherlands Organisation for Applied Scientific Research (TNO) Physics and Electronic Laboratory, The Hague, 1.2 ed".

[4] "J. Saffold, "*Principles of modern radar - basis principles"*, ch. 4, pp. 112–164. SciTech, 2010".

[5] "S t.Johns College of Engineering & Technology, India Global Journal of Researches in Engineering Civil And Structural Engineering Volume 13 Issue 4 Version 1.0 Year 2013Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Inc. (USA)"

[6] "H. V. Hitney, "Refractive effects from VHF to EHF - part B: propagation models," *Advisory Group for Aerospace Research & Development*, vol. LS-196, pp. 4A–1 – 4A–13, 1994"

[7] "H. R. Reed and C. M. Russel, "*Ultra high frequency propagation"*. Chapman & Hall LTD, London, 2nd ed., 1965"

[8] http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/freseq.html

[9] https://www.physicsclassroom.com/class/refrn/Lesson-2/Snell-s-Law

[10] B. R. Bean and E. J. Dutton, "*Radio Meteorology"*. Dover Publications, New York, March 1966.

[11] E. K. Smith and S. Weintraub, "The constants in the equation for atmospheric refractive index at radio frequencies," *Proceedings of the IRE*, vol. 41, no. 8, pp. 1035–1037, 1953

[12] "J. M. D. Coey, "Magnetism and Magnetic Materials", 2009"

[13] "Space and Naval Warfare Systems Command (SPAWAR), "*User's manual*

(UM) for Advanced Refractive Effects Predictions System (AREPS)." Space and Naval Warfare Systems Command (SPAWAR), San Diego, 3.6 ed., December 2006"

[14] "K. H. Craig, "Clear-air characteristics of the troposphere," in *Propagation of radio waves* (L. Barclay, ed.), ch. 7, pp. 103–128, The Institution of Electrical Engineers, London, 2nd ed., 2003"

[15] "T. Wilbrink, "Elektromagnetische propagatie." Royal Netherlands Navy, August 2010."

[16] "H. V. Hitney, J. H. Richter, R. A. Pappert, K. D. Anderson, and G. B. Baumgartner, "Tropospheric radio propagation assessment," *Proceedings of the IEEE*, vol. 73, no. 2, pp. 265–283, 1985"

[17] "I. Sirkova, "Brief review on PE method application to propagation channel modeling in sea environment," *Central European Journal of Engineering*, vol. 2, no. 1, pp. 19–38, 2012"

[18] "G. D. Dockery and J. Goldhirsh, "Atmospheric data resolution requirements for propaga- tion assessment: case studies for range-dependent coastal environments," in *Propagation Assessment in Coastal Environments*, pp. 7–1 – 7–13, September 1994"

[19] Tamer Becherray, " Electromagnetism , Maxwell equations, Wave Propagation and Emission " 2012.

[20] Nicolas Pinel ,Christophe Bourlier, 'Electromagnetic Wave Scattering from Random Rough Surfaces' ,2013

[21] *Sumayya Balkees P A Kalyan Sasidhar Sethuraman Rao* 'A Survey based Analysis of Propagation Models Over the Sea' *International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2015*

[22] Imtiaz Alam , Asad Waqar, Muhammad Aamir, Shahzad Hassan, Syed Asim Ali Shah 'Anomalous waves propagating at very high frequency in the atmosphere and their disturbances due to changes in refractivity profiles' www.journals.elsevier.com/results-in-physics 2017.

[23] V. K. Ivanov, V. N. Shalyapin, and Yu. V. Levadnyi, Determination of the Evaporation Duct Height from Standard Meteorological Data, IZVESTIYA, ATMOSPHERIC AND OCEANIC PHYSICS Vol. 43 No. 1 2007

[24] Adewumi Adebayo Segun1, Alade Micheal Olusope2, Adewumi Hope Kofoworola, Influence of Air Temperature, Relative Humidity and Atmospheric Moisture on UHF Radio Propagation in South Western Nigeria, International Journal of Science and Research (IJSR) Volume 4 Issue 8, August 2015

[25] Sean Victor Hum, Atmospheric Effects Attenuation by Atmospheric Gases

[26] ANOMALOUS PROPAGATION (DUCTING) EFFECTS INAERONAUTICAL VHF BAND, AERONAUTICAL MOBILE COMMUNICATIONS PANEL (AMCP) Working Group D Honolulu, HAWAI 19-28 January 1999

[27] Amajama Joseph1, Force of Atmospheric Humidity on (UHF) Radio Signal, International Journal of Scientific Research Engineering & Technology (IJSRET), ISSN 2278 – 0882 Volume 5, Issue 2, February 2016

[28] Wenwan Ding,1 KunWang,2 and Yunliang Long1, Study of the Electromagnetic Waves Propagation over the Improved Fractal Sea Surface Based on Parabolic Equation Method, Hindawi Publishing Corporation International Journal of Antennas and Propagation Volume 2016, Article ID 8235752

[29] Adegboyega Gabriel Adisa, Refractivity Variation Effect on Radio Wave Propagation. International Journal of Science and Research (IJSR) Volume 4 Issue 6, June 2015

[30] Xiao-Wei Guan, Li-Xin Guo, Ya-Jiao Wang, and Qing-Liang Li2, Parabolic Equation Modeling of Propagation over Terrain Using Digital Elevation Model,, China Research Institute of Radio Wave Propagation, March 2018.

[31] Alam, N. Mufti, S. A. A. Shah, and M. Yaqoob, The Effect of Refractivity on propagation at UHF and VHF Frequencies, Hindawi Publishing Corporation International Journal of Antennas and Propagation Volume 2016

[32] Global sensitivity of parabolic equation radar wave propagation simulation to sea state and atmospheric refractivity structure School of Coastal and Marine Systems Science, Coastal Carolina University, Conway, South Carolina, USA September 2015

[33] Atmospheric Effects on Radio Frequency (RF) Wave Propagation in a Humid, Near-surface Environment Naval Postgraduate School MS Thesis Samuel P. Mason March 2010

[34] https://cds.climate.copernicus.eu/cdsapp

[35] http://glossary.ametsoc.org/wiki/Hypsometric_equation

[36] Davidson, K. L. *Assessment Of Atmospheric Factors in EM/EO Propagation*. Course notes, Department of Meteorology, Naval Postgraduate School, Monterey, CA, 2003

[37] Stahlhut, K. D. *Refractivity in the Arctic Regions*. Master's thesis. Naval Postgraduate School, Monterey, CA. 2006

[38] Electromagnetic Diffraction and Propagation Problems. International Series of Monographs in Electromagnetic Waves, Vol. 1Article *in* American Journal of Physics 35(4):362-363 · January 1967

[39] A. Hasegawa, F. Tappert, Transmission of stationary nonlinear optical pulses in dispersive dielectric fibers. I. Anomalous dispersion, Appl. Phys. Lett. 23 (1973), 142–144.

[40] "Craig,K. H., ″ Propagation modeling in the troposphere: Parabolic equation method,″ *IEEE Electronics Letters*, Vol. 24, Issue 18,1136–1139,1988".

[41] "Dockery,G. D., ″ Modeling electromagnetic wave propagation in the troposphere using the parabolic equation,″ *IEEE Transactions on Antennas and Propagation*, Vol. 36,Issue 10,1464–1470,1988".

[42] "Craig,K. H. and M. F. Levy, ″Parabolic equation modelling of the effects of multipath and ducting on radar systems,″ *IEEE Proc. F*, Vol. 138,No. 2,153–162,1991".

[43] http://www.sjsu.edu/faculty/watkins/helmholtz.htm

[44] Levnet Sevgi, 'Electromagnetic Modeling & Simulation Chapter 15', 2014.

[45] G¨okhan APAYDIN, Levent SEVG, "Propagation modeling and path loss prediction tools for high frequency surface wave radars" Turk J Elec Eng & Comp Sci, Vol.18, No.3, 2010