3-11-2011

Integration of a Worldwide Atmospheric Based Model with a Live Virtual Constructive Simulation Environment

David B. Simmons

INTEGRATION OF A WORLDWIDE ATMOSPHERIC BASED MODEL WITH A LIVE VIRTUAL CONSTRUCTIVE SIMULATION ENVIRONMENT

THESIS

David B. Simmons, Captain, USAF
AFIT/GAP/ENP/11-M09

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/GAP/ENP/11-M09

INTEGRATION OF A WORLDWIDE ATMOSPHERIC BASED MODEL WITH A LIVE VIRTUAL CONSTRUCTIVE SIMULATION ENVIRONMENT

THESIS

Presented to the Faculty

Department of Engineering Physics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Applied Physics

David B. Simmons, BS

Captain, USAF

March 2011

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/GAP/ENP/11-M09

INTEGRATION OF A WORLDWIDE ATMOSPHERIC BASED MODEL WITH A LIVE VIRTUAL CONSTRUCTIVE SIMULATION ENVIRONMENT

David B. Simmons, BS

Captain, USAF

Approved:

Steven T. Fiorino, PhD (Chairman)	28 FEB 11 Date
Ronald F. Tuttle, PhD (Member)	2 MAR 2011 Date
Lt Col Robb M. Randall (Member)	28 FEB 2011 Date

AFIT/GAP/ENP/11-M09

Abstract

Yearly DoD spends millions of dollars on Modeling and Simulation tools in order to accomplish two fundamental tasks: make better decisions and develop better skills. Simulators that are based on realistic models enable the USAF to properly train, educate, and employ military forces. LEEDR is an atmospheric model based on worldwide historic weather data that is able to predict the extinction, absorption, and scattering of radiation across a broad range of the electromagnetic spectrum. Through this study LEEDR models the propagation of 1.0642 micron laser radiation at worldwide locations and through various environmental conditions. This modeled laser transmission output, based on realistic atmospheric and aerosol propagation effects, was correlated to simulated laser target lock-on ranges derived from a generic laser targeting pod. This correlated information was incorporated into The Air Force Research Laboratory's XCITE Live, Virtual, and Constructive (LVC) threat generation simulator. The simulated laser target lock-on ranges, correlated to realistic atmospheric propagation effects, increased the fidelity and realism inside the XCITE LVC threat generation environment providing users the opportunity to make better decisions and develop better skills.

Acknowledgments

I would like to express my appreciation to my faculty advisor, Dr. Steven Fiorino, for his guidance, support and optimistic attitude throughout the course of this effort. He provided me direction and encouragement at the critical stages of research. His expertise is greatly appreciated. I would also like to thank committee members Lt Col Robb Randall and Dr. Ronald Tuttle for invaluable feedback and advice. I am grateful for the help received from my fellow physics peers. I would also like to thank Craig Eidman, from The Air Force Research Laboratory for both the support and flexibility provided to me in this endeavor.

I am grateful to my dad who was the first member of his family to attend college. He eventually earned his PhD through sheer determination and hard work and taught me to develop my talents and accomplish everything I set my mind to. For decades my mother's love and service have been a constant beacon. Finally, I am especially appreciative for the love and patience of my wife and children. Together may we continue to "pursue with eager feet" the Roads that lie ahead while enjoying our time together.

David B. Simmons

Table of Contents

Page

List of Figures

Figure Page

List of Tables

Table Page

List of Acronyms

AGL	Above Ground Level
ANAM	Advanced Navy Atmospheric Model
AFIT	Air Force Institute of Technology
BL	Boundary Layer
CAS	Close Air Support
DoD	Department of Defense
EM	Electromagnetic
ExPERT	Extreme and Percentile Environmental Reference Table
GADS	Global Aerosol Data Set
JTAC	Joint Terminal Attack Controllers
LEEDR	Laser Environmental Effects Definition and Reference
LVC	Live, Virtual, Constructive
M&S	Modeling and Simulation
MODTRAN	MODerate resolution atmospheric TRANsmission
RH	Relative Humidity
TAWS	Target Acquisition Weapons Software
USAF	United States Air Force
WPAFB	Wright-Patterson Air Force Base
XCITE	eXpert Common Immersive Theater Environment

INTEGRATION OF A WORLDWIDE ATMOSPHERIC BASED MODEL INTO A LIVE VIRTUAL CONSTRUCTIVE SIMULATION ENVIRONMENT

I. Introduction

Background

The United States Air Force (USAF) relies extensively on modeling and simulation (M&S). M&S provides an important role in the Air Force's ability to train warfighters, develop new systems, and assess the complexities of a changing battlespace. (Lord, 2010) Simulations are used to run wargaming scenarios and can link together remote forces during distributed training exercises. M&S supports the needs of the USAF and helps fulfill its mission. The USAF utilizes M&S for two primary tasks: to make better decisions and develop better skills. (Lord, 2010)

In addition, the use of simulation tools minimizes procurement costs associated with purchasing expensive hardware and software and helps reduce the sustainment costs. Their use also facilitates the weapons procurement process and improves the actual military infrastructure. The third most important military M&S role involves its effective use in training. (Farmer, 1999) Unfortunately, one of the current challenges facing the effective implementation of M&S training tools is that the fidelity of some databases and software is often insufficient to support required environments. (Lord, 2010)

Current USAF education and training applications require a variety of models and simulations. Live simulations link real operators and real equipment during simulated operations. For example, the USAF conducts live simulation training during Red Flag exercises, hosted by Nellis Air Force Base, at the Nevada Test and Training Range. Virtual simulations link real operators and combine both real and simulated equipment during simulated operations. Virtual cockpit simulators are used to train flight crew. Constructive models and simulations are used for educational wargaming and represent a system and its employment. Using a constructive environment pilots, can be placed in virtual cockpit simulators and battle against adaptive simulated adversaries.

Live, Virtual, and Constructive (LVC) simulations provide trainees an environment to effectively learn from personal mistakes and failures. For instance, simulation platforms provide a safe environment where initial weapons platform familiarization training occurs. In near-realistic environments trainees are able to increase their skills and gain familiarization with the weapons platform and its successful operation. Simply put, simulation tools streamline the overall training process and are effectively used to train and assess a warfighters skills and knowledge.

A model represents a physical reality and can be a simplified representation of any actual observable phenomena. Scientific models often employ mathematics in their formulation and use. A simulation tool that is based on an accurate model can provide a realistic and useful experience for users. LVC models can simulate air, space, land, or sea operations and are used for military training and to execute wargaming scenarios.

The Laser Environmental Effects Definition and Reference (LEEDR) is a worldwide atmospheric characterization model that is based on historic weather data. The LEEDR atmospheric model will be used in this research. LEEDR is able to predict the extinction, absorption, and scattering of radiation across a broad range of the electromagnetic (EM) spectrum. This makes LEEDR extremely useful because it can calculate the amount of laser radiation that propagates through the atmosphere.

The Warfighter Readiness Research Division is part of The Air Force Research Laboratory, 711th Human Performance Wing. Its mission is to: "Research, demonstrate, and transition leading-edge human performance methods and technologies that provide the warfighter the necessary knowledge and skills to dominate the decision environment." The Division leads science and technology development that improves the decision-making abilities and performance of warfighters. (AFRL Human Effectiveness Directorate, 2010) This is accomplished by researching training methods and technologies and then adapting them for the warfighters use and benefit.

The AFRL's Immersive Environments Branch is assigned to the Warfighter Readiness Research Division. The Immersive Environments Branch researches, develops, and demonstrates the leading edge technologies and innovative concepts that are able to support the evolution of immersive environments for training and rehearsal. (AFRL Human Effectiveness Directorate, 2010) The branch has developed, improved, and maintains a variety of in house cutting-edge LVC models and simulators.

One of these simulators is the eXpert Common Immersive Theater Environment (XCITE). XCITE is a threat generator that combines friendly and enemy forces in the simulated LVC environment. It operates in real-time and integrates with other software packages to provide training and wargaming scenarios. XCITE generates and runs environments to link friendly forces against opposing LVC enemy threats.

The Immersive Environments Branch also attempts to further develop commercially available software programs and calculation engines by applying them to urgent needs. In some cases enhancements can be made to existing software to adapt it to the required warfighter test and training simulation environment. For instance, the commercial video game industry uses software gaming engines that provide and render an exciting and challenging environment for the video game user. Unfortunately, these engines do not correctly model and render all the "real-world" physics based inputs and environments. However, if realistic models can be incorporated into existing software and simulations a higher fidelity product is created in less time and for less money.

Problem Statement

A model that is not based on realistic inputs fails to provide the user with a completely realistic experience. This lower fidelity model may be easier to build than its higher fidelity counterpart, but it likely provides a less accurate training experience and less than stellar wargaming results. One of the challenges facing the Immersive Environments Branch is the inability to render complete physically realistic training content in the LVC simulation environment.

Specifically, in current military operations many important tasks are completed with the electromagnetic waves that range from the radio frequencies, through the far infrared, and into the near infrared and the visible. The XCITE LVC threat generation simulation environment lacks complete representations that accurately model the propagation of these hyper-spectral electromagnetic waves through the atmosphere.

Purpose

The purpose of this work is to add another level of realism into the XCITE LVC threat generation simulation environment. This research shows that physically realistic atmosphere and aerosol models have non-negligible effects on the simulated propagation of laser radiation in the XCITE LVC environment. Specifically, the study varies inputs to the LEEDR model and records the effects these variations have on the resulting laser path transmittance. These recorded variations in laser path transmittance will then be correlated to simulated laser target-lock-on ranges that are based on a generic USAF airborne laser targeting pod.

A secondary purpose is to show that the fidelity of the XCITE LVC training environment will be increased by deriving simulated target lock-on ranges from a realistic atmospheric propagation model. The belief is that increasing the fidelity of the simulator will improve the simulation training environment and help users to make better decisions, develop better skills, and enhance the planning of wargaming scenarios.

Hypothesis

The central research question for this work is "Can the LEEDR atmospheric model create more realism in the XCITE LVC training environment?" The answer to this question will be based on two important research parameters. First, LEEDR will simulate the propagation effects on laser radiation paths through the atmosphere. The model will calculate how much of the laser radiation is transmitted through the atmosphere. This calculated value is extremely important and is called the laser path transmittance. The laser path transmittance will be correlated to the second and more important parameter, the laser target lock-on range.

The laser target lock-on range is a familiar parameter to flight crew and is a measurable metric. The final simulated laser target lock-on ranges generated by this work will be based on output from the LEEDR realistic atmosphere propagation model. These simulated laser target lock-on ranges will be correlated to modeled laser propagation path transmittances. If output from the LEEDR atmospheric model improves the simulated laser target lock-on ranges in the XCITE LVC environment, then the level of realism is increased and the hypothesis may be affirmatively answered. It is believed that the laser target lock-on range variations will be caused by differences in environmental conditions due to geographic location and time of day.

Research Approach

It will be shown that physically realistic atmosphere and aerosol models have non-negligible effects on the simulated propagation of 1.0642 laser radiation in the XCITE LVC threat generation environment. Initially, simulations will be run in LEEDR to accurately predict the atmospheric effects on the propagation of 1.0642 micrometer laser radiation. The laser wavelength of 1.0642 micrometers is of interest because of its military utility and direct impact on current military operations. 1.0642 micrometers is the standard wavelength used by the USAF airborne laser targeting sensors and designators and atmospheric effects on this laser wavelength are of vital military interest. LEEDR inputs will be varied and the resulting variations in laser path transmittance recorded.

The Target Acquisition Weapons Software (TAWS) will then be run and simulated target lock-on ranges generated. These simulated target lock-on ranges will be based on a generic USAF airborne laser targeting pod. The LEEDR simulated laser path transmittances will be correlated to corresponding TAWS simulated target lock-on ranges. A lookup table will be populated with the correlated transmittances and target lock-on ranges. This table will be incorporated into the XCITE LVC environment. The lookup table will provide the ability to simulate engagement scenarios based on simulated laser target lock-on range differences that were caused by atmospheric and aerosol propagation effects on the laser radiation. Subsequent XCITE scenarios will be run using the correlated simulated laser target lock-on ranges.

The following inputs will be varied in the LEEDR atmospheric model: worldwide location, atmosphere model, aerosol effects model, time of day, rain, and surface visibility. The following LEEDR inputs will remain constant: season, humidity, laser wavelength, aircraft upper altitude, and laser radiation slant path. During some simulations the atmosphere model, rain, and surface visibility will be held constant. During the last simulation the aircraft upper altitude and laser radiation slant path will be decreased.

Outline

Section two of this paper contains a review of the atmospheric effects on the laser radiation propagation including absorption, scattering and atmospheric extinction and transmission. It also discusses both the TAWS software and the XCITE LVC threat generation simulation environment. Chapter three explains the steps taken to prove the stated hypothesis. Chapter four analyses the work and discusses the final results. Chapter five includes the summary of the findings. It discusses the impacts that the LEEDR atmospheric propagation model could have in a XCITE LVC threat generation simulation. It also provides recommendations for future of work.

II. Literature Review

Chapter Overview

It is important to correctly predict the propagation of laser radiation through the atmosphere. (Cohen, 2009) The purpose of this research is to incorporate into XCITE laser target lock-on ranges that are correlated to realistic LEEDR atmospheric model calculated laser path transmittances. In order to understand LEEDR, it is important to understand the structure of Earth's atmosphere. It is also important to understand the effects the atmosphere has on the propagation of laser radiation. This chapter concludes discussing the Target Acquisitions Weapons Software and the XCITE live virtual constructive threat generation simulation environment.

Atmospheric Structure

The propagation of radiation is affected by the Earth's atmosphere. The atmosphere is divided into separate layers: troposphere, stratosphere, mesosphere, and thermosphere. The lowest two kilometers of the atmosphere is called the atmospheric boundary layer (BL). The boundary layer is created by frictional forces between the atmospheric winds and the Earth's surface. The thickness of the boundary layer varies. During the day it is usually between 1.5 and 2.0 kilometers thick. At night the boundary layer thickness can decrease to less than 500 meters. Good vertical mixing of the atmosphere occurs within the boundary layer and as altitude increases, the water vapor mixing ratio, aerosol and pollutant concentrations, and the potential temperature are nearly constant.

Concentrations of atmospheric aerosol constituents within the boundary layer are typically higher than the aerosol concentrations in the upper atmosphere. Therefore the boundary layer can exhibit higher aerosol scattering than the upper atmosphere. Relative humidity (RH) measures how saturated with water vapor the air is. The relative humidity varies around the Earth with climate and temperature differences. It varies with altitude through the boundary layer and upper atmosphere. Throughout the day temperature variations can cause the relative humidity to fluctuate throughout the boundary layer. Aerosol scattering in the boundary layer can be affected by worldwide relative humidity differences and changes. These relative humidity differences and changes can adversely affect the propagation of electromagnetic radiation through the boundary layer.

Approximately the lowest 50 meters of the boundary layer is called the surface layer. The rate of change of temperature and potential temperature through the surface layer differs than the corresponding temperature change rates through the boundary layer. Although, as altitude increases through the surface and boundary layers, the water vapor mixing ratio and aerosol and pollutant concentrations are nearly constant. Therefore surface weather data can be used to characterize the water vapor mixing ratio and aerosol and pollutant concentrations throughout the boundary layer. A large amount of worldwide historic surface weather data has been collected. This extensive collection of surface data can be used to characterize the atmospheric structure of the boundary layer. Therefore, the boundary layer aerosol scattering can be modeled with reasonable accuracy based on this extensive historic surface weather data.

The atmosphere is made of molecules, dry and liquid aerosols and liquid and ice water particles. Pollutants in the atmosphere are aerosols. Clouds and precipitation are created by the liquid and ice water particles. Dry air is composed of the following molecules: nitrogen (78%), oxygen (21%), argon (~1%), and several other trace gases. The atmosphere contains approximately 9,350 parts per million of argon and 380 parts per million of carbon dioxide. In the lower atmosphere nitrogen, oxygen, argon, and carbon dioxide maintain a near constant concentration. The concentrations of the other trace gases vary significantly with altitude. (Perram, et. al., 2010) The concentrations of water vapor and ozone can vary throughout the atmosphere and over time. The variable concentration trace gases affect laser propagation more than those gases with constant atmospheric concentrations. As a matter of fact, some constituents that make up a smaller fraction of the total volume of the atmosphere have a larger influence on laser propagation than those molecules that are found in higher concentrations. (Petty 2006)

Water is an important part of the atmosphere. The concentration of this aerosol is usually higher within the boundary layer than above it. The water solubility of certain aerosols affects the laser propagation. Water can begin to condense on these water-soluble aerosols and increase their size. Therefore water soluble aerosols are affected by relative humidity changes. (Perram, et. al., 2010) Soluble aerosols are often clay-based and are found over many continental regions. Sea salt spray causes soluble aerosols to exist over oceans. Insoluble aerosols do not absorb water based on relative humidity. They are often made up of mineral dusts and usually found in the Earth's desert regions. (Perram, et. al., 2010) As changes in the relative humidity increases the size of water soluble aerosols, negative laser propagation effects may result. Regions of the world that contain higher concentrations of water soluble aerosols, when combined with higher relative humidity, can show decreased propagation of laser radiation.

The transmission of laser radiation is directly affected by key atmospheric constituents. At the shorter visible and ultraviolet wavelengths, molecules in the atmosphere can scatter more of the radiation. At longer wavelengths the atmospheric constituent gases affect the absorption of the laser radiation. If the atmospheric absorption is high then less laser radiation propagates and the transmittance is low. When the atmospheric absorption is low then more laser radiation may propagate and the transmittance can be high.

Atmospheric Effects

The atmosphere decreases the laser propagation through absorption and scattering. Absorption of laser radiation heats the atmosphere. Scattering causes the radiation to travel off its original propagation path. The total radiation absorption or scattering usually varies along the path of propagation. (Petty 2006) Many of the adverse laser propagation effects can be calculated. (Perram, et. al., 2010)

Absorption

Absorption usually causes the atmosphere to gain thermal energy in the form of heat. The trace gases and water vapor in the atmosphere typically affect the absorption of the laser radiation more than the higher concentration atmospheric constituents. The zenith transmittance of the cloud and aerosol free atmosphere is shown in Figure 1.

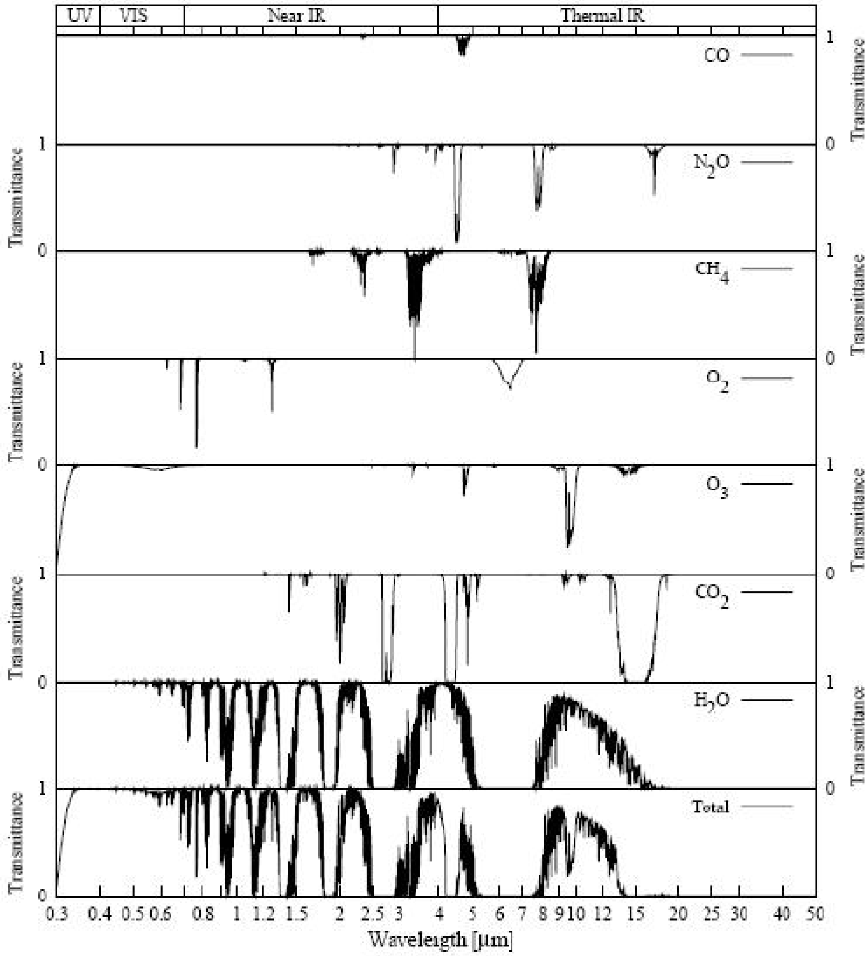

Figure 1. Transmittance of cloud & aerosol free atmosphere (Adapted, Petty, 2006)

The upper plots show the absorption due to single atmospheric constituents. The bottom plot shows the combined effect of all the atmospheric constituents. Molecular scattering is not shown in these plots. (Petty 2006) Figure 1 shows that water vapor is the single most important absorber across this portion of the spectrum. Carbon dioxide, ozone and oxygen are also important.

Scattering

Scattering removes energy from the laser beam. The energy lost to scattering can possibly be detected off-axis or it may exceed eye safety thresholds. (Perram, et. al.,

2010) For military operations this is significant because adversaries can see where the laser is pointing and where it originates from. Also friendly forces may accidently receive unsafe laser radiation in their eyes.

Two types of atmospheric scattering processes exist: Rayleigh and Mie. Molecular scattering is based on Rayleigh theory. Atmospheric constituents scatter the laser radiation in all directions, but most of the radiation is scattered in the forward and backward directions. (Petty, 2006) The atmospheric constituents causing Rayleigh scattering are smaller than the laser radiation wavelength. Rayleigh scattering in the upper atmosphere gives the sky its blue color. Aerosol scattering is based on the Wiscombe Mie model. The aerosols scatter most of the laser radiation in the forward direction. As the aerosol sizes increase the amount of forward laser scattering also increases. (Petty, 2006) Mie scattering occurs when the aerosols are equal in size to the laser radiation. Mie scattering is why clouds are white. (Marek, 2009)

Molecular scattering is significant for visible wavelengths, especially blue and violet. Figure 2 shows atmospheric electromagnetic radiation attenuation effects from molecular absorption and hydrometeor distributions (rain, clouds, fog). In addition to molecular absorption, the black line is affected to a small degree by some continental aerosols and molecular scattering. This plot is produced with LEEDR code. Aerosol scattering effects are usually greater than molecular scattering effects in the lower atmosphere and the boundary layer. (Perram, et. al., 2010)

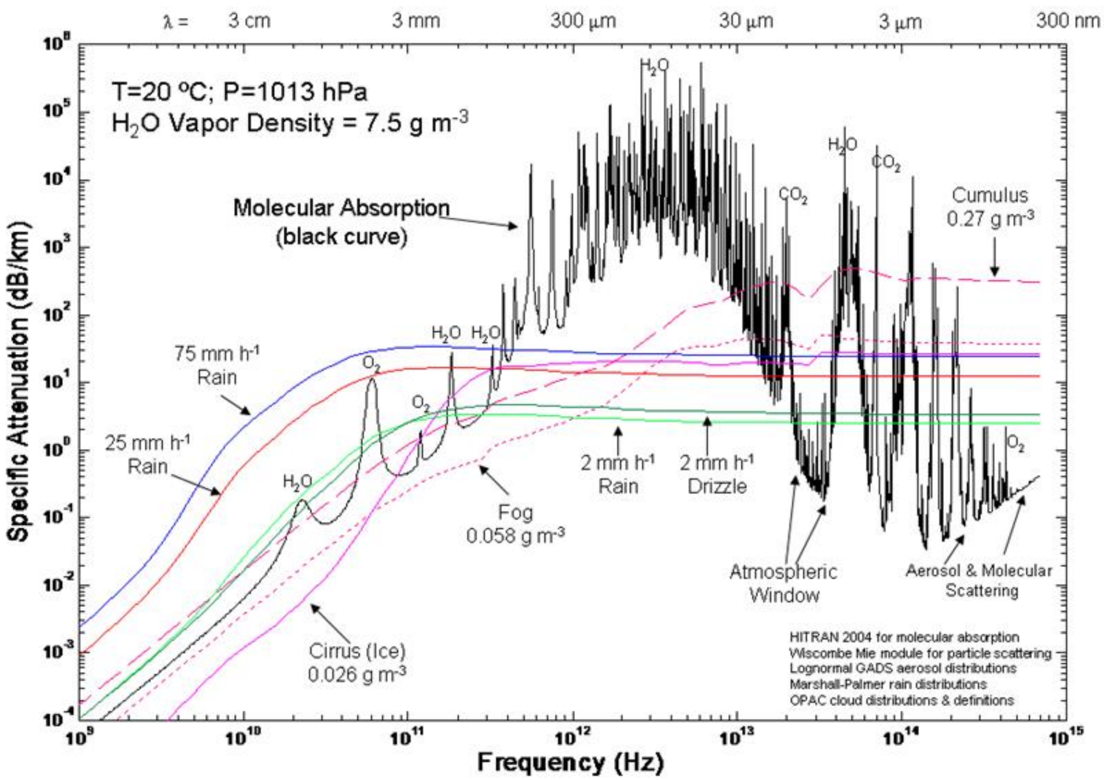

Figure 2. Specific attenuation from 30 cm to ~ 0.4 µm (Adapted Perram, et. al., 2010)
The black line is molecular absorption with some effects of continent average aerosols and molecular scattering included. Colored lines represent the specific attenuation that would be added for the hydrometeor distributions shown (rain, clouds, fog). Derived from AFIT LEEDR code.

The relative humidity affects the size of water soluble aerosols and as the relative humidity increases above 50% the water soluble aerosols grow in size. These larger sized aerosols can cause increased aerosol scattering which adversely affects the propagation of electromagnetic radiation through the atmosphere. The concentration of these water soluble aerosols is typically higher in the boundary layer than above it. The relative humidity within the boundary layer varies with altitude and usually increases with increasing altitude. This causes an increase in extinction near the top of the boundary layer throughout much of the world. (Perram, et. al., 2010) The boundary layer relative humidity also varies throughout the world. Historic surface weather data can be used to characterize the atmospheric structure of the boundary layer and therefore, the boundary layer aerosol scattering can be accurately calculated.

Turbulence

Turbulence is caused by temperature differences, wind, and other turbulence. Turbulence affects the propagation of laser radiation. It can cause changes in the atmospheric index of refraction. Correctly accounting for the variation of the index of refraction improves performance predictions for weapons and systems. (Cohen, 2009) Turbulence also changes the phase of propagating light. This affects the intensity of visible light and is why stars appear to twinkle. (Perram, et. al., 2010)

The Calculation of Atmospheric Transmission and Extinction

Atmospheric transmission and extinction are important. A laser targeting designator needs to be powerful enough so that a laser guided bomb can first find the laser spot, then lock onto, and finally guide itself to it. The atmosphere affects, and can degrade, the laser propagation.

The atmospheric index of refraction, N, has both real and imaginary parts. The real part, n_r, is related to the electromagnetic wave phase speed propagating through the atmosphere. The imaginary part, n_i, describes the rate of absorption of the electromagnetic wave. It is called the absorptive index. (Petty, 2006) The total extinction of the laser radiation is a combination of both absorption and scattering. The effects of absorption and scattering on the laser propagation differ. Turbulence also affects the laser propagation. In order to calculate the total energy loss of laser propagation the total extinction must be found. Thus the absorption and scattering effects for all molecules, aerosols, and water must be considered.

The laser extinction can be expressed in terms of laser transmission through the atmosphere. Transmittance, which is easier to visualize than extinction, describes the fraction of initial laser radiation that survives the propagation over a finite distance, x. (Petty, 2006) A transmittance of 0 is equivalent to complete extinction of the laser radiation and a transmittance of 1 is equivalent to complete transmission. The Beer–Lambert law of absorption defines transmittance as the ratio of the laser radiation intensity at a distance x, to the initial laser intensity. This law is valid for laser transmission through a homogeneous absorbing medium with absorption coefficient, β_a,

$$t \equiv \frac{I_x}{I_0} = e^{(-\beta_a x)} \tag{1}$$

where $I(x)$ is the laser intensity at a distance and I_0 is the initial laser intensity.

The rate at which laser energy is absorbed by the atmosphere is proportional to the absorption coefficient, β_a. The rate at which laser energy is scattered by the atmosphere is proportional to the scattering coefficient, β_s. The total rate at which laser energy is lost through the atmosphere is proportional to the total extinction coefficient, β_e. In an inhomogeneous absorbing medium these rates vary with distance, *s*. Therefore

$$\beta_e(s) = \beta_a(s) + \beta_s(s) \tag{2}$$

where $\beta_e(s)$, $\beta_a(s)$, and $\beta_s(s)$, have units of inverse length. In order to calculate the total path transmittance, $t(s)$, through an inhomogeneous absorbing material an integration is performed over the path length. The products of the small length, δs, and uniform total extinction, $\beta_e(s)$, through this length, are summed from beginning point *s1* to ending point *s2* as follow:

$$t(s) \equiv \frac{I(s_2)}{I(s_1)} = e^{[-\int_{s_1}^{s_2} \beta_e(s) \delta s]} \quad (3)$$

where $I(s_2)$ is the laser intensity after propagating a distance s_2 and $I(s_1)$ is the initial laser intensity. This equation is valid for calculating the total path transmittance of laser radiation through the Earth's inhomogeneous atmosphere.

Target Acquisition Weapons Software (TAWS)

The Target Acquisition Weapons Software (TAWS) is tactical decision aid and mission planning software that predicts weapon and navigation system performance. The TAWS software merges electro-optical systems, targets, and the atmosphere. It can be used to modify mission execution tactics or to evaluate mission environmental conditions. TAWS can also be a useful modeling tool for military planning. It gives users easy access to weather and geographic information, and sensor databases. It can handle multiple targets, locations, sensors, and sensor altitudes in a single analysis and implements a modular system design. (Gouveia, et al., 2002)

TAWS incorporates weather, sensor, and mission information in order to predict system performance. It is able to predict maximum detection and lock-on ranges for sensors. The sensor information is categorized into the following regions of the spectrum: Infrared, mid wave 3-5 micrometers and long wave 8-12 micrometers; Visible including TV and Night Vision Goggle systems, 0.4–0.9 micrometers; and Laser, 1.0642 micrometers. (Scheidecker, 2005)

AFRL XCITE Threat Generator

The Immersive Environments Branch developed the eXpert Common Immersive Theater Environment (XCITE) in order to provide the military the ability to generate both friendly and adversary forces in a simulated environment. XCITE's objective is to maximize high fidelity physics based representation of threat systems and their interaction with the combat environment. XCITE runs in real-time and integrates with other software packages using standardized data protocols to provide LVC training and wargaming scenarios.

The XCITE software uses models to generate aircraft, weapons, radar, and electronic warfare simulations. Operators can simulate single, 2-ship, 3-ship, or 4-ship aircraft formations. Once added, these formations are automatically configured for formation flying and have command and control capabilities. These formations can be directed and can perform many combat maneuvers. (Best, et. al., 2006) XCITE can bring warfighting teams together to "train in complex scenarios more frequently, cheaply, and effectively, while reducing constraints imposed by safety, security, and environmental factors." (Best, et. al., 2006) XCITE has been used to conduct joint distributed exercises between forces collocated around the world. Exercise Pacific Link 2, conducted in September 2006, was one of these exercises. (Best, et. al., 2006)

XCITE was developed to provide an electronic warfare training environment complete with high-fidelity radar and jammer models. Eventually XCITE's design was expanded and a high performance flight model was added. Currently, XCITE is unable to predict the extinction of laser radiation across a broad range of the electromagnetic spectrum. It is unable to calculate the amount of laser radiation that is absorbed and scattered by realistic worldwide season, atmosphere, and time of day effects.

Summary

The atmosphere is made up of different layers. Laser propagation is affected by the atmosphere. Aerosols and molecules within the atmosphere attenuate laser radiation through absorption and scattering. The effects within the atmosphere and boundary layer cause degradation of the laser propagation. XCITE is a useful threat generation simulation environment for the military. It is able to be run real time and facilitates effective military simulation training. XCITE is unable to predict the extinction of laser radiation across a broad range of the electromagnetic spectrum caused by realistic worldwide season, atmosphere, and time of day effects.

III. Methodology

Chapter Overview

This chapter demonstrates the steps followed to determine if the LEEDR atmospheric model could create more realism in the XCITE LVC threat generation environment. It explains the scenario that was modeled inside LEEDR. It shows how various LEEDR laser path transmittances were correlated to simulated laser target lock-on ranges and subsequently incorporated into the XCITE LVC simulation. TAWS bridged the gap between LEEDR transmittances and simulated XCITE lock-on ranges.

Initially a characterization of the LEEDR atmosphere and aerosol models was completed. A laser propagation path was defined in LEEDR. The laser path originated at 3,000 meters Above Ground Level (AGL) and terminated at 0 meters AGL. With this configuration a laser propagation slant path length of 5,000 meters is possible and this is what was modeled. This path is based on a possible flight profile for a USAF medium-altitude long-endurance Remotely Piloted Aircraft (RPA). It must be noted that the atmospheric laser propagation effects will vary depending on the chosen upper altitude and laser slant path.

Initially LEEDR was used to predict the atmospheric effects on the propagation of 1.0642 micrometer laser radiation. LEEDR inputs were varied and the resulting variations in laser path transmittance recorded. A single geographic location was modeled in LEEDR in order to characterize the laser propagation effects of various atmosphere and aerosol models. Then atmospheric laser propagation effects were modeled in LEEDR at various worldwide sites. With these characterizations completed, LEEDR was then used to compare worldwide atmospheric laser propagation effects.

Finally, changes in surface visibility and rain were simulated in order to characterize these laser propagation effects.

TAWS was run to generate simulated target lock-on ranges. These simulated target lock-on ranges were based on a generic USAF airborne laser targeting pod. The previously obtained LEEDR simulated laser path transmittances were then correlated to corresponding TAWS simulated target lock-on ranges. A lookup table was populated with the correlated transmittances and target lock-on ranges. This table was eventually incorporated into the XCITE LVC environment. The lookup table provided the ability to simulate engagement scenarios based on laser target lock-on range differences. These range differences were caused by atmospheric and aerosol effects on laser propagation. XCITE scenarios were run based on the simulated laser target lock-on ranges.

Laser Environmental Effects Definition and Reference (LEEDR)

LEEDR is a worldwide atmospheric model that is based on historic weather data. LEEDR is able to predict the extinction, absorption and scattering of radiation across a broad range of the electromagnetic spectrum. LEEDR can calculate the amount of laser radiation that propagates through the atmosphere. LEEDR has two primary purposes:

> 1. To create correlated, physically realizable vertical profiles of meteorological data and environmental effects such as gaseous and particle extinction, optical turbulence, cloud free line of sight; and
> 2. To allow graphical access to, and export of, the probabilistic data from the Extreme and Percentile Environmental Reference Tables (ExPERT) database. (Fiorino, et al., 2008)

Atmospheric conditions and effects and laser propagation parameters can be varied within LEEDR. This allows LEEDR to "produce profiles of meteorological data and effects that could actually occur, or have actually occurred, at a particular location and time, and attach the statistical likelihood of such occurrence for that time and place. This differs significantly from using "standard" atmospheric profiles (e.g. the U.S. Standard Atmosphere) in engineering analyses or simulations." (Fiorino, et al., 2008)

LEEDR utilizes several climate databases. This research used the ExPERT database and the Global Aerosol Data Set (GADS). The ExPERT database utilizes data from 573 worldwide ground sites. These sites are shown by tiny red circles in Figure 3.

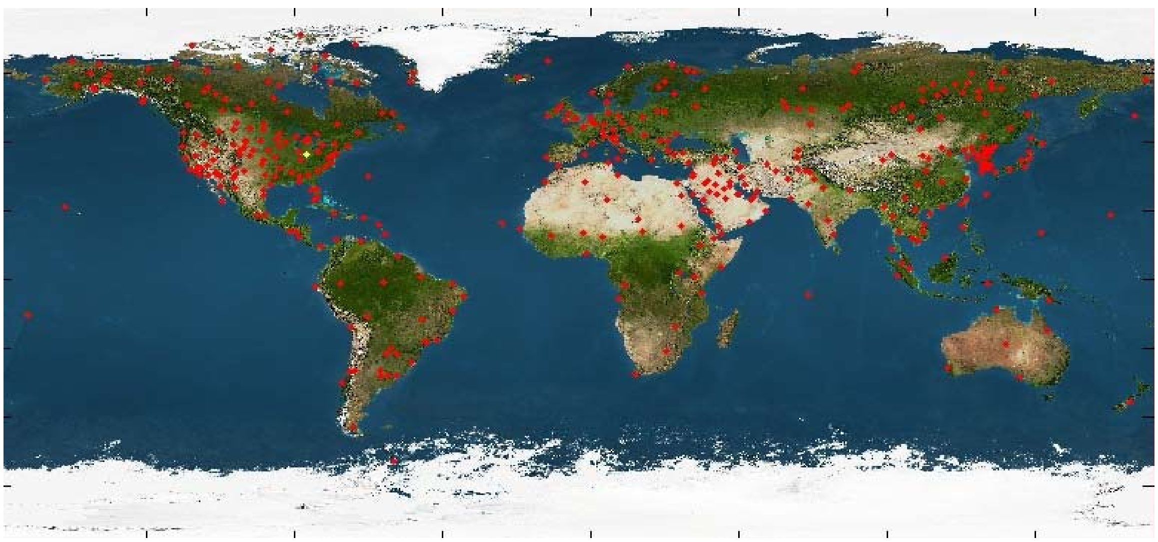

Figure 3. 573 ExPERT sites

Within LEEDR thirteen separate atmosphere models for climate regions are available. The five atmosphere models used in this research were: 1976 US Standard, 1976 US Standard Dry, Standard Desert, ExPERT Summer, and the ExPERT Summer with standard aerosols.

LEEDR has 19 separate aerosol models and one user defined profile. Initial research was conducted using LEEDR to model the effects from many of the aerosol profiles. The final results for this work were based on the Advanced Navy Aerosol Model (ANAM) and the continental average aerosol effects model. The continental average aerosol effects model provides a good overall estimate of the average aerosol content over land. By using this single aerosol model across multiple geographic locations valid comparisons were made between worldwide path transmittance variations. In another instance, a comparison at Port Sudan, Sudan was made using both the ANAM and the continental average aerosol models. Port Sudan lies on the Red Sea and provided a good location to compare the variation between the ANAM and continental average aerosol models. Aerosol effects caused by the world's oceans and seas vary from aerosol effects typical over Earth's continents.

LEEDR uses Rayleigh theory to calculate molecular scattering effects. It uses the HITRAN 2004 database line strength information to calculate molecular absorption effects. The Wiscombe Mie model is used to calculate aerosol scattering and absorption effects. (Fiorino, et al., 2008) LEEDR sums both the molecular and aerosol absorptions in order to calculate the total absorption. To calculate the total scattering LEEDR sums both the molecular and aerosol scattering. (LEEDR Reference Manual, 2010)

LEEDR also has the ability to model rain, clouds, fog, wind, atmospheric turbulence, and reduced visibility. Turbulence will affect the laser propagation. In this research turbulence effects were neglected and the turbulence model, HV 5/7, with a turbulence multiplier of 1, was selected. This work modeled LEEDR effects using the climatology wind profile, light rain and reduced surface visibility.

The LEEDR "Location" screen shown in Figure 4 was used to set the location dependent inputs. The LEEDR "Atmosphere" and "Laser/Geometry" tabs were used to vary other parameters. The following inputs were varied in LEEDR: Current location (by selecting one of the 573 ExPERT Sites), atmosphere model, aerosol effects model, time of day, surface visibility, light rain (5mm / hour). Aircraft upper altitude and laser slant path were changed during the last simulation. The following LEEDR inputs were held constant: Summer season, humidity, 1.0642 micrometers laser wavelength, aircraft upper altitude, and laser propagation slant path.

All the ExPERT sites selected within LEEDR were set to a relative humidity percentile at the median or 50th percentile. This essentially sets the relative humidity for the LEEDR atmospheric model equal to approximately the average summer humidity based on the site-specific historic weather data. Setting the relative humidity to the 99^{th} percentile indicates the extremely humid case that only occurs 1% of the time at that geographic location. LEEDR varied the relative humidity between worldwide locations based on climate, time of day, and altitude. The LEEDR model varied the height of the boundary layer depending on time of day. The default LEEDR boundary layer heights are 500m, 1000m, and 1524m, depending on time of day.

Figure 4. LEEDR atmospheric profile inputs screen

LEEDR Atmosphere and Aerosol Effects Characterization

The purpose of this step was to characterize the effects realistic worldwide atmospheric and aerosol models have on the calculated laser propagation. First LEEDR was used to characterize the aerosol effects on the laser propagation at a single site.

For the single site tests, the following LEEDR inputs were held constant: Nellis AFB ExPERT site, summer season, 50% - average humidity, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain. The following LEEDR inputs were varied: atmosphere model, aerosol effects model, and time of day.

The Nellis AFB ExPERT site was selected because it provides a good representation of the high desert western United States climate. It also encompasses the Nevada Test and Training Range where the USAF periodically conducts live simulation military training during the Red Flag exercises. Providing a realistic LVC training simulation at this location will provide enhanced preparation for actual military training missions.

Laser path transmittances were obtained from LEEDR using the following atmosphere models: US 1976 Standard, US 1976 Standard Dry, Standard Desert, and ExPERT. Laser path transmittances were obtained using the following aerosol models: GADS, Urban, Maritime Clean, Continental Clean, Continental Polluted, Desert, Clear, Rural(MODTRAN), Urban(MODTRAN), and Continental Average.

Figure 5 shows the various LEEDR generated laser path transmittances. The laser path transmittances varied greatly between some of the atmosphere and aerosol effects models. Each individually plotted laser path transmittance varied slightly across time of day changes. The highest value of path transmittance, approximately 0.98, corresponds to the ExPERT atmosphere and clear aerosol effects models and nearly all the laser radiation is transmitted. The clear aerosol model has fewer aerosols and molecules to absorb and scatter the laser radiation than the other aerosol models.

The lowest laser path transmittance of 0.34 was calculated from the urban MODTRAN aerosol effects model. Higher levels of aerosols in the urban MODTRAN model absorb and scatter more of the simulated laser radiation and lower its total path transmittance. Therefore, in order to obtain accurate laser propagation results care must be taken to select the appropriate aerosol model.

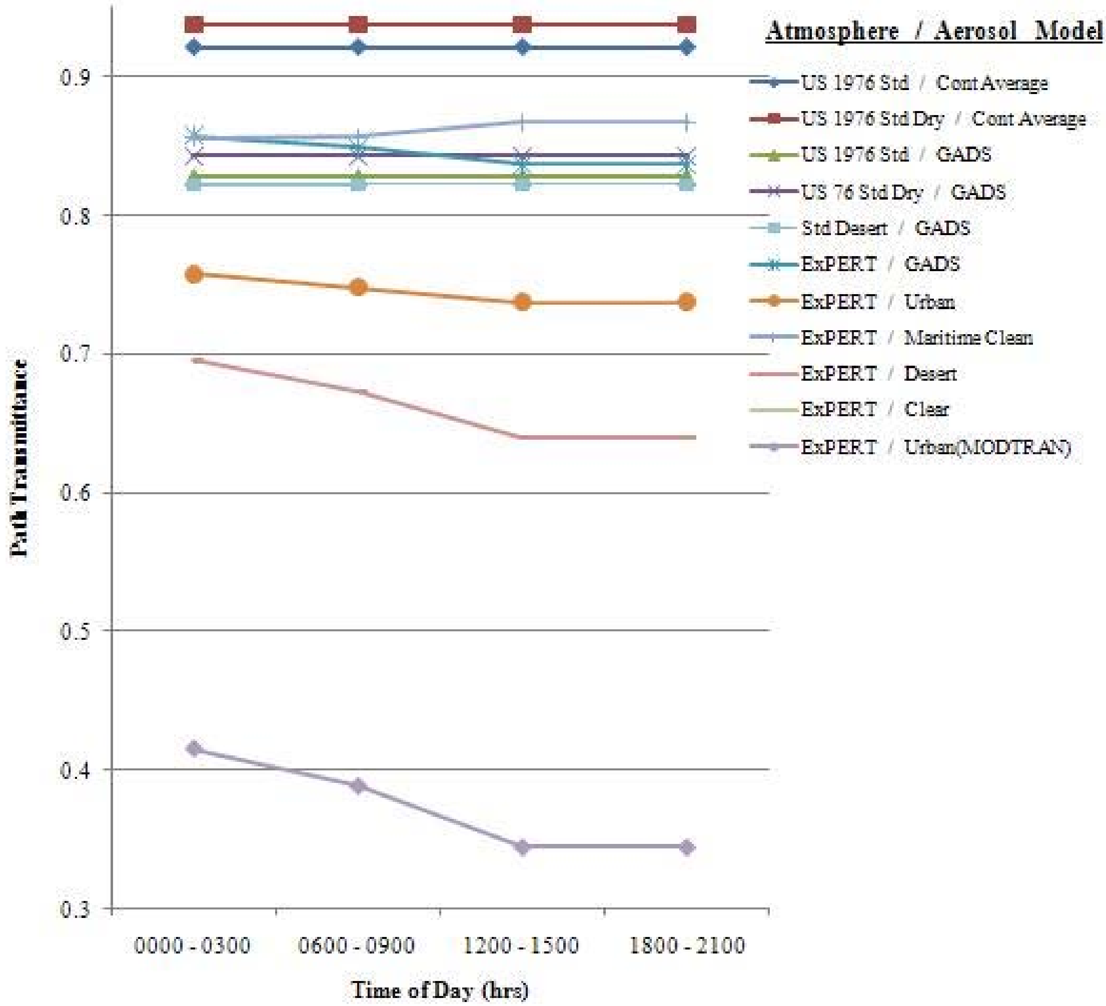

Figure 5. LEEDR laser path transmittance vs. atmosphere, aerosol, and time of day US 1976 Standard and US 1976 Standard Dry simulations modeled using the continental average and GADS aerosol models. ExPERT plots are based on a 50% - average summer day at the Nellis AFB ExPERT site using noted aerosol models and 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Figure 5 also shows that the calculated laser path transmittance varied using the GADS aerosol model with four separate atmosphere models (US 1976 Standard. US

1976 Standard Dry, Std Desert, and ExPERT). The laser path transmittance at the Nellis AFB ExPERT site is affected by the following parameters: atmosphere model, aerosols effects model, and time of day. The time of day changes affected the thickness of the boundary layer which then impacted the absorption and scattering of the laser radiation through the boundary layer. The relative humidity also changes during the day and as it increases, more scattering of the laser radiation occurs because water soluble aerosols grow in size, and scatter more energy, as relative humidity increases above 50%. Water soluble aerosols are only a small component of the aerosol mixture at Nellis AFB, and relative humidity often stays below 50%, so the effect of greater aerosol scattering with increasing relative humidity is minimized at Nellis AFB.

This impacts the research because it demonstrates that realistic aerosol models affect the simulated laser propagation in the LEEDR atmospheric model. The LEEDR atmospheric model will therefore be able to create more realism in the XCITE LVC training environment by realistically modeling aerosol atmospheric effects.

The second purpose of this step was to characterize the effects realistic worldwide atmospheric models have on the simulated laser propagation. The following LEEDR inputs were held constant: ExPERT atmosphere model, GADS aerosol model, summer season, 50% - average humidity, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, and 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain. The LEEDR laser extinction calculations for the ExPERT atmosphere and GADS aerosol models differ between worldwide sites. The following LEEDR inputs were varied: Worldwide location and time of day.

Figure 6 shows various worldwide LEEDR generated laser path transmittances. The differences in the modeled laser path transmittances are attributed to the variations between the geographic-specific atmosphere and aerosol models. Kabul and Fayzabad, Afghanistan exhibit the highest path transmittances between 0.89 and 0.91. The modeled laser path transmittance at Nellis AFB is approximately 0.83. These three locations are arid climates and laser radiation typically propagates farther in the lower humidity environments because of lower aerosol scattering effects.

Wadi Halfa, Khartoum, and Port Sudan exhibit lower path transmittances. These three cities are also located in hot arid climates but Khartoum is located in the center of Sudan and receives a significant amount of precipitation in July and August. Port Sudan is located on the Red Sea and is affected by a mixture of continental and ocean aerosols. These locations exhibit large aerosol scattering caused by water-soluble aerosols above and in the boundary layer. This increased laser aerosol scattering occurs because above 50% relative humidity the water soluble aerosols grow in size. These water soluble aerosols are a significant component of the aerosol mixture at Port Sudan. The LEEDR model is calculating realistic effects on the simulated laser path transmittance.

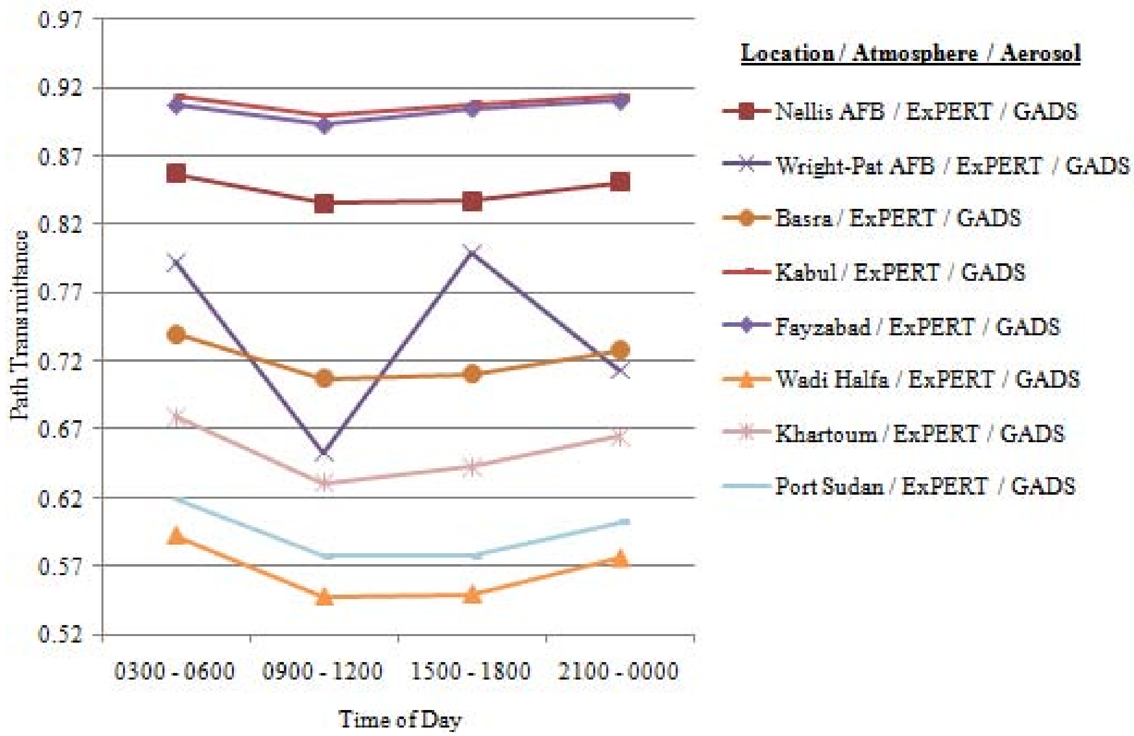

Figure 6. LEEDR laser path transmittance vs. worldwide ExPERT site and time of day Plots are based on ExPERT atmosphere and GADS aerosol models, 50% - average summer, 1.0642 µm laser wavelength, 3,000m upper altitude, 5,000m laser slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Finally, aerosol scattering affects the modeled laser radiation at Wright-Patterson AFB (WPAFB). Throughout the day both the relative humidity and boundary layer depth fluctuate. These changes cause large variations in the modeled laser path transmittance. The predominant reason that the path transmittance varies so widely at WPAFB is that the air became saturated with water vapor (99%) at the top of the boundary layer. During the 0900 – 1200 time frame the thickness of this saturated portion of the boundary layer is approximately 700 meters. During the 0300 – 0600 and 1500 – 1800 time frames the thickness of this saturated portion of the boundary layer is between 100 and 200 meters. During the 2100 – 0000 time frame the thickness of this saturated portion of the boundary layer is between 400 and 500 meters. The depth of this saturated portion of the boundary layer is three times greater during the 0900 – 1200 time frame than it is during either the 0300 – 0600 or 1500 – 1800 time frames and therefore the water soluble aerosol scattering is significantly higher. This decreases the laser path transmittance.

LEEDR Atmosphere and Aerosol Effects Simulations

In the previous step GADS was used in order to model the aerosol effects between worldwide sites. The aerosol effects from the GADS model vary between worldwide sites because the modeled aerosol concentrations are based on local site specific historic weather data. The purpose of this step was to compare worldwide path transmittances based on variations in the atmospheric model, depending on worldwide site, and the time of day. These worldwide path transmittance variations caused by the ExPERT model were also compared to path transmittances calculated from the US 1976 Standard and the US 1976 Standard Dry atmospheric models. The continental average aerosol model was used as a common aerosol model among the worldwide calculations and therefore allows for a valid comparison between worldwide atmospheric sites.

The following LEEDR inputs were held constant: Summer season, 50% - average humidity, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain. The following LEEDR inputs were varied: atmosphere model (US 1976 Standard, US 1976 Standard Dry, and ExPERT), aerosol effects model, and time of day.

Figure 7 shows the LEEDR generated laser path transmittances. The path transmittance calculated from the US 1976 Standard Dry model was 0.94 throughout the day. The path transmittance calculated from the US 1976 Standard was 0.92 throughout the day. Most of the laser path transmittances calculated from the ExPERT worldwide sites fall between, or very near to, the laser path transmittances calculated from these two standard models.

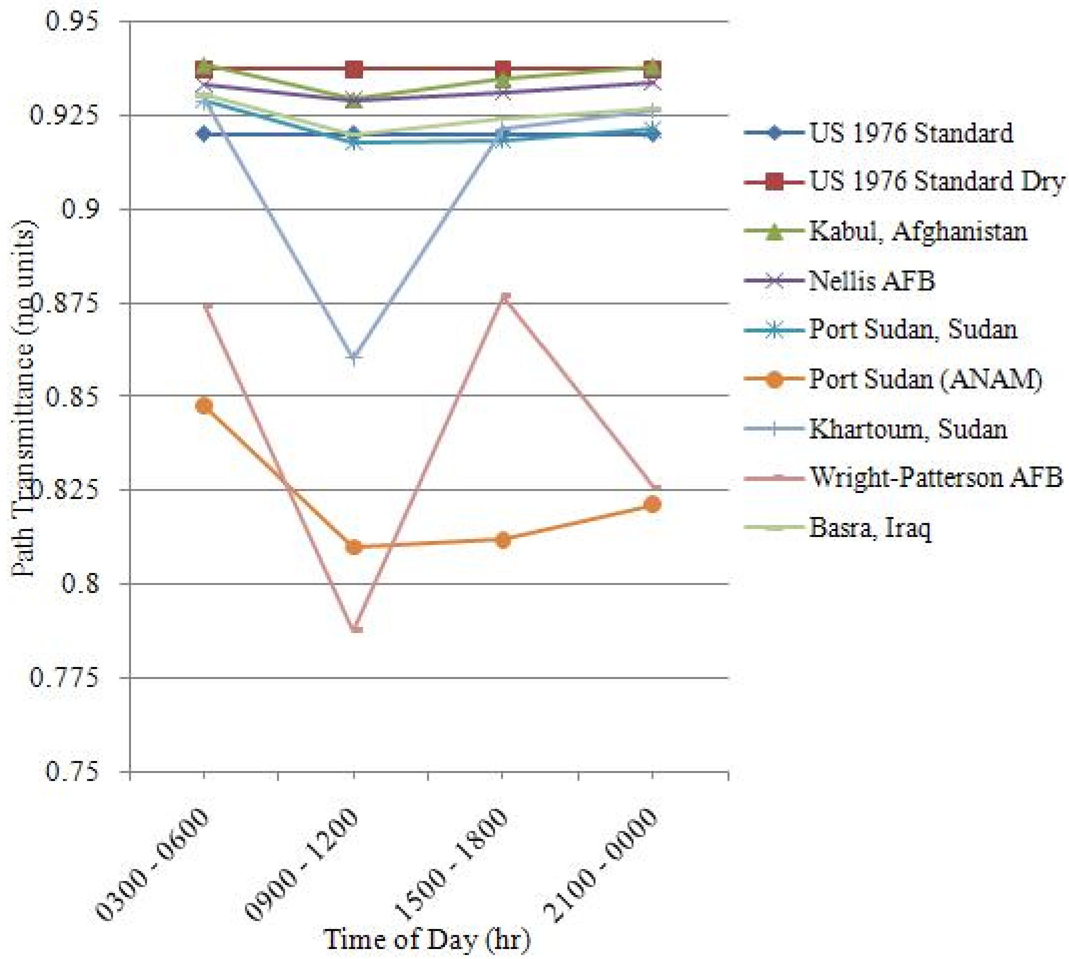

Figure 7. LEEDR laser path transmittance vs. worldwide ExPERT site and time of day All LEEDR worldwide simulations modeled using ExPERT atmosphere and continental average aerosol model unless noted otherwise. US 1976 Standard and US 1976 Standard Dry simulations modeled using the continental average aerosol model. Plots are based on a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

The laser path transmittance calculated at the Khartoum, Sudan ExPERT site during the 0900 – 1200 drops to 0.86 from 0.93. As mentioned earlier, Khartoum receives a significant amount of precipitation in July and August. During the 0300 - 0600 time frame the modeled boundary layer is 500 meters thick. The relative humidity is 55.4% at the top of this boundary layer. During the 0900 - 1200 time frame the modeled boundary layer is 1524 meters. The relative humidity near the top 200 meters of the boundary layer is 99% and the air is saturated with water vapor. This significantly increases aerosol scattering effects on the laser radiation and decreases the laser path transmittance.

The path transmittances calculated at the WPAFB ExPERT site throughout the day are significantly lower than the path transmittance based on the 1976 US standard. The path transmittance during the 0900 – 1200 time frame drops to 0.79 from 0.87. The final two path transmittances are 0.88 and 0.83. During the 0300 - 0600 time frame the modeled boundary layer is 500 meters thick. The relative humidity is 99% through the top 200 meters of this boundary layer. During the 0900 - 1200 time frame the modeled boundary layer is 1524 meters. The relative humidity near the top 700 meters of the boundary layer is 99% and the air is saturated with water vapor. This significantly increases aerosol scattering effects on the laser radiation and decreases the laser path transmittance.

Figure 8 shows a LEEDR generated total extinction plot. This plot was created from the following LEEDR inputs: Nellis AFB ExPERT site, US 1976 Standard atmosphere, continental average aerosol model, summer season, 50% - average humidity, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, and 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

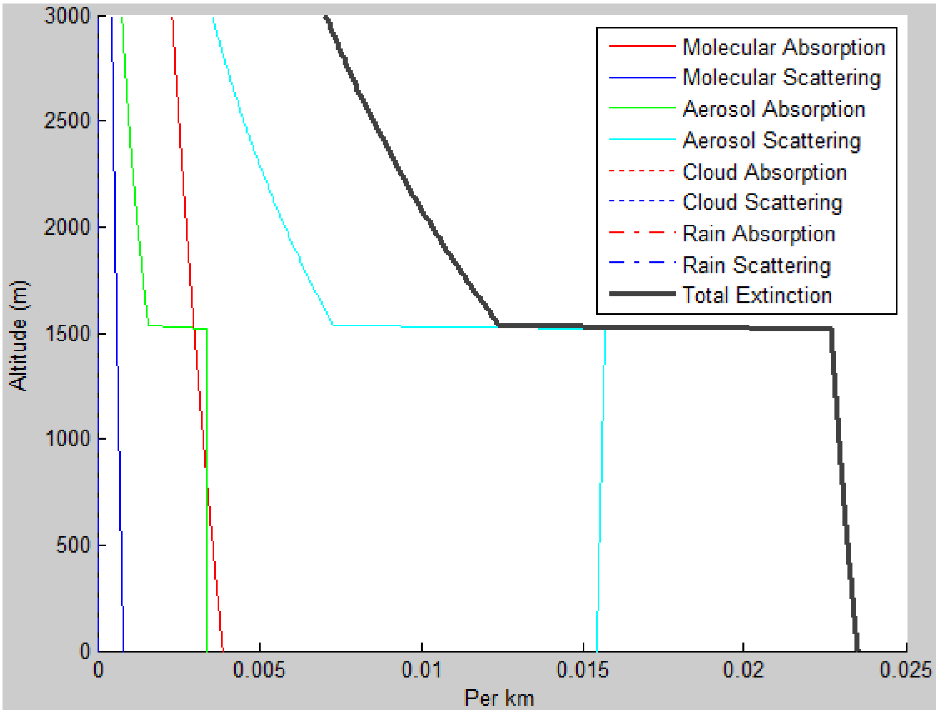

Figure 8. LEEDR total laser extinction vs. altitude - Standard Atmosphere
Modeled in LEEDR using 1976 US Standard atmosphere and continental average aerosol models. Plots based on 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

This figure shows that based on the US 1976 Standard atmosphere model the laser atmospheric extinctions caused by aerosol absorption and scattering effects slowly increase with decreasing altitude and then drastically increases at 1524 meters, the top of the boundary layer. The laser extinctions then remain nearly constant through the boundary layer. The laser extinctions caused by molecular absorption and scattering effects increase with decreasing altitude and do not change at the boundary layer. In this scenario, molecular scattering has a minimal effect on the laser extinction. Molecular scattering effects usually occur at higher altitudes.

The total laser extinction increases with decreasing altitude, but within the boundary layer it increases less than above the boundary layer because here its change is affected mostly by the molecular absorption and scattering effects. The aerosol scattering remains nearly constant through the boundary layer. The relative humidity decreases from 47.99% at 2500 meters to 46.8% at the 1524 meter boundary layer and then decreases to 44.44% at the ground level. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. The aerosol (insoluble, soot, and water soluble) concentrations change drastically at the boundary layer. The concentration or water soluble aerosols, which has the greatest effect on aerosol scattering, increases from 2005.5 molecules/cm^3 at 2500 meters to 3145.3 molecules/cm^3 at 1524 meters and then jumps to 7000 molecules/cm^3 within the boundary layer. (Refer to Appendix A) This drastic change in concentration at the boundary layer, with negligible relative humidity change, increases the total extinction at the boundary layer. Then the total aerosol scattering extinction gradually decreases throughout the boundary layer.

Figure 9 shows a similar LEEDR total laser extinction plot that was generated with all of the same inputs as those for Figure 8 except this plot is modeled using the Nellis AFB ExPERT site. The plots for laser atmospheric extinctions caused by the molecular absorption and scattering, and aerosol absorption are similar to the previous plots calculated from the US 1976 Standard atmosphere. Figure 9 shows that within the boundary layer the laser extinction caused by aerosol scattering differs significantly from the previous plot and decreases which causes the total laser extinction to decrease.

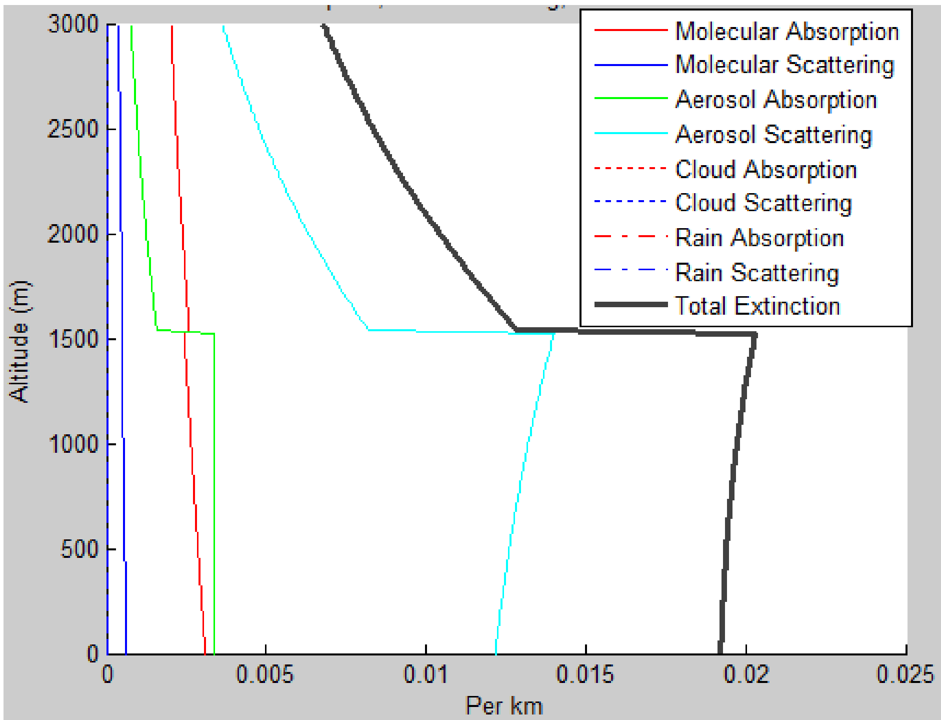

Figure 9. LEEDR total laser extinction vs. altitude - Nellis AFB 0900-1200
Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

This decrease in total extinction is caused by differences in relative humidity. The relative humidity increases from 53.2% at 2500 meters to 58.3% at 100 meters above the boundary layer. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. The relative humidity then greatly decreases to 31.6% at the 1524 meter boundary level and quickly decreases to 15.7% at the ground level. The Nellis ExPERT site exhibits large changes in relative humidity with decreasing altitude. Both Figure 8 and Figure 9 were based on the continental average aerosol model so the aerosol concentrations are identical. Recall that the water soluble aerosol concentrations are more than twice as large throughout the boundary layer as they are above the boundary (7000 molecules/cm^3 versus 3145.3 molecules/cm^3). As the relative humidity quickly decreases with altitude through the boundary layer (and the water soluble aerosol concentration remains constant) both the aerosol and total laser extinctions decrease. The LEEDR model is calculating realistic atmospheric effects on the laser propagation.

Figure 10 shows a similar LEEDR total laser extinction plot that was generated with all of the same inputs as those for Figure 8 and Figure 9, except this plot is modeled using the WPAFB ExPERT site. The effects from aerosol scattering and total extinction are markedly different than the previous two plots. The explanation for the difference is identical as before, the details and results change. The aerosol concentrations are identical to the previous figures. The relative humidity increases from 54.9% at 2500 meters to 60.4% at the 100 meters above the boundary layer. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. This is very close to the relative humidity Nellis AFB, but 29.1% higher than the corresponding relative humidity modeled using the US 1976 Standard . The relative humidity is 99% from the top of the boundary layer until nearly 700 meters below it. This saturation of the air with water vapor greatly affects the laser propagation. The relative humidity then decreases to 62.8% at the ground level. The relative humidity variations between the US 1976 Standard, Nellis ExPERT site, and the WPAFB site are demonstrated by the resulting total extinction variations. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. The LEEDR model is calculating realistic atmospheric effects on the laser propagation and these effects can show significant variations.

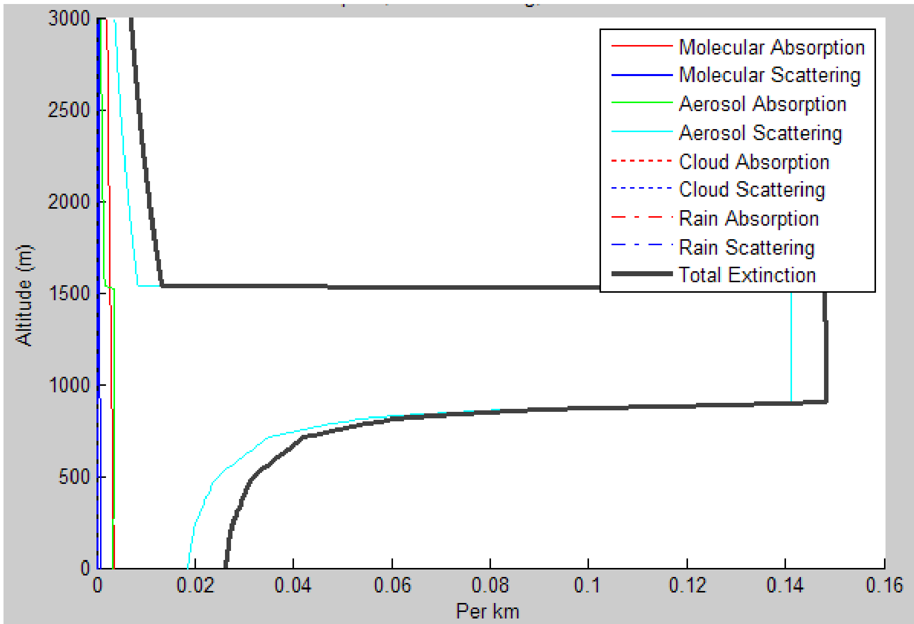

Figure 10. LEEDR total laser extinction vs. altitude - WPAFB 0900-1200
Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

The results show that the modeled laser path transmittance is affected by the worldwide location (which affects the calculations in the LEEDR atmosphere model) and time of day. Similar aerosol concentrations at separate worldwide locations cause variations in laser path transmittance due to local environmental conditions. This impacts the research because it demonstrates that the LEEDR atmospheric model can create more realism in the XCITE LVC training environment by realistically modeling worldwide laser propagation based on atmosphere, aerosol, and time of day effects. This LEEDR output can be correlated to laser target lock-on ranges and may create more realism in the XCITE LVC training environment.

LEEDR Reduced Visibility and Rain Simulations

The purpose of this step was to characterize the laser propagation effects that realistic reduced visibility and rain cause. This is important because the Earth's atmosphere isn't always clear and cloud free and surface visibility fluctuates based on climate and atmospheric conditions. Simulations modeling clouds were not conducted because clouds completely attenuate the laser propagation. These simulations were conducted using the Nellis AFB ExPERT site and the more humid WPAFB ExPERT site.

The following LEEDR inputs were held constant: Summer season, 50% - average humidity, continental average aerosol model, 0900 – 1200 time of day, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain. The following LEEDR inputs were varied: ExPERT site and surface visibility. Laser path transmittances were obtained from LEEDR based on the following surface visibilities: 5, 10, 15, 20, 30, 40, 50, and 60 kilometers. The LEEDR modeled laser path transmittances were correlated to TAWS calculated target lock-on-ranges. Results and analysis follow in the next chapter.

Finally light rain effects were modeled in LEEDR. Two separate setups were modeled. In the first simulation the following LEEDR inputs were held constant: Light (5 mm/hr) rain, lower rain altitude, summer season, 50% - average humidity, continental average aerosol model, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

The following LEEDR inputs were varied: Upper rain altitude, ExPERT site, and time of day. Laser path transmittances were obtained from LEEDR at the Nellis AFB and WPAFB ExPERT sites throughout the day. Upper rain altitude was modeled at 3,000 and 500 meters. Clouds were not included when the upper rain altitude was set at 500 meters because the laser propagation through the clouds would have been 0. Even though this is an unrealistic case, these results can be compared to the previous simulations conducted at 3,000 meters.

At WPAFB during the 0900 – 1200 time frame with rain modeled from 500 meters to the ground level the laser path transmittance was 0.33. With rain modeled from 3000 meters to ground level the path transmittance was 0.005. With no rain modeled the path transmittance was 0.79. At Nellis AFB during the 0900 – 1200 time frame with rain modeled from 500 meters to the ground level the laser path transmittance was 0.39. With rain modeled from 3000 meters to ground level the path transmittance was 0.006. With no rain modeled the path transmittance was 0.93. These LEEDR modeled laser path transmittances were correlated to TAWS calculated target lock-on-ranges.

During the second modeled rainy day the following LEEDR inputs were held constant: light (5 mm/hr) rain, lower rain altitude, upper rain altitude, summer season, 50% - average humidity, continental average aerosol model, 1.0642 micrometers laser wavelength, 500 meter aircraft upper altitude, 1,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

The following LEEDR inputs were varied: ExPERT site and time of day. Laser path transmittances were obtained from LEEDR at the Nellis AFB and WPAFB ExPERT sites throughout the day. This scenario modeled the deck of clouds directly above the 500 meter aircraft altitude. Rain was modeled from 500 meters to the ground level.

At WPAFB during the 0900 – 1200 time frame with the laser targeting pod simulated at 500 meters and rain modeled from 500 meters to the ground level the laser path transmittance was 0.35. At Nellis AFB with the same conditions the laser path transmittance was 0.36. These LEEDR modeled laser path transmittances were correlated to TAWS calculated target lock-on-ranges.

Figure 11 shows the LEEDR generated total laser extinction at WPAFB during the 0900 – 1200 time frame. The molecular and aerosol absorption and scattering and rain absorption effects on the propagation of the laser radiation are small. Rain scattering affects the laser propagation greatly. The relative humidity modeled at WPAFB decreases from 80.6% at 500 meters to 62.9% at the ground level. The change in relative humidity affects the aerosol scattering and therefore the laser propagation, but its effect is almost two orders of magnitude less than the rain scattering (extinction of 0.025 km^{-1} versus 0.98 km^{-1}). The modeled rain absorption extinction was also 0.025 per km. Similar results are shown in Figure 12 based on the Nellis AFB ExPERT site. The modeled relative humidity decreases from 19.6% at 500 meters to 15.7% at the ground level. The modeled aerosol scattering is 0.012 km^{-1}, rain absorption 0.025 km^{-1}, and rain scattering .98 km^{-1}. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. Light (5 mm/hr) rain causes large rain scattering effects and laser extinction and lowers the laser propagation.

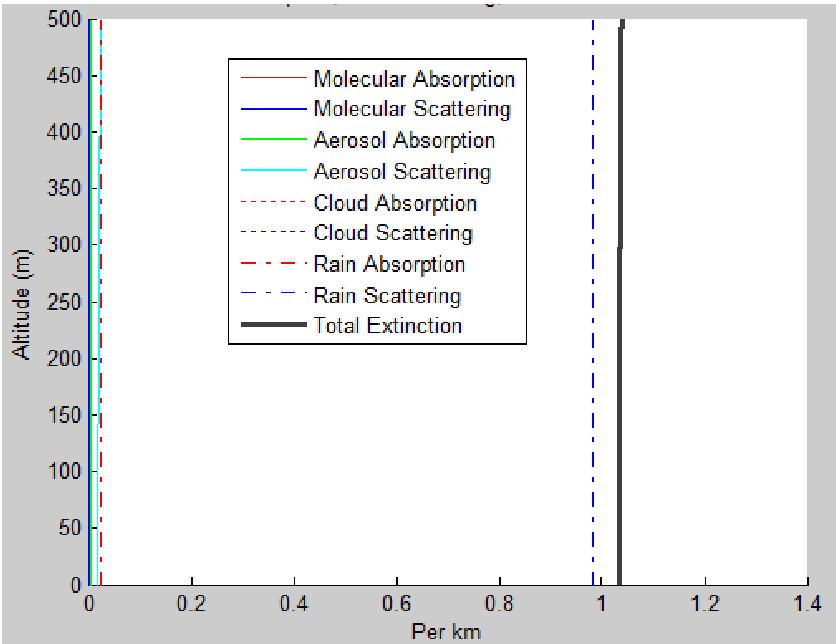

Figure 11. LEEDR laser total extinction vs. altitude - WPAFB 0900-1200
Plot is based on light rain (5 mm/hr), ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 μm laser wavelength, 500 m upper altitude, 1,000 m slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

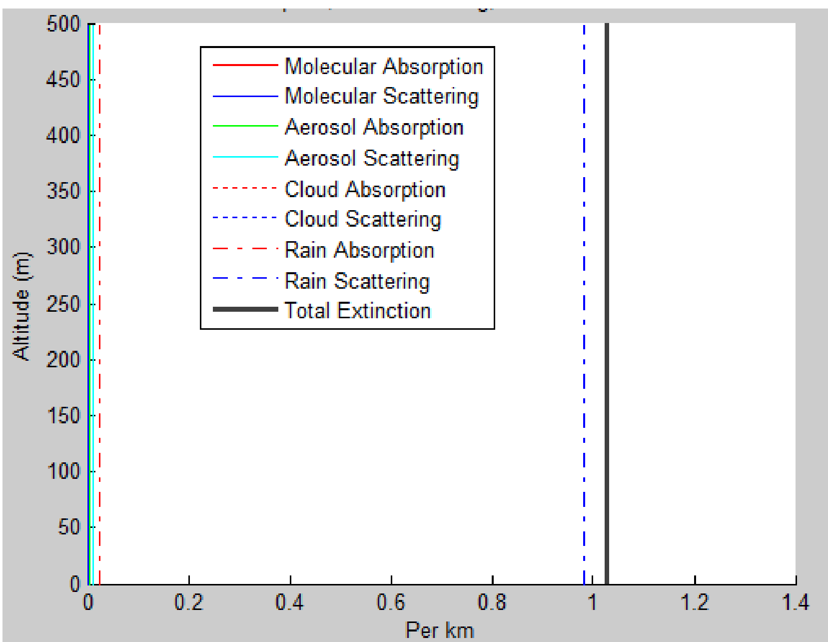

Figure 12. LEEDR laser total extinction vs. altitude - Nellis AFB 0900-1200
Plot is based on light rain (5 mm/hr), ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 μm laser wavelength, 500 m upper altitude, 1,000 m laser slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

These results show that the modeled laser path transmittance is affected by the surface visibility variations and light (5mm/hr) rain. This impacts the research because it demonstrates that the LEEDR atmospheric model can create more realism in the XCITE LVC training environment by realistically modeling worldwide laser propagation based on surface visibility and rain. This LEEDR output can be correlated to laser target lock-on ranges and to create realistic environments in the XCITE LVC simulation.

TAWS Correlation

TAWS was run to generate simulated target lock-on ranges. These simulated ranges were based on a 7002/5000 generic USAF airborne laser designator and targeting pod. The target location was set at the Nevada Test and Training Range. The following TAWS inputs were held constant: Summer season, 1.0642 micrometers laser wavelength, 3,000 meter sensor upper altitude, no rain, surface visibility 10 km. The following TAWS inputs were varied: surface aerosol index and time of day. Weather data was not utilized in TAWS. Differences in transmittances were calculated based on variations in aerosol indices. The following aerosol indices were modeled: Rural, Urban, Troposphere, Desert, White Phosphorus Camouflage Smoke, Fog Oil Camouflage Smoke, Hexachloroethane Camouflage Smoke, Fog Heavy Advection, Fog Moderate Radiation, Dust Light Loading, Dust Heavy Loading, and Dust High Explosive.

A limited list of transmittance and target lock-on ranges based on aerosol index was output from TAWS. These TAWS calculated transmittance values did not match the LEEDR generated path transmittances. Linear interpolation and extrapolation was conducted to generate TAWS transmittance and target lock-on ranges that correlated to the exact LEEDR calculated path transmittances. A lookup table was populated with the LEEDR calculated laser path transmittances and the correlated TAWS calculated target lock-on ranges. This table was then programmed into the XCITE LVC threat generation environment.

Incorporation of Laser Target Lock-On Ranges

The end result of this work was the creation and population of this lookup table and its final incorporation into the XCITE LVC threat generation environment simulator. The lookup table provided the ability to simulate engagement scenarios based on laser target lock-on range differences. These correlated range differences were caused by LEEDR modeled atmospheric, aerosol and time of day effects on the laser propagation. XCITE scenarios were then run based on these simulated laser target lock-on ranges.

Summary

LEEDR successfully modeled the atmospheric, aerosol and time of day effects on the propagation of 1.0642 micrometer laser radiation and output corresponding laser path transmittances. The modeled laser path transmittances were affected by the worldwide location, atmosphere model, aerosol model and time of day. In several simulations the environmental conditions caused large aerosol scattering that was affected by the time of day and the relative humidity. These modeled laser path transmittances were correlated to TAWS calculated laser target lock-on ranges and incorporated into the XCITE LVC simulation. This impacts the research because it demonstrates that the LEEDR atmospheric model can create more realism in the XCITE LVC training environment by realistically modeling worldwide atmosphere, aerosol, and time of day effects.

IV. Analysis and Results

Chapter Overview

This chapter discusses the clear and cloud free, reduced surface visibility, and rain modeled target lock-on ranges that were correlated to LEEDR path transmittances.

Clear and Cloud Free Modeled Target Lock-On Ranges

Figure 13 shows laser target lock-on ranges versus time of day. TAWS was used to correlate these ranges to the LEEDR modeled laser path transmittances. The correlated ranges are based on the following LEEDR inputs: Summer season, 50% - average humidity, 1.0642 micrometers laser wavelength, 3,000 meter aircraft upper altitude, 5,000 meter laser propagation slant path, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain. Within TAWS a 7002/5000 generic USAF airborne laser designator and targeting pod was selected. The worldwide location and time of day were varied. The continental aerosol effects model was used for all simulations save the second Port Sudan that was simulated with ANAM. The US 1976 Standard, US 1976 Standard Dry, and ExPERT atmosphere models were selected. The correlated laser target lock-on ranges are affected by worldwide location, time of day and aerosol model.

Figure 13 shows that the laser target lock-on range correlated to the US 1976 Standard Dry model was 8.85 km throughout the day. The target lock-on range correlated to the US 1976 Standard was 8.61 km throughout the day. Correlated lock-on ranges to Kabul, Nellis AFB, and Port Sudan(continental average aerosol model) ExPERT sites are similar to the ranges correlated to the US 1976 Standard and US 1976

Standard Dry models. The laser lock-on range correlated to the Khartoum, Sudan ExPERT site during the 0900 – 1200 drops to 7.78 km from 8.54 km. As mentioned earlier, Khartoum receives a significant amount of precipitation in July and August. During the 0300 – 0600 time frame the modeled boundary layer is 500 meters thick and the relative humidity is 55.4% at the top. During the 0900 - 1200 time frame the modeled boundary layer is 1524 meters and the relative humidity through the top 200 meters is 99% and the air is saturated with water vapor. This significantly increases aerosol scattering effects on the laser radiation and decreases the correlated laser lock-on range.

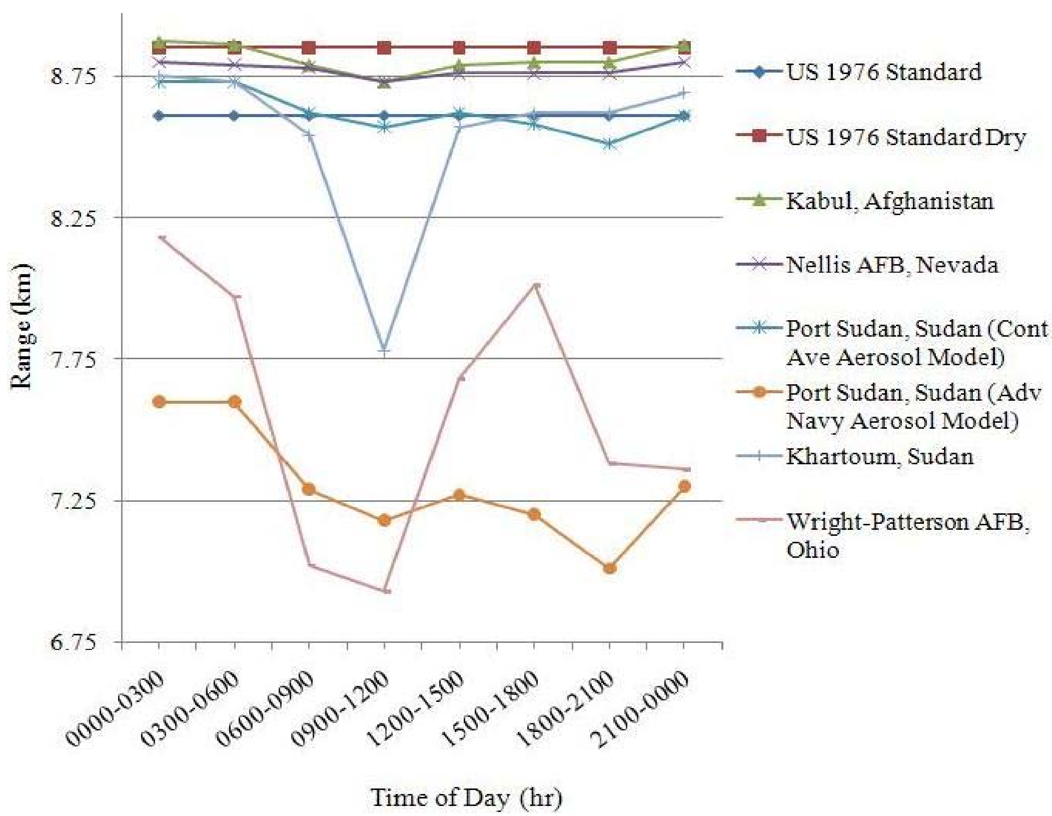

Figure 13. XCITE simulated target lock-on range vs. worldwide site and time of day
All worldwide simulations modeled in LEEDR using ExPERT atmosphere and continental average aerosol model unless noted otherwise. US 1976 Standard and US 1976 Standard Dry simulations modeled using the continental average aerosol model. Plots are based on a 50% - average summer, 1.0642 μm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Figure 13 also shows that throughout the day the WPAFB and Port Sudan (ANAM) correlated target lock-on ranges are lower than the target lock-on range correlated to the US 1976 Standard. During the 0900 – 1200 time frame the WPAFB ExPERT site correlated laser lock-on range decreases to 6.93 km. This is 1.68 km shorter than the target lock-on range correlated to the US 1976 Standard. The relative humidity is higher at WPAFB ExPERT site and varies during the day. Water soluble aerosols are a large component of the aerosol mixture at WPAFB and the relative humidity was 99% through the top 700 meters of the boundary layer. This higher relative humidity creates more laser aerosol scattering through the boundary layer because above 50% the water soluble aerosols grow in size and scatter more energy. LEEDR successfully used the ExPERT worldwide surface weather data to accurately characterize the boundary layer aerosol scattering and its affect on the laser propagation.

Finally, Figure 13 shows that the Port Sudan target lock-on ranges, that were correlated to the continental average aerosol model, are nearly identical to the ranges correlated to the US 1976 Standard Atmosphere model. These Port Sudan, ANAM correlated target lock-on ranges are more than 1 km shorter because of increased aerosol scattering. The relative humidity was only 64.2% at the top of the boundary layer (Refer to Appendix A), but the sea salt spray causes larger soluble aerosols to exist over oceans and seas. These larger sized modeled aerosols decreased the correlated ANAM laser target lock-on ranges.

The percentage differences between the correlated lock-on ranges modeled by the US 1976 Standard atmosphere and the ranges correlated to the worldwide ExPERT sites are shown in Table 1. In this table the correlated range to the US 1976 Standard atmosphere is used as a baseline and all other correlated ranges shown are compared to it. The correlated lock-on ranges to Kabul, Nellis AFB, and Port Sudan(continental average aerosol model) ExPERT sites are within 3.0% of the 8.61 km correlated US 1976 Standard range. These dryer climates exhibit higher path transmittances and have higher correlated lock-on ranges because the lower relative humidity's cause less laser aerosol scattering. Once again, the ExPERT worldwide surface weather data is used by LEEDR to accurately model the boundary layer aerosol scattering and its affect on the laser propagation.

Table 1. Variations in simulated lock-on ranges from range based on US 1976 Standard All worldwide simulations modeled in LEEDR using ExPERT atmosphere and continental average aerosol model unless noted otherwise. US 1976 Standard and US 1976 Standard Dry simulations modeled using the continental average aerosol model. Plots are based on a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Time of Day:	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-0000
Location / Atmosphere / Aerosol	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)	Delta from US 1976 Std (%)
US 1976 Standard / Cont Ave	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
US 1976 Standard dry / Cont Ave	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%	2.8%
Kabul / ExPERT / Cont Ave	3.0%	2.9%	2.1%	1.4%	2.1%	2.2%	2.2%	2.9%
Nellis AFB / ExPERT / Cont Ave	2.2%	2.1%	2.0%	1.4%	1.7%	1.7%	1.7%	2.2%
Port Sudan / ExPERT / Cont Ave	1.4%	1.4%	0.1%	-0.5%	0.1%	-0.3%	-1.2%	0.0%
Khartoum / ExPERT / Cont Ave	1.6%	1.4%	-0.8%	-9.6%	-0.5%	0.1%	0.1%	0.9%
WP AFB / ExPERT / Cont Ave	-5.0%	-7.4%	-18.5%	-19.5%	-10.8%	-7.0%	-14.3%	-14.5%
Port Sudan / ExPERT / ANAM	-11.7%	-11.7%	-15.3%	-16.6%	-15.6%	-16.4%	-18.6%	-15.2%

Table 1 also shows that one of the correlated ranges modeled using the WPAFB ExPERT site was degraded up to 19.5% when compared to the correlated range modeled using the US 1976 Standard. One of the correlated ranges modeled using the Port Sudan (ANAM) ExPERT site was degraded up to 18.6% when compared to the correlated range modeled using the US 1976 Standard. The higher variable relative humidity modeled by the WPAFB ExPERT site caused higher laser aerosol scattering from water soluble aerosols that increased in size. Sea salt spray caused larger soluble aerosols modeled at Port Sudan, ANAM to scatter more laser radiation and reduce the correlated target lock-on range.

Finally the correlated range difference from the Khartoum, Sudan was 9.6% lower during the 0900 – 1200 time frame than the correlated range modeled using the US 1976 Standard. The largest difference during the rest of the day was 1.6%. During the 0900 – 1200 time frame the relative humidity near the top 200 meters of the boundary layer is 99% and the air is saturated with water vapor. This increases the laser aerosol scattering effects and decreases the correlated laser lock-on range.

A comparison of the site specific correlated lock-on ranges can be made. During the 0900 – 1200 time frame the laser target lock-on ranges at the Khartoum and WPAFB ExPERT sites show a larger total difference than during other time frames from each respective site. The Khartoum correlated range difference between the 0900 – 1200 and the 0000 – 0300 time frames is 0.97 km. The corresponding WPAFB correlated range difference is 1.25 km. Table 2 and Table 3 show that during the 0900 – 1200 time frame the Khartoum correlated target lock-on range is 11.1% lower than the 0000 – 0300 correlated lock-on range. Excluding the 0900 – 1200 time frame, the next largest variation occurred during the 0600 – 0900 time frame and was only 2.4%. Table 3 shows that between the 0900 – 1200 and 0000 – 0300 time frames the WPAFB correlated ranges differed by 15.3%.

Table 2. Variations in laser simulated target lock-on ranges throughout the day Modeled in LEEDR using ExPERT atmosphere and continental average aerosol model and a 50% - average summer, 1.0642 µm laser wavelength, 3,000 m upper altitude, 5,000 m slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Time of Day:	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-0000	Daily Ave
Location / Atmosphere / Aerosol	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)	Delta from 0000-0300 Range (%)
Khartoum / ExPERT / Cont Ave	0.0%	-0.2%	-2.4%	-11.1%	-2.1%	-1.5%	-1.5%	-0.7%	-2.7%

Table 3. Variations in simulated lock-on range compared to 0000–0300 time frame range Modeled in LEEDR using ExPERT atmosphere and continental average aerosol model and a 50% - average summer, 1.0642 µm laser wavelength, 3,000 m upper altitude, 5,000 m slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Time of Day:	0900-1200
Location / Atmosphere / Aerosol	Delta from 0000-0300 Range (%)
Khartoum / ExPERT / Cont Ave	-11.1%
WP AFB / ExPERT / Cont Ave	-15.3%

These results show that significant variations, up to 19.5%, occurred between ranges correlated to path transmittances modeled using the US 1976 Standard atmosphere model versus ranges correlated to path transmittances modeled using the worldwide ExPERT sites. These correlated ranges vary during the day and one calculated range during the day varied by 15.3% from the beginning of the day. These results are based on relative humidity and aerosol scattering variations. This demonstrates realistic worldwide lock-on variations based on atmosphere, aerosol, and time of day effects.

Reduced Surface Visibility and Rain Modeled Target Lock-On Ranges

The surface visibility was varied between 5 km and 60 km at the Nellis and WPAFB ExPERT sites. The path transmittances were recorded at each modeled surface visibility and correlated to TAWS generated target lock-on ranges. Figure 14 shows that the simulated lock-on ranges are affected by worldwide location and surface visibility.

Figure 14 also shows that the correlated target lock-on ranges increase with increasing surface visibility. The previous simulations, with identical conditions, were run using LEEDR default visibilities of 59.64 km at the Nellis AFB ExPERT site and 42.96 km at the WPAFB site. Table 4 shows a comparison of the target lock-on ranges modeled with reduced surface visibilities to the range calculated using the default LEEDR visibility. Several of the WPAFB correlated lock-on ranges show considerable degradation with low surface visibility. The reduced surface visibility is caused by higher aerosol and pollutant concentrations which cause increased aerosol absorption and scattering of the laser radiation. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. Decreased surface visibility causes degradations in correlated laser lock-on ranges. This demonstrates that the LEEDR atmospheric model can create more realism in the XCITE LVC training environment by realistically modeling worldwide surface visibility effects. LEEDR is able to use the ExPERT climate surface database to accurately model the boundary layer aerosol scattering and its affect on the laser propagation.

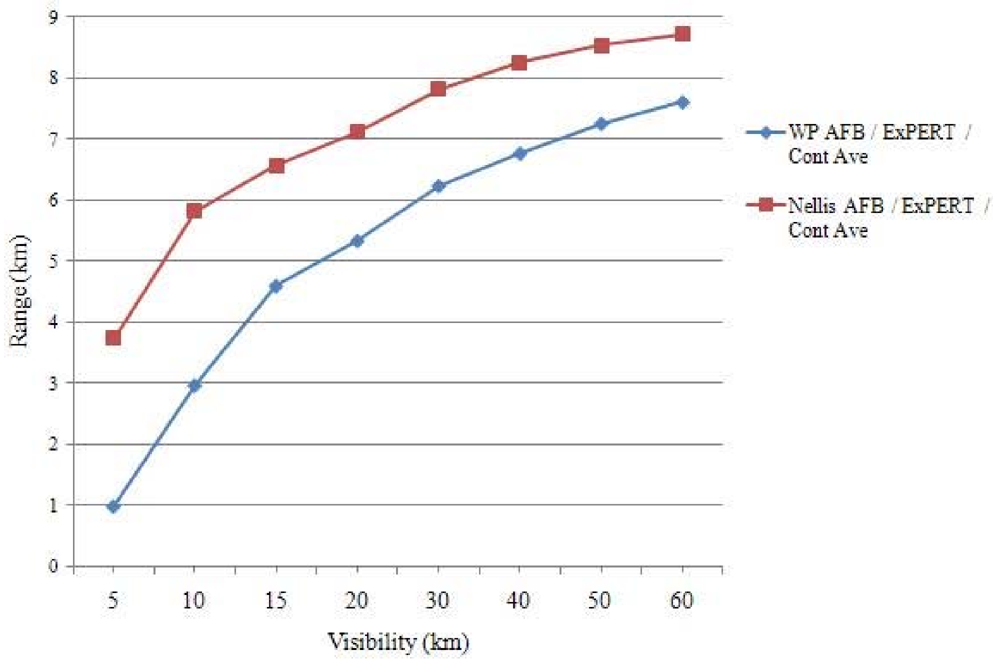

Figure 14. Simulated target lock-on range vs. surface visibility - 0900–1200
Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, no rain.

Table 4. Variations in simulated lock-on ranges from default LEEDR visibility range
Based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Surface Visibility:	5	10	15	20	30	40	50	60
Location / Atmosphere / Aerosol	Δ from default vis	Δ from default vis	Δ from default vis	Δ from default vis	Δ from default vis	Δ from default vis	Δ from default vis	Δ from default vis
WP AFB / ExPERT / Cont Ave	-85.7%	-57.1%	-33.6%	-22.9%	-10.0%	-2.3%	4.8%	9.8%
Nellis AFB / ExPERT / Cont Ave	-57.3%	-33.3%	-24.9%	-18.6%	-10.4%	-5.4%	-2.2%	-0.1%

Finally rain was added into the simulation by modeling a light, 5 mm per hour, rain at the Nellis AFB and WPAFB ExPERT sites with the aircraft at 3,000 m AGL and a 5,000 m laser slant path. Figure 15 shows results from three scenarios: no rain, light rain from ground level to the 3,000 m AGL, and light rain from ground level to 500 m AGL.

The third scenario did not model clouds because they would completely attenuate the laser propagation. Even though this is an unrealistic case, it was modeled in order to provide a comparison with the previous simulations at 3,000 meters AGL. The simulated lock-on ranges through 500 m rain are 50% lower than the corresponding ranges modeled without rain. Table 5 shows numerically the effect rain had in these scenarios. Practically, none of the laser radiation propagates through the rain modeled from 0 to 3,000 meters AGL. When compared to the lock-on ranges through clear skies, the ranges of the laser radiation through 500 m rain is reduced by approximately 60% at both the Nellis AFB and WPAFB ExPERT sites.

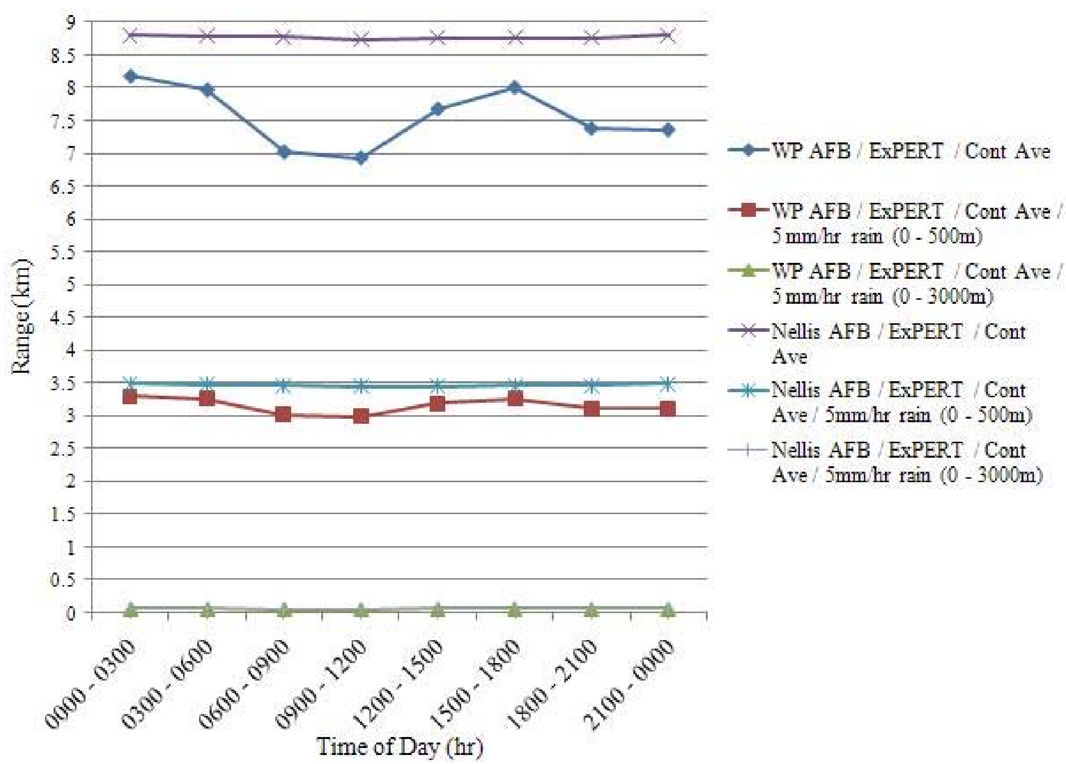

Figure 15. Simulated target lock-on range vs. time of day with and without light rain
Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

Table 5. Variations in simulated lock-on ranges with light rain (5 mm/hr) – 3,000 m Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 μm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

Time of Day:	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-0000
Location / Atmosphere / Aerosol / Rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain
WP AFB / ExPERT / Cont Ave / 5 mm/hr rain (0-500m)	-59.7%	-59.1%	-57.1%	-56.9%	-58.5%	-59.3%	-57.9%	-57.9%
WP AFB / ExPERT / Cont Ave / 5 mm/hr rain (0-3000m)	-99.4%	-99.3%	-99.3%	-99.3%	-99.3%	-99.4%	-99.3%	-99.3%
Nellis AFB / ExPERT / Cont Ave / 5mm/hr rain (0-500m)	-60.5%	-60.5%	-60.6%	-60.6%	-60.6%	-60.5%	-60.5%	-60.5%
Nellis AFB / ExPERT / Cont Ave / 5mm/hr rain (0-3000m)	-99.4%	-99.4%	-99.4%	-99.4%	-99.4%	-99.4%	-99.4%	-99.4%

Rain was then modeled within LEEDR from the ground level to 500 meters AGL. The aircraft was modeled at 500 meters (directly below the clouds) with a selected laser slant path of 1,000 meters. Figure 16 shows the correlated target lock-on ranges with and without light rain effects throughout the day at the Nellis AFB and WPAFB ExPERT sites. The ranges correlated to both ExPERT sites are adversely affected by the light rain and are both approximately 3.1 km throughout the day. This is at least 50% lower than the ranges modeled without rain effects. The rain absorbs some of the laser radiation and scatters a significant amount of it. This rain scattering reduces the simulated target lock-on ranges. Refer to Appendix A for a LEEDR generated output file that shows the detailed atmospheric effects and characteristics. Table 6 shows the laser target lock-on ranges modeled with rain compared to the simulated ranges modeled without rain. The modeled lock-on ranges through light rain are reduced by approximately 60%. The simulated laser target lock-on ranges are affected by both the worldwide location and light, 5 mm per hour, rain.

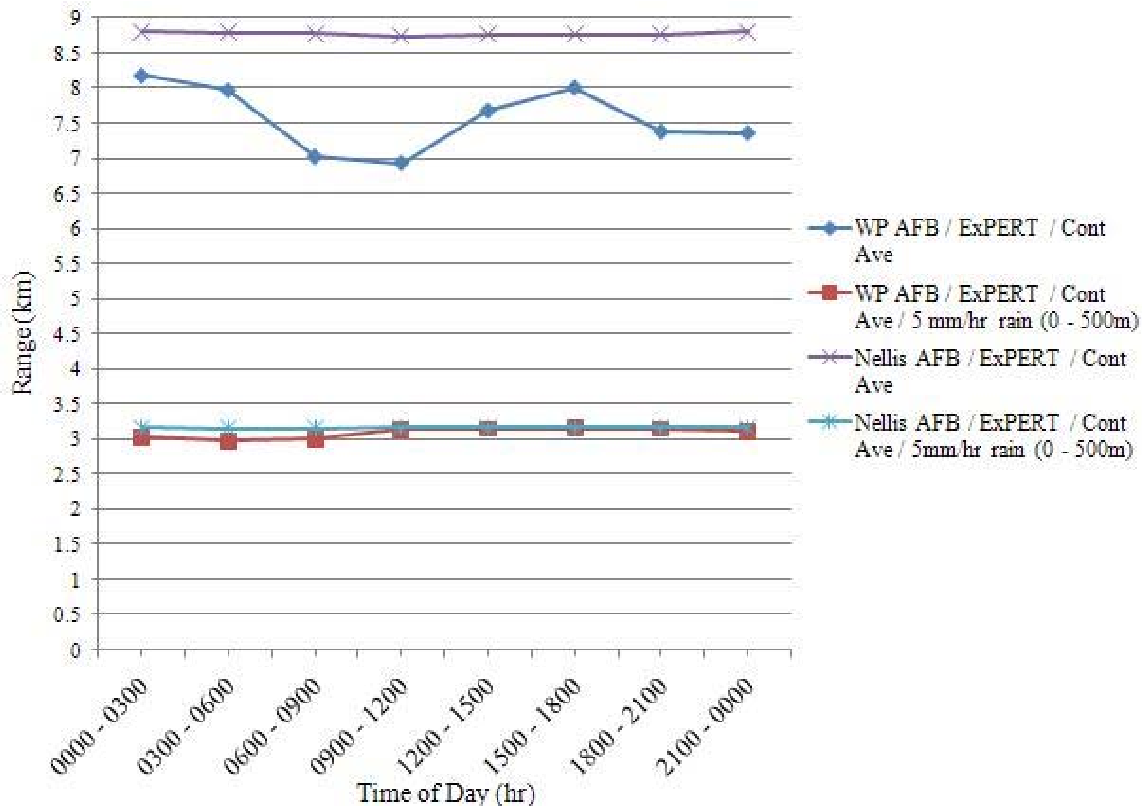

Figure 16. Simulated target lock-on range vs. time of day with and without light rain
Plot is based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 500 meter upper altitude, 1,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

Table 6. Variations in simulated lock-on ranges with light rain (5 mm/hr) – 500 m
Based on ExPERT atmosphere, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 500 meter upper altitude, 1,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile.

Time of Day:	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-0000
Location / Atmosphere / Aerosol / Rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain	Delta from no rain
WP AFB / ExPERT / Cont Ave / 5 mm/hr rain (0 - 500m)	-63.1%	-62.7%	-57.3%	-54.8%	-59.1%	-60.7%	-57.5%	-57.9%
Nellis AFB / ExPERT / Cont Ave / 5mm/hr rain (0 - 500m)	-64.1%	-64.2%	-64.1%	-63.8%	-63.9%	-63.9%	-63.9%	-64.1%

These results show that the modeled laser path transmittance is affected by the surface visibility variations and light, 5mm per hr, rain. This impacts the research because it demonstrates that the LEEDR atmospheric model can create more realism in the XCITE LVC training environment by realistically modeling worldwide laser propagation based on both surface visibility and rain.

Summary

LEEDR successfully modeled the worldwide atmospheric, aerosol, time of day, reduced surface visibility, and rain effects on the propagation of 1.0642 micrometer laser radiation. Environmental conditions caused some aerosol and rain absorption and large aerosol and rain scattering effects based on worldwide time of day and the relative humidity variations. LEEDR modeled laser path transmittances were correlated to TAWS generated laser target lock-on ranges and subsequently used to create realistic environments in the XCITE LVC simulation. The ExPERT worldwide surface weather data was used within LEEDR to accurately model the boundary layer aerosol and rain scattering effects on the laser propagation. This impacts the research because it demonstrates that the LEEDR atmospheric model, with extensive historic surface weather data, can create more realism in the XCITE LVC training environment by realistically modeling worldwide atmosphere, aerosol, time of day, reduced surface visibility, and rain effects.

V. Conclusions and Recommendations

Chapter Overview

This chapter draws the final conclusions, discusses the significance and makes recommendations for future research.

Conclusions of Research

The LEEDR atmospheric model was used to create more realism for the XCITE LVC training environment by realistically modeling worldwide 1.0642 micrometer laser transmission based on variations in atmosphere & aerosol models, time of day, surface visibility, and rain. These atmospheric effects caused differences in the LEEDR modeled laser transmission. Taking into account these realistic atmospheric effects improved the predicted laser transmission. These LEEDR modeled variations in laser transmission were correlated to simulated target lock-on ranges and incorporated into XCITE.

Actual target lock-on ranges also exhibit differences caused by atmospheric effects. Therefore, both the simulated and actual target lock-on ranges exhibit changes based on atmospheric effects. This demonstrates that the LEEDR atmospheric model created more realism in the XCITE LVC training environment. The original research question can now be answered in the affirmative because the simulation is exhibiting realistic variations.

The aerosol absorption and scattering effects on the laser propagation were evaluated in several different scenarios, including the average effects over continents, through light rain, and through limited surface visibility environments. The results clearly show, as expected, that worldwide geographic locations, with their respective climates and atmospheres, affect the 1.0642 micrometer laser propagation. With all other variables equal, this laser radiation propagates farther in the dryer atmospheres and climates and is absorbed and scattered more in higher humidity atmospheres and climates.

It is shown that the laser propagation at worldwide geographic sites is affected by the atmospheric conditions at each specific location. Many sites can be approximated well using the US 1976 Standard Atmosphere. Target lock-on ranges modeled from locations that contain lower water vapor content generally have less variation from the range modeled using the US 1976 Standard Atmosphere. Conversely, those geographic areas and climates that contain higher water vapor content in the atmosphere result in modeled target lock-on ranges that vary significantly from the range based on the US 1976 Standard Atmosphere. During the 0900 – 1200 time frame, the target lock-on range based on the US 1976 Standard atmosphere model was 19.5% higher than the target lock-on range calculated at the WPAFB ExPERT site.

In addition, except during the 0900 – 1200 time frame the simulated laser target lock-on ranges at Khartoum, Sudan, matched well the range modeled using the US 1976 Standard atmosphere. During the 0900 – 1200 time frame the correlated target lock-on range varied 9.6% from range modeled using the 1976 US Standard atmosphere. The largest correlated target lock-on range variation, from the range modeled using the 1976 US Standard atmosphere, during the rest of the day was only 1.6%. Variations in worldwide atmospheric conditions cause differences in laser path transmittances. These differences manifest themselves in variations in simulated correlated target lock-on ranges.

These results clearly show that the modeled time of day can affect the overall laser transmission. Simulated target lock-on ranges were correlated to different path transmittances caused by variations in time of day. The correlated laser target lock-on ranges modeled during the 0900 – 1200 time frame at the Khartoum and WPAFB ExPERT sites differ by more than 10% from their respective modeled ranges during the 0000 – 0300 time frame. The correlated range modeled at Khartoum varied 11.1% during 0900 – 1200 time frame. The correlated range modeled at WPAFB varied 15.3% during 0900 – 1200 time frame. Excluding the 0900 – 1200 time frame, the largest Khartoum variation in correlated target lock-on range during all other time frames was only 2.4% (during the 0600 – 0900 time frame).

The results also demonstrate the importance of realistically modeling the local aerosol effects. Simulated target lock-on ranges were correlated to various path transmittances caused by aerosol effects. Two simulations were modeled at the Port Sudan, Sudan ExPERT site. Each simulation used the ExPERT atmosphere model. The correlated range modeled using the continental average aerosol model is 19.4% higher than the correlated range modeled using ANAM during the 0900 – 1200 time frame. Aerosols can greatly affect laser transmission. The aerosol effects caused by oceans differ greatly from the aerosol effects over land. In order to calculate accurate laser propagation correct aerosol models need to be utilized.

Reducing the surface visibility also adversely affected the correlated laser target lock-on range. The simulated target lock-on range decreased as the modeled surface visibility was lowered. The correlated target lock-on range modeled at WPAFB with 5 km surface visibility was 85.7% lower than the correlated range based on the LEEDR default surface visibility.

Several simulations also showed that the 1.0642 micrometer laser propagation was adversely affected by the light, 5 mm per hour, rainfall. With the aircraft modeled at 500 meters AGL and a laser slant path of 1,000 meters, the correlated target lock-on ranges modeled at the Nellis AFB and WPAFB ExPERT sites were approximately 60% lower than the corresponding simulated target lock-on ranges modeled with no rain. In addition, the laser was unable to propagate through a 5,000 meter slant path length when the aircraft was simulated at 3,000 meter AGL and light, 5 mm per hour, rain was modeled.

Significance of Research

This research showed that historic surface weather data, that was relatively easy to obtain, was used by LEEDR to characterize the atmospheric structure of the boundary layer and accurately calculate the aerosol and rain absorption and scattering effects. These atmospheric effects were correlated to laser target lock-on ranges and showed non-negligible effects in the XCITE LVC environment.

Currently DoD operates in various continents, climates, and environmental conditions. In order to fulfill its mission the US military employs sensors and weapons that utilize electromagnetic radiation to propagate through the atmosphere. LEEDR utilizes extensive databases to accurately calculate the atmospheric effects on the propagation of hyper-spectral electromagnetic radiation that are used by military weapons and sensors. LEEDR can provide vital modeling for US military preparation.

In this research LEEDR incorporated more realism in the XCITE LVC training environment by realistically modeling worldwide laser transmission based on variations in atmosphere & aerosol models, time of day, surface visibility, and rain. These atmospheric effects caused differences in the LEEDR modeled laser transmission and these variations in laser transmission were correlated to simulated target lock-on ranges and incorporated into XCITE and showed that realistic weather models affect simulation outcomes. LEEDR gives XCITE the ability to create a realistic picture of atmospheric propagation of the visible, mid wave IR, long wave IR, RADAR, LLTV, NVG and laser radiation. Using the LEEDR model XCITE can render and share EM radiation calculations and effects among all of the simulated sensors and participants.

The realistic weather effects modeled by LEEDR and integrated into the XCITE LVC environment thereby increased its fidelity. Correlating simulated target lock-on ranges to modeled atmospheric effects helps USAF XCITE users make better decisions and develop better skills. It also helps create enhanced wargaming scenarios and can help the DoD prepare for its current and future worldwide missions.

Recommendations for Future Research

There are several ways in which similar future research will provide significant value. First, the entire LEEDR atmospheric model can be integrated into the XCITE LVC threat generation simulator environment. Once integrated into XCITE every simulation employing the propagation of hyper-spectral electromagnetic waves that range from the radio frequencies, through the far infrared, and into the near infrared and the visible will be based on physically realistic models. The modeled atmospheric data will be shared by all the simulated XCITE sensors and among all simulation participants. Several sensors that could rely on this realistically modeled data include: Targeting Pods, Radar, SAR, NVG, TV, LADAR, and the pilot-in-the-loop's eyes. It is important to correlate the atmospheric and time of day effects among all the simulated sensors and participants.

Secondly, the Human Effectiveness Directorate simulates realistic experiences for Joint Terminal Attack Controllers (JTAC) executing Close Air Support (CAS). They enable JTAC's to practice forward CAS while immersed in a simulated environment. This simulated environment lacks realistic atmospheric based inputs. A major limitation of currently employed laser guided weapons is the degradation of the laser designator due to the realistic battlefield conditions. Warfighters currently do not have the capability to rehearse in simulated environments with degraded infrared performance caused by realistic atmospheric attenuation and battlefield induced contaminants. As the laser light from the target designator propagates through haze and other pollutants some of the laser radiation is scattered by these atmospheric aerosols. This scattering leaves a visual trail from the covert JTAC to the target he is illuminating. With the proper equipment enemy forces are able to see this scattered laser trail and discover not only what is being targeted, but more importantly, the location of the JTAC that is lasing the target illumination. This places both the JTAC's life and his mission success in danger.

Also, past operational mishaps have shown that laser degradation can cause significant complications for JTACS executing CAS. These complications can contribute to fratricide and unnecessary collateral damage. This can occur when significant levels of haze, dust, pollution, fog, or other battlefield contaminants scattering the laser radiation. The laser spot illuminating the target decreases in intensity due to these absorption and scattering effects. An inbound laser guided weapon may inadvertently guide to bright laser spots caused by aerosol scattering instead of the laser spot located on the target. This can put the lives of the JTAC and innocent by standards in jeopardy. By incorporating realistic atmospheric and aerosol models into the CAS simulated environment, JTAC's will be able to experience the realistic atmospheric conditions that lead to negative laser degradation that can cause unintended effects. These simulated experiences will better prepare them for real world experiences exhibiting similar laser degradation and could help prevent them from making fatal mistakes.

Finally, LEEDR gives the video game industry the ability to correlate all simulated gaming sensors to one predictive atmospheric model. Within an interactive video game LEEDR can model atmospheric, weather, rain, reduced visibility, and time of day effects across most of the electromagnetic spectrum. These atmospheric and weather effects can be correlated and linked to all the available hyper-spectral gaming sensors (visual, NVG, IR, SAR, LLTV, etc). LEEDR also allows these realistic atmospheric effects to be rendered by software engines. It also allows gamers the opportunity to experience firsthand the realistic atmospheric effects from rain, wind, fog, sun glare, dust, reduced visibility, and battlefield induced contaminants on all their available weapons and sensors. While battling enemy forces at night, or during a downpour, the future techno-gamer can quickly switch to his LLTV or infrared goggles and terminate his opponent. Increasingly, video games are incorporating more realism in order to provide gamers realistic experiences. Fully integrating the realistic LEEDR atmospheric model into video games provides one more level of realism for video game users.

Appendix A

LEEDR Outputs - US 1976 Standard Atmosphere Model

Alt (m)	Temp (F)	Dewpoint (F)	Pressure (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec. Absorp (1/km)	Molec. Scatter. (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter. (1/km)	Cloud Absorp (1/km)	Cloud Scatter. (1/km)	Total Absorp (1/km)	Total Scatter (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen (cm^-3)	Water-sol Aerosol Concen (cm^-3)
0	59	37.40	1013.3	44.44	0.003	0.015	0.004	0.001	3.06	215.29	1.7E-14	0.000	0.000	0.000	0.000	0.007	0.016	0.024	0.400	8300.00	7000.00
100	57.83	36.42	1001.4	44.58	0.003	0.015	0.004	0.001	3.03	215.93	6.5E-15	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
200	56.66	35.43	989.56	44.72	0.003	0.015	0.004	0.001	3.01	216.57	2.5E-15	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
300	55.49	34.45	977.72	44.87	0.003	0.015	0.004	0.001	2.98	217.21	1.1E-15	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
400	54.32	33.46	966.20	45.01	0.003	0.015	0.004	0.001	2.96	217.85	5.2E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
500	53.15	32.48	954.70	45.16	0.003	0.016	0.004	0.001	2.93	218.49	3.1E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
600	51.98	31.49	943.20	45.31	0.003	0.016	0.004	0.001	2.91	219.13	2.2E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
700	50.81	30.51	932.00	45.46	0.003	0.016	0.003	0.001	2.89	219.77	1.8E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
800	49.64	29.53	920.84	45.62	0.003	0.016	0.003	0.001	2.90	220.31	1.6E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
900	48.47	28.54	909.67	45.78	0.003	0.016	0.003	0.001	2.97	220.68	1.5E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
1000	47.3	27.56	898.79	45.94	0.003	0.016	0.003	0.001	3.04	221.05	1.4E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
1100	46.13	26.57	887.95	46.10	0.003	0.016	0.003	0.001	3.11	221.42	1.3E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
1200	44.96	25.59	877.12	46.27	0.003	0.016	0.003	0.001	3.18	221.79	1.2E-16	0.000	0.000	0.000	0.000	0.007	0.016	0.023	0.400	8300.00	7000.00
1300	43.79	24.60	866.54	46.44	0.003	0.016	0.003	0.001	3.25	222.16	1.1E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.023	0.400	8300.00	7000.00
1400	42.62	23.62	856.03	46.61	0.003	0.016	0.003	0.001	3.32	222.52	1.1E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.023	0.400	8300.00	7000.00
1500	41.45	22.64	845.51	46.78	0.003	0.016	0.003	0.001	3.36	222.33	9.9E-17	0.000	0.000	0.000	0.000	0.006	0.016	0.023	0.400	8300.00	7000.00
1600	40.28	21.65	835.24	46.96	0.002	0.007	0.003	0.001	3.39	221.39	9.3E-17	0.000	0.000	0.000	0.000	0.004	0.008	0.012	0.180	3729.44	3145.31
2000	35.6	17.63	794.96	47.52	0.001	0.006	0.003	0.001	3.48	217.62	7.1E-17	0.000	0.000	0.000	0.000	0.004	0.006	0.010	0.147	3053.42	2575.17
2500	29.75	12.46	746.78	47.99	0.001	0.005	0.003	0.000	3.59	212.90	5.1E-17	0.000	0.000	0.000	0.000	0.003	0.005	0.009	0.115	2378.00	2005.54

Modeled in LEEDR using 1976 US Standard atmosphere and continental average aerosol models. Based on a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

LEEDR Outputs - Nellis AFB ExPERT Model

Alt. (m)	Temp (F)	Dewpoint (F)	Pressure (mb)	Rel Hum (%)	Aerosol Absorption (1/km)	Aerosol Scatter. (1/km)	Molec. Absorption (1/km)	Molec. Scatter. (1/km)	Wind Speed (m/s)	Wind Direction (deg)	CN^2	Rain Absorption (1/km)	Rain Scatter. (1/km)	Cloud Absorption (1/km)	Cloud Scatter. (1/km)	Total Absorption (1/km)	Total Scatter. (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen. (cm^-3)	Water-sol Aerosol Concen (cm^-3)
0	90.26	37.54	945.08	15.70	0.003	0.012	0.003	0.001	3.06	215.29	1.7E-14	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
100	88.50	37.25	933.77	16.41	0.003	0.012	0.003	0.001	3.03	215.93	6.5E-15	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
200	86.74	36.97	922.56	17.15	0.003	0.012	0.003	0.001	3.01	216.57	2.5E-15	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
300	84.99	36.68	911.47	17.94	0.003	0.012	0.003	0.001	2.98	217.21	1.1E-15	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
400	83.23	36.40	900.49	18.76	0.003	0.013	0.003	0.001	2.96	217.85	5.2E-16	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
500	81.47	36.11	889.61	19.64	0.003	0.013	0.003	0.001	2.93	218.49	3.1E-16	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
600	79.72	35.82	878.84	20.56	0.003	0.013	0.003	0.001	2.91	219.13	2.2E-16	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.400	8300.00	7000.00
700	77.96	35.54	868.18	21.54	0.003	0.013	0.003	0.001	2.89	219.77	1.8E-16	0.000	0.000	0.000	0.000	0.006	0.013	0.020	0.400	8300.00	7000.00
800	76.20	35.25	857.62	22.57	0.003	0.013	0.003	0.001	2.90	220.31	1.6E-16	0.000	0.000	0.000	0.000	0.006	0.013	0.020	0.400	8300.00	7000.00
900	74.45	34.96	847.17	23.65	0.003	0.013	0.003	0.001	2.97	220.68	1.5E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1000	72.69	34.67	836.81	24.80	0.003	0.013	0.003	0.001	3.04	221.05	1.4E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1100	70.93	34.38	826.57	26.02	0.003	0.013	0.003	0.001	3.11	221.42	1.3E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1200	69.17	34.09	816.42	27.31	0.003	0.013	0.003	0.001	3.18	221.79	1.2E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1300	67.42	33.80	806.37	28.67	0.003	0.014	0.003	0.000	3.25	222.16	1.1E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1400	65.66	33.51	796.43	30.12	0.003	0.014	0.002	0.000	3.32	222.52	1.1E-16	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1500	63.90	33.21	786.58	31.65	0.003	0.014	0.002	0.000	3.36	222.33	9.9E-17	0.000	0.000	0.000	0.000	0.006	0.014	0.020	0.400	8300.00	7000.00
1600	50.50	36.42	786.46	58.29	0.002	0.008	0.003	0.001	3.39	221.39	9.3E-17	0.000	0.000	0.000	0.000	0.004	0.008	0.013	0.180	3729.44	3145.31
2000	46.48	31.64	749.24	55.99	0.001	0.006	0.002	0.000	3.48	217.62	7.1E-17	0.000	0.000	0.000	0.000	0.004	0.007	0.010	0.147	3053.42	2575.17
2500	41.43	25.68	703.30	53.19	0.001	0.005	0.002	0.000	3.59	212.90	5.1E-17	0.000	0.000	0.000	0.000	0.003	0.005	0.008	0.115	2378.00	2005.54

Modeled in LEEDR using Nellis AFB ExPERT atmosphere, 0900 - 1200 time frame, continental average aerosol model, a 50% - average summer, 1.0642 μm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

Alt. (m)	Temp. (F)	Dewpoint (F)	Pressure (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec Absorp (1/km)	Molec. Scatter (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter (1/km)	Cloud Absorp (1/km)	Cloud Scatter (1/km)	Total Absorp (1/km)	Total Scatter (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen. (cm^-3)	Water-sol Aerosol Concen. (cm^-3)
0	68.67	55.49	983.43	62.80	0.003	0.018	0.004	0.001	1.12	231.36	1.73E-14	0.000	0.000	0.000	0.000	0.007	0.019	0.026	0.400	8300.00	7000.00
100	66.91	55.17	971.75	65.96	0.003	0.019	0.003	0.001	1.39	235.57	6.52E-15	0.000	0.000	0.000	0.000	0.007	0.020	0.027	0.400	8300.00	7000.00
200	65.15	54.85	960.18	69.29	0.003	0.020	0.003	0.001	1.66	239.77	2.54E-15	0.000	0.000	0.000	0.000	0.007	0.020	0.027	0.400	8300.00	7000.00
300	63.40	54.53	948.72	72.83	0.003	0.021	0.003	0.001	1.93	243.98	1.07E-15	0.000	0.000	0.000	0.000	0.007	0.022	0.029	0.400	8300.00	7000.00
400	61.64	54.21	937.37	76.58	0.003	0.023	0.003	0.001	2.20	248.19	5.19E-16	0.000	0.000	0.000	0.000	0.007	0.023	0.030	0.400	8300.00	7000.00
500	59.88	53.89	926.14	80.56	0.003	0.025	0.003	0.001	2.47	252.39	3.08E-16	0.000	0.000	0.000	0.000	0.007	0.025	0.032	0.400	8300.00	7000.00
600	58.12	53.57	915.01	84.79	0.003	0.029	0.003	0.001	2.74	256.60	2.23E-16	0.000	0.000	0.000	0.000	0.007	0.030	0.037	0.400	8300.00	7000.00
700	56.37	53.25	903.99	89.27	0.003	0.034	0.003	0.001	3.01	260.81	1.85E-16	0.000	0.000	0.000	0.000	0.007	0.035	0.042	0.400	8300.00	7000.00
800	54.61	52.93	893.08	94.04	0.003	0.051	0.003	0.001	3.25	264.04	1.64E-16	0.000	0.000	0.000	0.000	0.007	0.051	0.058	0.400	8300.00	7000.00
900	52.85	52.61	882.28	98.87	0.004	0.135	0.003	0.001	3.45	265.70	1.50E-16	0.000	0.000	0.000	0.000	0.007	0.136	0.143	0.400	8300.00	7000.00
1000	51.94	51.94	871.58	99.00	0.004	0.141	0.003	0.001	3.64	267.36	1.39E-16	0.000	0.000	0.000	0.000	0.007	0.142	0.148	0.400	8300.00	7000.00
1100	51.07	51.07	860.99	99.00	0.004	0.141	0.003	0.001	3.83	269.02	1.30E-16	0.000	0.000	0.000	0.000	0.007	0.142	0.148	0.400	8300.00	7000.00
1200	50.20	50.20	850.50	99.00	0.004	0.141	0.003	0.001	4.03	270.67	1.21E-16	0.000	0.000	0.000	0.000	0.006	0.142	0.148	0.400	8300.00	7000.00
1300	49.34	49.34	840.12	99.00	0.004	0.141	0.003	0.001	4.22	272.33	1.14E-16	0.000	0.000	0.000	0.000	0.006	0.142	0.148	0.400	8300.00	7000.00
1400	48.47	48.47	829.83	99.00	0.004	0.141	0.003	0.001	4.41	273.99	1.06E-16	0.000	0.000	0.000	0.000	0.006	0.142	0.148	0.400	8300.00	7000.00
1500	47.61	47.61	819.66	99.00	0.004	0.141	0.003	0.001	4.59	275.19	9.93E-17	0.000	0.000	0.000	0.000	0.006	0.142	0.148	0.400	8300.00	7000.00
1600	53.78	40.43	817.89	60.44	0.002	0.008	0.003	0.001	4.74	275.78	9.29E-17	0.000	0.000	0.000	0.000	0.004	0.009	0.013	0.180	3729.44	3145.31
2000	49.81	35.61	780.22	57.93	0.001	0.006	0.003	0.000	5.35	278.14	7.12E-17	0.000	0.000	0.000	0.000	0.004	0.007	0.011	0.147	3053.42	2575.17
2500	44.82	29.61	733.29	54.89	0.001	0.005	0.002	0.000	6.11	281.08	5.10E-17	0.000	0.000	0.000	0.000	0.003	0.005	0.009	0.115	2378.00	2005.54

LEEDR Outputs - WPAFB ExPERT Atmosphere

Modeled in LEEDR using WPAFB ExPERT atmosphere, 0900 - 1200 time frame, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

LEEDR Outputs - Port Sudan ExPERT Atmosphere Continental Average Aerosol

Alt. (m)	Temp (F)	Dewpoint (F)	Pressure (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec. Absorp (1/km)	Molec. Scatter. (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter. (1/km)	Cloud Absorpn (1/km)	Cloud Scatter. (1/km)	Total Absorp (1/km)	Total Scatter. (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen. (cm^-3)	Water-sol Aerosol Concen. (cm^-3)
0	97.38	63.03	1008.2	32.53	0.003	0.014	0.003	0.001	2.76	282.19	1.73E-14	0.000	0.000	0.000	0.000	0.007	0.015	0.021	0.400	8300.00	7000.00
100	95.62	62.72	996.29	33.95	0.003	0.014	0.003	0.001	3.00	284.27	6.52E-15	0.000	0.000	0.000	0.000	0.007	0.015	0.022	0.400	8300.00	7000.00
200	93.86	62.41	984.48	35.45	0.003	0.014	0.003	0.001	3.25	286.34	2.54E-15	0.000	0.000	0.000	0.000	0.007	0.015	0.022	0.400	8300.00	7000.00
300	92.10	62.10	972.79	37.02	0.003	0.015	0.003	0.001	3.49	288.42	1.07E-15	0.000	0.000	0.000	0.000	0.007	0.015	0.022	0.400	8300.00	7000.00
400	90.35	61.79	961.21	38.68	0.003	0.015	0.003	0.001	3.74	290.50	5.19E-16	0.000	0.000	0.000	0.000	0.007	0.015	0.022	0.400	8300.00	7000.00
500	88.59	61.48	949.75	40.42	0.003	0.015	0.003	0.001	3.98	292.57	3.08E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.022	0.400	8300.00	7000.00
600	86.83	61.16	938.39	42.27	0.003	0.015	0.003	0.001	4.23	294.65	2.23E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.022	0.400	8300.00	7000.00
700	85.08	60.85	927.14	44.21	0.003	0.015	0.003	0.001	4.47	296.73	1.85E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.022	0.400	8300.00	7000.00
800	83.32	60.54	916.01	46.25	0.003	0.016	0.003	0.001	4.68	298.31	1.64E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.023	0.400	8300.00	7000.00
900	81.56	60.22	904.98	48.41	0.003	0.016	0.003	0.001	4.82	299.08	1.50E-16	0.000	0.000	0.000	0.000	0.006	0.016	0.023	0.400	8300.00	7000.00
1000	79.80	59.91	894.06	50.70	0.003	0.016	0.003	0.001	4.96	299.86	1.39E-16	0.000	0.000	0.000	0.000	0.006	0.017	0.023	0.400	8300.00	7000.00
1100	78.05	59.59	883.25	53.10	0.003	0.017	0.003	0.001	5.10	300.63	1.30E-16	0.000	0.000	0.000	0.000	0.006	0.017	0.023	0.400	8300.00	7000.00
1200	76.29	59.27	872.54	55.65	0.003	0.017	0.003	0.001	5.24	301.41	1.21E-16	0.000	0.000	0.000	0.000	0.006	0.018	0.024	0.400	8300.00	7000.00
1300	74.53	58.96	861.94	58.34	0.003	0.018	0.003	0.001	5.38	302.18	1.14E-16	0.000	0.000	0.000	0.000	0.006	0.018	0.024	0.400	8300.00	7000.00
1400	72.78	58.64	851.44	61.18	0.003	0.018	0.003	0.001	5.53	302.96	1.06E-16	0.000	0.000	0.000	0.000	0.006	0.019	0.025	0.400	8300.00	7000.00
1500	71.02	58.32	841.05	64.19	0.003	0.019	0.003	0.001	5.54	303.54	9.93E-17	0.000	0.000	0.000	0.000	0.006	0.019	0.025	0.400	8300.00	7000.00
1600	80.80	45.29	835.55	28.67	0.002	0.008	0.003	0.001	5.40	303.86	9.29E-17	0.000	0.000	0.000	0.000	0.005	0.009	0.013	0.235	4869.17	4106.53
2000	74.44	41.88	799.41	31.03	0.002	0.007	0.002	0.000	4.83	305.13	7.12E-17	0.000	0.000	0.000	0.000	0.004	0.008	0.012	0.205	4261.37	3593.93
2500	66.43	37.62	754.82	34.53	0.001	0.006	0.002	0.000	4.11	306.72	5.10E-17	0.000	0.000	0.000	0.000	0.004	0.007	0.010	0.174	3607.17	3042.19

Modeled in LEEDR using Port Suda ExPERT atmosphere, 0900 - 1200 time frame, continental average aerosol model, a 50% - average summer, 1.0642 μm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

LEEDR Outputs - Port Sudan ExPERT Atmosphere ANAM

Alt (m)	Temp (F)	Dewpoint (F)	Pressure (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec. Absorp (1/km)	Molec. Scatter. (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter. (1/km)	Cloud Absorp (1/km)	Cloud Scatter. (1/km)	Total Absorp (1/km)	Total Scatter. (1/km)	Total Extinction (1/km)	NAM/ANAM Aerosol Concen. (cm^-3)	NAM/ANAM Aerosol Concen. (cm^-3)	NAM/ANAM Aerosol Concen. (cm^-3)	NAM/ANAM Aerosol Concen. (cm^-3)
0	97.38	63.03	1008.21	32.53	0.001	0.075	0.003	0.001	2.76	282.2	1.73E-14	0.000	0.000	0.000	0.000	0.004	0.075	0.080	2000.000	24.991	0.029	0.016
100	95.62	62.72	996.29	33.95	0.000	0.054	0.003	0.001	3.00	284.3	6.52E-15	0.000	0.000	0.000	0.000	0.003	0.055	0.058	2000.000	24.991	0.029	0.000
200	93.86	62.41	984.48	35.45	0.000	0.054	0.003	0.001	3.25	286.3	2.54E-15	0.000	0.000	0.000	0.000	0.003	0.055	0.058	2000.000	24.991	0.029	0.000
300	92.10	62.10	972.79	37.02	0.000	0.055	0.003	0.001	3.49	288.4	1.07E-15	0.000	0.000	0.000	0.000	0.003	0.055	0.059	2000.000	24.991	0.029	0.000
400	90.35	61.79	961.21	38.68	0.000	0.055	0.003	0.001	3.74	290.5	5.19E-16	0.000	0.000	0.000	0.000	0.003	0.056	0.059	2000.000	24.991	0.029	0.000
500	88.59	61.48	949.75	40.42	0.000	0.056	0.003	0.001	3.98	292.6	3.08E-16	0.000	0.000	0.000	0.000	0.003	0.056	0.059	2000.000	24.991	0.029	0.000
600	86.83	61.16	938.39	42.27	0.000	0.056	0.003	0.001	4.23	294.6	2.23E-16	0.000	0.000	0.000	0.000	0.003	0.057	0.060	2000.000	24.991	0.029	0.000
700	85.08	60.85	927.14	44.21	0.000	0.056	0.003	0.001	4.47	296.7	1.85E-16	0.000	0.000	0.000	0.000	0.003	0.057	0.060	2000.000	24.991	0.029	0.000
800	83.32	60.54	916.01	46.25	0.000	0.057	0.003	0.001	4.68	298.3	1.64E-16	0.000	0.000	0.000	0.000	0.003	0.057	0.061	2000.000	24.991	0.029	0.000
900	81.56	60.22	904.98	48.41	0.000	0.057	0.003	0.001	4.82	299.1	1.50E-16	0.000	0.000	0.000	0.000	0.003	0.058	0.061	2000.000	24.991	0.029	0.000
1000	79.80	59.91	894.06	50.70	0.000	0.058	0.003	0.001	4.96	299.9	1.39E-16	0.000	0.000	0.000	0.000	0.003	0.059	0.062	2000.000	24.991	0.029	0.000
1100	78.05	59.59	883.25	53.10	0.000	0.060	0.003	0.001	5.10	300.6	1.30E-16	0.000	0.000	0.000	0.000	0.003	0.061	0.064	2000.000	24.991	0.029	0.000
1200	76.29	59.27	872.54	55.65	0.000	0.063	0.003	0.001	5.24	301.4	1.21E-16	0.000	0.000	0.000	0.000	0.003	0.063	0.066	2000.000	24.991	0.029	0.000
1300	74.53	58.96	861.94	58.34	0.000	0.065	0.003	0.001	5.38	302.2	1.14E-16	0.000	0.000	0.000	0.000	0.003	0.066	0.069	2000.000	24.991	0.029	0.000
1400	72.78	58.64	851.44	61.18	0.000	0.068	0.003	0.001	5.53	303.0	1.06E-16	0.000	0.000	0.000	0.000	0.003	0.068	0.071	2000.000	24.991	0.029	0.000
1500	71.02	58.32	841.05	64.19	0.000	0.070	0.003	0.001	5.54	303.5	9.93E-17	0.000	0.000	0.000	0.000	0.003	0.071	0.074	2000.000	24.991	0.029	0.000
1600	80.80	45.29	835.55	28.67	0.000	0.024	0.003	0.001	5.40	303.9	9.29E-17	0.000	0.000	0.000	0.000	0.003	0.024	0.027	898.661	11.229	0.013	0.000
2000	74.44	41.88	799.41	31.03	0.000	0.020	0.002	0.000	4.83	305.1	7.12E-17	0.000	0.000	0.000	0.000	0.002	0.020	0.023	735.764	9.194	0.011	0.000
2500	66.43	37.62	754.82	34.53	0.000	0.016	0.002	0.000	4.11	306.7	5.10E-17	0.000	0.000	0.000	0.000	0.002	0.016	0.018	573.012	7.160	0.008	0.000

Modeled in LEEDR using Port Suda ExPERT atmosphere, 0900 - 1200 time frame, ANAM, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and no rain.

LEEDR Outputs - Nellis AFB ExPERT Model - 15 km Surface Visibility

Alt. (m)	Temp. (F)	Dewpnt (F)	Press. (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec. Absorp (1/km)	Molec Scatter. (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter. (1/km)	Cloud Absorp (1/km)	Cloud Scatter. (1/km)	Total Absorp (1/km)	Total Scatter. (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen. (cm^-3)	Water-sol. Aerosol Concen. (cm^-3)
0	90.26	37.54	945.08	15.70	0.016	0.058	0.003	0.001	3.06	215.29	1.7E-14	0.000	0.000	0.000	0.000	0.019	0.058	0.077	0.400	8300.00	7000.00
100	88.50	37.25	933.77	16.41	0.016	0.058	0.003	0.001	3.03	215.93	6.5E-15	0.000	0.000	0.000	0.000	0.019	0.059	0.078	0.400	8300.00	7000.00
200	86.74	36.97	922.56	17.15	0.016	0.058	0.003	0.001	3.01	216.57	2.5E-15	0.000	0.000	0.000	0.000	0.019	0.059	0.078	0.400	8300.00	7000.00
300	84.99	36.68	911.47	17.94	0.016	0.059	0.003	0.001	2.98	217.21	1.1E-15	0.000	0.000	0.000	0.000	0.019	0.059	0.078	0.400	8300.00	7000.00
400	83.23	36.40	900.49	18.76	0.016	0.059	0.003	0.001	2.96	217.85	5.2E-16	0.000	0.000	0.000	0.000	0.019	0.060	0.079	0.400	8300.00	7000.00
500	81.47	36.11	889.61	19.64	0.016	0.060	0.003	0.001	2.93	218.49	3.1E-16	0.000	0.000	0.000	0.000	0.019	0.060	0.079	0.400	8300.00	7000.00
600	79.72	35.82	878.84	20.56	0.016	0.060	0.003	0.001	2.91	219.13	2.2E-16	0.000	0.000	0.000	0.000	0.019	0.061	0.080	0.400	8300.00	7000.00
700	77.96	35.54	868.18	21.54	0.016	0.061	0.003	0.001	2.89	219.77	1.8E-16	0.000	0.000	0.000	0.000	0.019	0.061	0.080	0.400	8300.00	7000.00
800	76.20	35.25	857.62	22.57	0.016	0.061	0.003	0.001	2.90	220.31	1.6E-16	0.000	0.000	0.000	0.000	0.019	0.062	0.081	0.400	8300.00	7000.00
900	74.45	34.96	847.17	23.65	0.016	0.062	0.003	0.001	2.97	220.68	1.5E-16	0.000	0.000	0.000	0.000	0.019	0.063	0.081	0.400	8300.00	7000.00
1000	72.69	34.67	836.81	24.80	0.016	0.063	0.003	0.001	3.04	221.05	1.4E-16	0.000	0.000	0.000	0.000	0.019	0.063	0.082	0.400	8300.00	7000.00
1100	70.93	34.38	826.57	26.02	0.016	0.063	0.003	0.001	3.11	221.42	1.3E-16	0.000	0.000	0.000	0.000	0.019	0.064	0.082	0.400	8300.00	7000.00
1200	69.17	34.09	816.42	27.31	0.016	0.064	0.003	0.001	3.18	221.79	1.2E-16	0.000	0.000	0.000	0.000	0.019	0.064	0.083	0.400	8300.00	7000.00
1300	67.42	33.80	806.37	28.67	0.016	0.065	0.003	0.000	3.25	222.16	1.1E-16	0.000	0.000	0.000	0.000	0.019	0.065	0.084	0.400	8300.00	7000.00
1400	65.66	33.51	796.43	30.12	0.016	0.065	0.002	0.000	3.32	222.52	1.1E-16	0.000	0.000	0.000	0.000	0.018	0.066	0.084	0.400	8300.00	7000.00
1500	63.90	33.21	786.58	31.65	0.016	0.066	0.002	0.000	3.36	222.33	9.9E-17	0.000	0.000	0.000	0.000	0.018	0.067	0.085	0.400	8300.00	7000.00
1600	50.50	36.42	786.46	58.29	0.007	0.038	0.003	0.001	3.39	221.39	9.3E-17	0.000	0.000	0.000	0.000	0.010	0.038	0.048	0.180	3729.44	3145.31
2000	46.48	31.64	749.24	55.99	0.006	0.030	0.002	0.000	3.48	217.62	7.1E-17	0.000	0.000	0.000	0.000	0.008	0.030	0.039	0.147	3053.42	2575.17
2500	41.43	25.68	703.30	53.19	0.005	0.023	0.002	0.000	3.59	212.90	5.1E-17	0.000	0.000	0.000	0.000	0.007	0.023	0.030	0.115	2378.00	2005.54

Modeled in LEEDR using Nellis ExPERT atmosphere, 0900 - 1200 time frame, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 3,000 meter upper altitude, 5,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and light, 15 km surface visibility.

LEEDR Outputs - Nellis AFB ExPERT Model - 5 mm/hr rain

Alt. (m)	Temp. (F)	Dewpnt (F)	Press. (mb)	Rel Hum (%)	Aerosol Absorp (1/km)	Aerosol Scatter. (1/km)	Molec. Absorp (1/km)	Molec. Scatter. (1/km)	Wind Speed (m/s)	Wind Dir. (deg)	CN^2	Rain Absorp (1/km)	Rain Scatter. (1/km)	Cloud Absorp (1/km)	Cloud Scatter. (1/km)	Total Absorp (1/km)	Total Scatter. (1/km)	Total Extinction (1/km)	Insoluble Aerosol Concen. (cm^-3)	Soot Aerosol Concen. (cm^-3)	Water-sol. Aerosol Concen. (cm^-3)
0	90.26	37.54	945.08	15.70	0.003	0.012	0.003	0.001	3.06	215.29	1.7E-14	0.025	0.982	0.000	0.000	0.032	0.994	1.026	0.400	8300.00	7000.00
100	88.50	37.25	933.77	16.41	0.003	0.012	0.003	0.001	3.03	215.93	6.5E-15	0.025	0.982	0.000	0.000	0.032	0.994	1.026	0.400	8300.00	7000.00
200	86.74	36.97	922.56	17.15	0.003	0.012	0.003	0.001	3.01	216.57	2.5E-15	0.025	0.982	0.000	0.000	0.032	0.994	1.026	0.400	8300.00	7000.00
300	84.99	36.68	911.47	17.94	0.003	0.012	0.003	0.001	2.98	217.21	1.1E-15	0.025	0.982	0.000	0.000	0.032	0.995	1.026	0.400	8300.00	7000.00
400	83.23	36.40	900.49	18.76	0.003	0.013	0.003	0.001	2.96	217.85	5.2E-16	0.025	0.982	0.000	0.000	0.032	0.995	1.026	0.400	8300.00	7000.00
500	81.47	36.11	889.61	19.64	0.003	0.013	0.003	0.001	2.93	218.49	3.1E-16	0.025	0.982	0.000	0.000	0.032	0.995	1.026	0.400	8300.00	7000.00

Modeled in LEEDR using Nellis ExPERT atmosphere, 0900 - 1200 time frame, continental average aerosol model, a 50% - average summer, 1.0642 µm laser wavelength, 500 meter upper altitude, 1,000 meter laser slant path length, HV 5/7 turbulence model with turbulence multiplier of 1, climatology wind profile, and light, 5 mm/hr, rain

Bibliography

AFRL Human Effectiveness Directorate [Online] // The Air Force Research Laboratory - 12 May 2010. - http://www.wpafb.af.mil/shared/media/document/AFD-070420-028.pdf

Best, Christopher, et. al. "Exercise Pacific Link 2: Coalition Distributed Mission Training Research" [Report] ; The Air Force Research Laboratory, Warfighter Readiness Research Division, (2006)

Cohen, Jeanette "Scintillation Measurements of Cn2", AFIT Thesis AFIT/GAP/ENP/09-M03, Dayton : Air Force Institute of Technology, (Mar 2009)

Farmer, E., Reimersma, J., Morall, J., Jorna, P.,(1999). *Handbook of Simulator-based training*. Ashgate Publishing Company, ISBN: 0754611876

Fiorino, S. T., Bartell, R. J., Krizo, M. J., Caylor, G. L., Moore, K. P., Harris, T. R., et al. "A first principles atmospheric propagation & characterization tool - the laser environmental effects definition and reference (LEEDR)." SPIE, 6878 (68780B), (2008).

Fiorino Steven T [et al.] "Comparison of a Worldwide, Hyperspectral Atmospheric Characterization Package to Measurements and MODTRAN" [Report]. - Wright-Patterson AFB : Air Force Institute of Technology Center for Directed Energy, 2008.

Fiorino Steven T [et al.] "Validation of a World-Wide Physics Based, High Spectral Resolution Atmospheric Characterization and Propogation Package or UV to RF wavelengths" [Report]. - Wright-Patterson AFB : Air Force Institute of Technology Center for Directed Energy, 2008.

Gouveia, Melanie J., Morrison, Jeffrey S., Bensinger, Richard B., Turkington, Ryan B., Wylie, Jack L., Gilbert, Craig V. "TAWS and NOWS: Software Products For Operational Weather Support"[Report], Hanscom AFB: The Air Force Research Laboratory, 2002

LEEDR v3.0 Reference Manual - Wright-Patterson AFB : Air Force Institute of Technology Center for Directed Energy, 2010.

Lord, William T., "Air Force Modeling and Simulation Vision for the 21st Century" [Report], SAF/CIO A6, (July 2010)

Marek, Seth L. "A Computational Tool for Evaluating THz Imaging Performance in Brownout Conditions at Land Sites Throughout the World", AFIT Thesis AFIT/GAP/ENP/09-M08, Dayton : Air Force Institute of Technology, (Mar 2009)

Perram, G. P., Cusumano, S. J., Hengehold, R. L., Fiorino, S. T. (2010). *An Introduction to Laser Weapon Systems*. Albuquerque, NM: The Directed Energy Professional Society.

Petty, G. W. (2006). *A first course in atmospheric radiation* (2nd ed.). Madison, WI: Sundog Publishing.

Scheidecker, Liz, "Performance of Target Acquisition Weapons Software (TAWS) off the of the central California coast.pdf." [Online] – March 24, 2005 – downloaded 28 Oct 2010 http://www.weather.nps.navy.mil/~psguest/OC3570/CDROM/winter2005/Scheidecker/report.pdf

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
24-03-2011	Master's Thesis	March 2010 – March 2011

TITLE AND SUBTITLE

Integration of a Worldwide Atmospheric Based Model with a Live Virtual Constructive Simulation Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Simmons, David B., Captain, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Physics (AFIT/ENP)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GAP/ENP/11-M09

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFRL711 HPW / Immersive Environments Branch
6030 South Kent Street, Bldg. 561
Mesa, AZ 85212-6061
Craig A. Eidman (480) 988-6561

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Yearly DoD spends millions of dollars on Modeling and Simulation tools in order to accomplish two fundamental tasks: make better decisions and develop better skills. Simulators that are based on realistic models enable the USAF to properly train, educate, and employ military forces. LEEDR is an atmospheric model based on worldwide historic weather data that is able to predict the extinction, absorption, and scattering of radiation across a broad range of the electromagnetic spectrum. Through this study LEEDR models the propagation of 1.0642 micron laser radiation at worldwide locations and through various environmental conditions. This modeled laser transmission output, based on realistic atmospheric and aerosol propagation effects, was correlated to simulated laser target lock-on ranges derived from a generic laser targeting pod. This correlated information was incorporated into The Air Force Research Laboratory's XCITE Live, Virtual, and Constructive (LVC) threat generation simulator. The simulated laser target lock-on ranges, correlated to realistic atmospheric propagation effects, increased the fidelity and realism inside the XCITE LVC threat generation environment providing users the opportunity to make better decisions and develop better skills.

15. SUBJECT TERMS

Laser Propagation, Atmosphere Effects, Aerosol Effects,

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Steven T. Fiorino, AFIT/ENP
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	84	(937) 255-3636, ext 4506 (steven.fiorino@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18