Simulating Atmospheric Free-Space Optical Propagation

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Outline

- Overview
- Unlicensed fixed-wireless technologies
- Atmospheric attenuations
- Weather parameters
- Meteorological visual range
- Attenuation due to rainfall
- Mie scattering: attenuation due to haze, fog and low clouds
- Simulight™ examples
- Concluding remarks

About UlmTech..

• Founded in September 2001

• Two Divisions: Free-Space optics and e-Learning

• Free-Space Optics Division:

  • Developing the first commercial software that simulates atmospheric propagation of optical wireless signals, the ***Simulight***™ (release date: March 01, 2002);

• e-Learning Division:

  • Intelligent Real-Time Multimedia Platform for Online Learning and Collaboration;

  • Working with Cox on launching the e-Learning Special Interest Group (SIG) within the San Diego Telecom Council (February 13, 2002).

About Simulight™..

Simulight™ considers the following optical propagation effects:

- Low altitudes propagation,
- Haze, rain, fog, low clouds and molecular scattering,
- Geometrical beam dispersion including diffraction effects,
- Water and carbon dioxide absorption,
- Absorption due to the presence of water vapor in the air,
- It supports wavelengths that span from 750 nm to 12 µm.

Why Broadband.. And Why Now..

• Service providers need to provide value-added services besides dumb data pipes to maximize their return on investment → Different levels of Service Level Agreements (SLAs).

• Improvements in Ethernet/IP networking enable different levels of end-to-end QoS, bandwidth on demand and rate control.

• Advances in Operation Support Systems OSS to facilitate billing, management and control.

• End-users are eager to access real-time multimedia applications for collaboration, training, distance learning.

• At the end of the day someone, besides investors, needs to pay for all those tremendous optical and networking advances and improvements.

Unlicensed Wireless Technologies (UWT)

Spectrum Band	Technology	Regulations and Standards
2.4 – 2.4825 GHz	Worldwide Coverage, indoor/outdoor, 11 and 22 Mbps, up to 15 miles, DS spreading and OFDM.	• ISM band: FCC part 15.247 and 15.249 • IEEE standard 802.11b,g
B1 5.15-5.25 B2 5.25-5.35 B3 5.725-5.825	Limited global coverage, Hiperlan in Europe (B1 and B2), indoor/outdoor (B2 and B3), 54 Mbps using OFDM on twelve non-overlapping 20 MHz bands, and some non-IEEE radios support 450 Mbps using QAM.	• UNII band: FCC part 15.407 • IEEE standard 802.11a
5.725-5.85 GHz	Open in Asia and part of Europe, DS spread spectrum, and some radios with 25 Mbps speed.	ISM Band: FCC part 15.247 and 15.249. No IEEE standard
24.05-24.250 GHz	Radios in this band are provided by Sierra Digital and are affected by rain.	FCC part 15.249. No IEEE standards

Unlicensed Wireless Technologies (Cont.)

Spectrum Band	Technology	Regulations and Standards
57-64 GHz (90 GHz and 120 GHz in progress)	Radios with Gigabit speeds, OOK modulation, no delay, few hundred meters in range due to Oxygen absorption.	FCC part 15.255 and 15.249. No IEEE standards.
200-300 THz	Free-Space Optics (FSO) using short (785-850 nm) and long wavelengths (1550 nm) signals, OOK modulation, no delay, speeds up to 2.5 Gbps and few kilometers in distances.	• Eye-safety IEC, FDA and ANSI regulation •No FCC regulation • No standards

Challenges: Frequency planning to avoid interferences, except for 60 GHz, and atmospheric penetration for frequencies above 10 GHz.

UWT Atmospheric Penetration

- Microwave signals above 10 GHz are mostly affected by rain fade.

- The availability of extensive global precipitation databases and rain fade modeling accurately estimates microwave deployment link availability.

- Free-Space Optics is affected by various weather conditions → The need of accurate channel modeling and weather databases.

Formed in February 2001 to unify vendors and service providers efforts to bring proper awareness and understanding of the technology.
www.fsoalliance.com

Atmospheric Propagation

Modeling FSO atmospheric propagation:

Deployment parameters: are related to the location and application of the FSO system installation: Range, Bandwidth, Wavelength …

FSO system parameters: are related to the deployed FSO system: location of the FSO system installation: number of transmitters (Tx) and Receivers (Rx), Tx diameter, Rx diameter, Tx power, Rx sensitivity, additional amplification, additional hardware losses..

Weather parameters: Meteorological Visual Range (Visibility), Temperature, Relative Humidity, fog model (non-selective, evolving, stable)…

Atmospheric attenuation

FSO systems are affected by the following weather conditions:

Absorption: is a Quantum effect with H_2O and CO_2 absorption bands defining the eight atmospheric windows 720 nm – 12000 nm (fine line absorption). Increasing humidity cause additional water absorption.

Rayleigh Scattering: due to scattering by air molecule. Very small compared to Mie scattering and is proportional to λ^{-4}

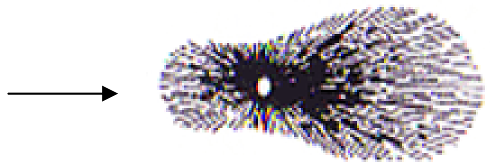
Mie Scattering: Due to scattering by small particles of sizes comparable to wavelength.

Turbulences (scintillation): Beam deviation, wander, broadening and power fluctuation.

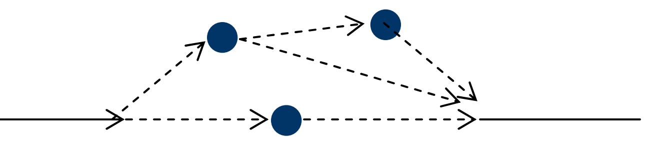
Rain Fade: Considered non-selective scattering. The attenuation is proportional to the rainfall rate (drop size distribution)

Scattering Effects

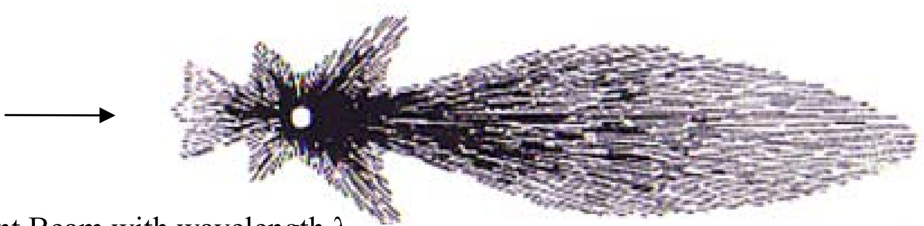
Incident Beam with wavelength λ



Small Particles with
diameter ≅ λ/4



Multiple-order scattering between Tx and Rx



Incident Beam with wavelength λ

Small Particles with diameter > λ

Earl J. McCartney, *Optics of the Atmosphere: Scattering by Molecules and Particles,* Wiley & Sons, New York, [1976].

Scattering patterns of electromagnetic waves by spherical particles.

Weather Parameters

History for Huntsville, Alabama Observed: **July 4, 2001**

http://www.wunderground.com/history/airport/KRMG/2001/6/29/DailyHistory.html

Time	Temp	Dewpoint	Pressure	Visibility	Wind Speed	Gust Speeds	Precipitat -ion	Conditions
17:06	84.2° F	73.4° F	30.04 in	10.0 mi	10.4 mph	N/A	N/A	Thunderstorm
17:53	73.0° F	69.1° F	30.06 in	1.0 mi	20.7 mph	32.2 mph	0.10 in	Light Thunderstorms and Rain
18:00	71.6° F	66.2° F	30.06 in	0.8 mi	15.0 mph	26.5 mph	0.09 in	Heavy Thunderstorms and Rain
18:16	69.8° F	68.0° F	30.06 in	2.0 mi	0.0 mph	N/A	0.21 in	Light Thunderstorms and Rain
18:24	69.8° F	68.0° F	30.06 in	8.0 mi	6.9 mph	N/A	0.24 in	Light Thunderstorms and Rain
18:53	70.0° F	69.1° F	30.06 in	10.0 mi	3.5 mph	N/A	0.29 in	Thunderstorm
22:53	69.8° F	68.0° F	30.09 in	9.0 mi	0.0 mph	N/A	N/A	Clear
23:53	69.8° F	68.0° F	30.09 in	8.0 mi	4.6 mph	N/A	N/A	Clear

Weather Parameters

Absolute Humidity: Mass of water vapor in a unit volume of air.
Saturation: Refers to the maximum possible amount of water vapor that air can hold (Temperature dependent) per unit volume.

Dew Point: Is the temperature at which saturation occurs. Related to temperature and Dewpoint.

Relative Humidity: The ratio of the absolute humidity to saturation. This parameter, along with temperature, is useful to determine additional water absorption.

Visibility: Distance for which the Contrast transmission of the atmosphere is 2% in reference to the wavelength 550 nm that the eye has the greatest sensitivity. It is a function of the extinction coefficient α.

$$V = |\ln(0.02)|/\alpha(\lambda) = 3.91/\alpha(\lambda=0.55\mu)$$

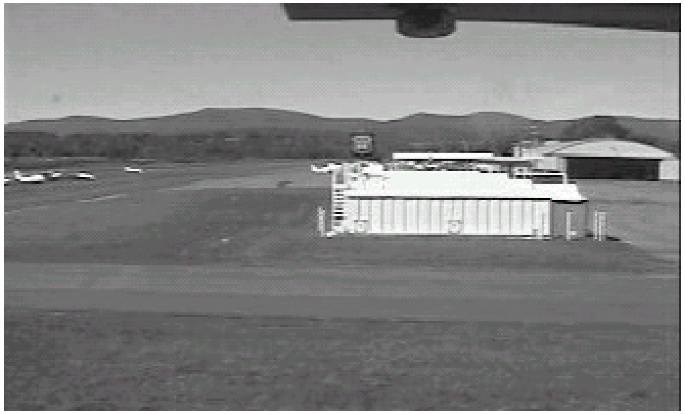
Meteorological Visual Range

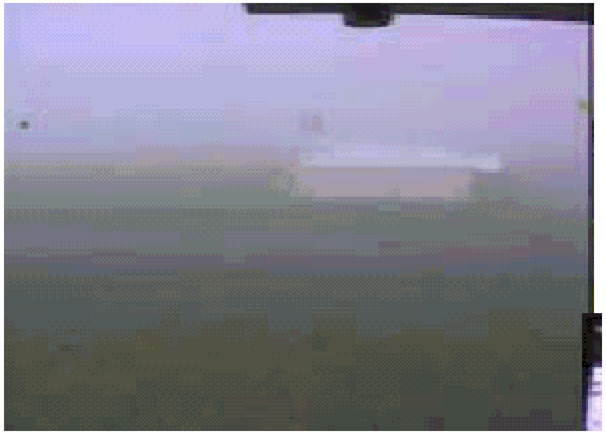
- Relative contrast is defined as follows:

$$\frac{C(V)}{C(0)} = \frac{L_{max}(V) - L_{min}(V)}{L_{min}(V)} \frac{L_{min}(0)}{L_{max}(0) - L_{min}(0)} \cong \frac{L_{max}(V)}{L_{max}(0)} = e^{-\alpha V}$$

- The above approximation holds when $L_{min}(0) << L_{max}(0)$ and $L_{min}(0)=L_{min}(V)$.
- If the background is the horizon, then $L_{min}(0)=L_{min}(V)$.
- Complete understanding of visibility measurement is essential.
- Meteorological visual ranges V are defined with the above two approximations. .
- The problem is how to use V to derive $\beta_{scat}(\lambda)$.

Meteorological Visual Range





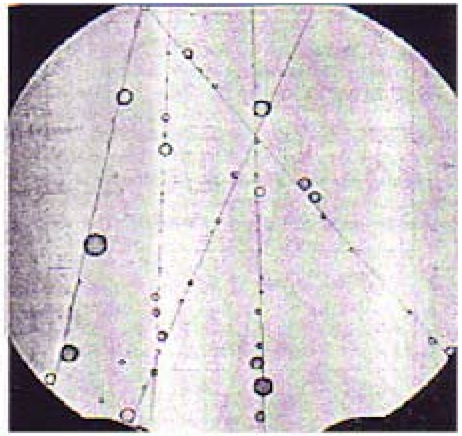
Background Contrast

"Using Camera Imagery to measure Visibility and fog", MIT Lincoln Lab Report 2001

Rainfall Attenuation

- Is considered non-selective scattering because the size of a raindrop (Diameter 0.01-10 mm) is much larger than the incident wavelength.

- An alternative way to compute rainfall attenuation is to measure the relative humidity and temperature instead of the visibility.



- In 1920, F.W. Preston, in an almost forgotten paper, claimed that *the obscuring power of falling rain is proportional only to the number of drops falling on unit area of the earth's surface per second.*

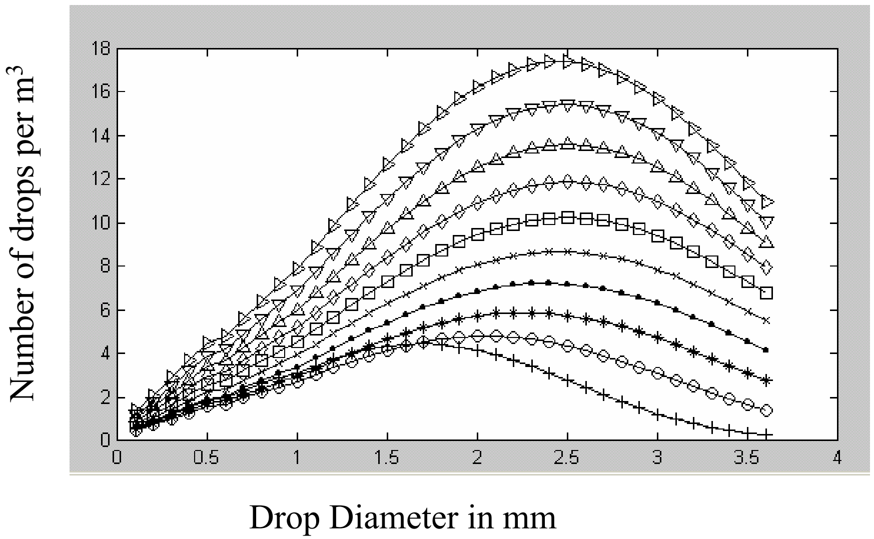
Rainfall Attenuation

- Since raindrops have radius between 0.01 and 1 mm with concentration between 10^{-2} and 10^{-5} per cm, then the raindrops are not superimposed.
- The total Scattering coefficient by rain is:

$$\beta^{rain}_{scatt} = \sum_a \pi\, a^2\, N_a\, Q_{scatt}\,(a/\lambda)$$

- Q_{scatt} is the scattering efficiency, also referred to by the Mie attenuation coefficient. For ratios $a/\lambda > 30$ the coefficient $Q_{scatt} \rightarrow 2$.
- Attenuation is governed by Beer's law (P. Bouguerin 1729, J. Heinrich Lambert in 1760 and August. Beer in 1852).
- The concentration of radius a drops N_a is given by Weibull distribution with parameters derived from experimental measurements.

Rainfall Attenuation



Caption:

mm/hr

(+) 10

(o) 20

(*) 30

(◊) 40

(●) 50

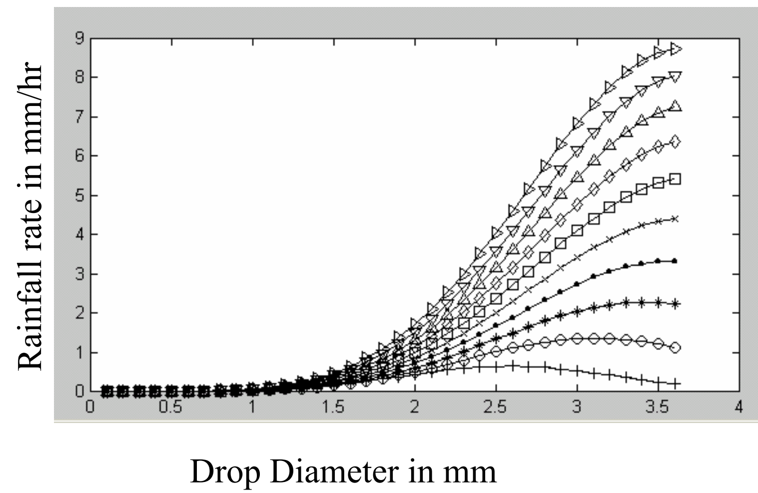
(x) 60

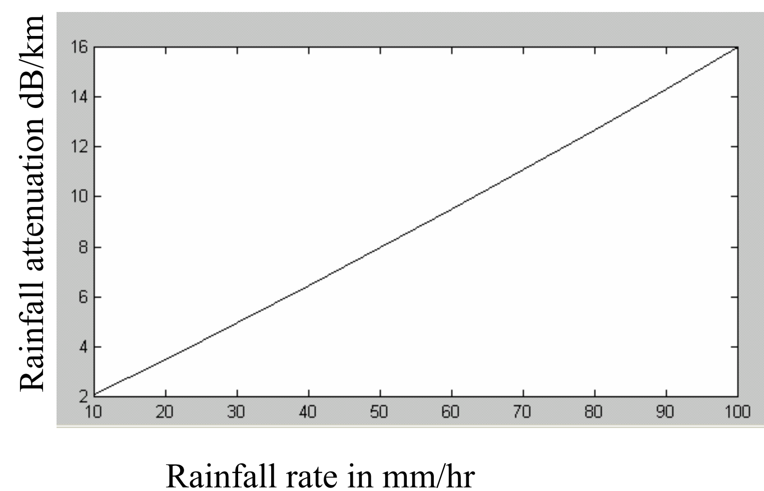
(□) 70

(Δ) 80

(∇) 90

(▷) 100

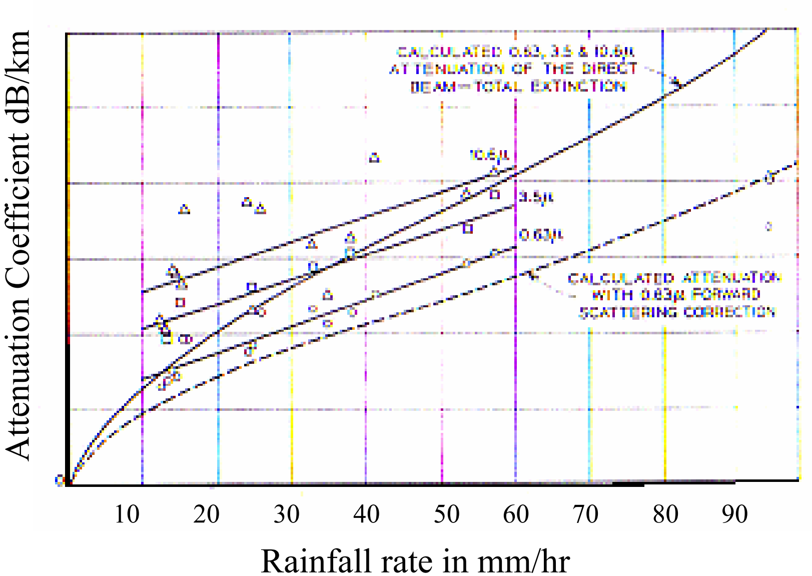


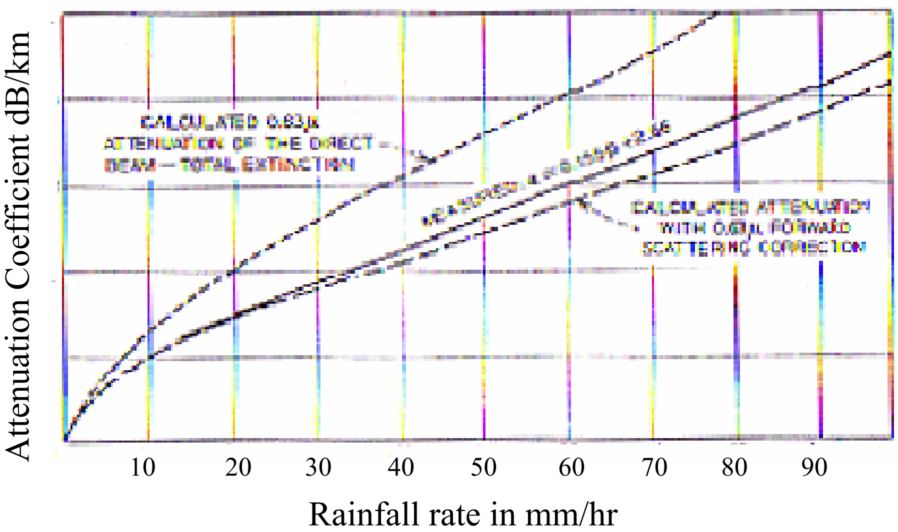


Simulation Results:

- Rainfall between 10-100 mm/hr
- Wavelength independent

Rainfall Attenuation





Measure attenuation coefficient of rain storm for 2.6 km path

"Effects of Precipitation on Propagation at 0.63, 3.5 and 1.06 microns", Chu & Hogg, Bell System Technical Journal, 1968

Measure wavelength dependence in propagation through rain is inverse to that through fog

Rainfall Attenuation

- Then we can compute the visibility from the equation since rainfall attenuation is independent of the wavelength:

$$V = \frac{17}{\tau_{scatt}^{rain} + \tau_{abs}^{R.H.}} \text{ Km}$$ where τ is the attenuatio n in dB/Km

- where, R.H. stands for Relative Humidity Absorption. The equation above is true in the absence of other molecular absorption and other types of scattering attenuation.

Huntsville, AL July 04 2001 (slide 13)

- For R.H. = 83% (derived from Dewpoint and Temperature), Rainfall rate = 12.7 mm/hr and Temperature = 22 C:

Calculated Meteorological Visual Range = 4.5 Km

- Measured average Meteorological Visual Range = 4.75 Km.

Mie Scattering

- Based on slide 15 assumptions, Visibility can be related to the extinction coefficient $\beta(\lambda=0.55\mu)$ by the following relation:

$$V = \frac{|\ln(0.02)|}{\beta(\lambda = 0.55\mu)} = \frac{3.91}{\beta(\lambda = 0.55\mu)}$$

- In most literatures, relating $\beta(\lambda=0.55\mu)$ to $\beta(\lambda)$ was performed using the following equation:

$$\beta(\lambda) = \beta(\lambda = 0.55\mu)\left(\frac{\lambda}{0.55}\right)^{-\delta} = \frac{3.91}{V}\left(\frac{\lambda}{0.55}\right)^{-\delta}$$

- The exponent $\delta = 1.6$ for good visibility, 1.3 for V=6-50 Km and 0.585 $V^{1/3}$ for visibility less than 6 Km.

- Problem: exponent value and the one-to-one relation between visibility and attenuation coefficient independent of droplet sizes and distributions.

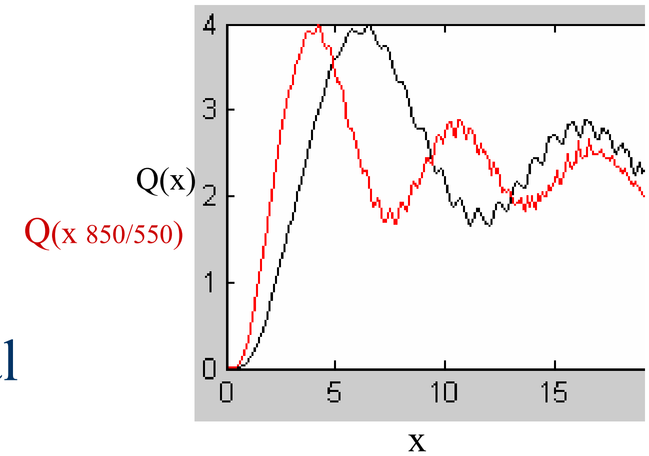
Mie Scattering

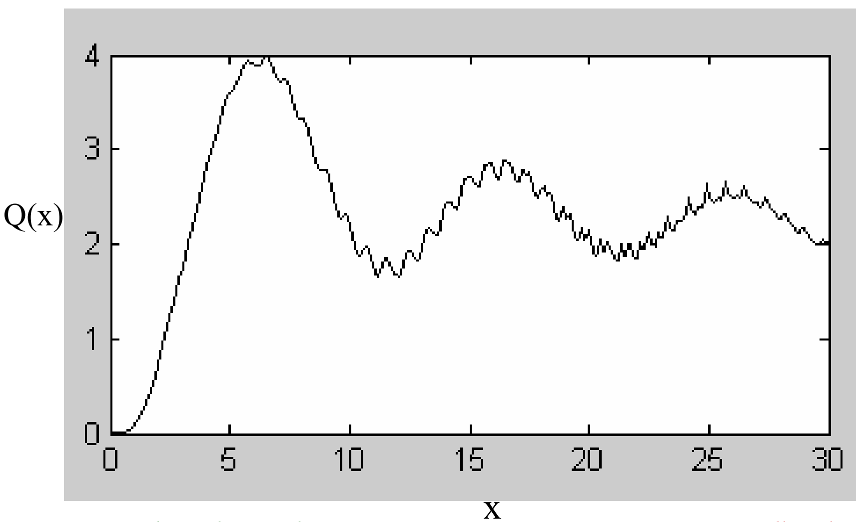
- The general equation to derive scattering coefficient is:

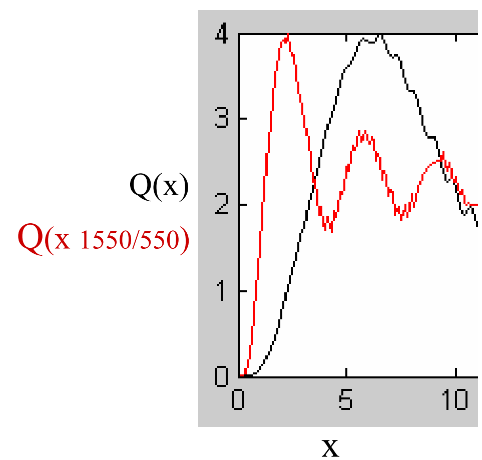
$$\beta_{scatt}(\lambda) = \sum_a \pi a^2 N_a Q_{scatt}(x)$$

where, $x = 2\pi a/\lambda$.

- λ dependence is not trivial due to the analytical expression of Q.



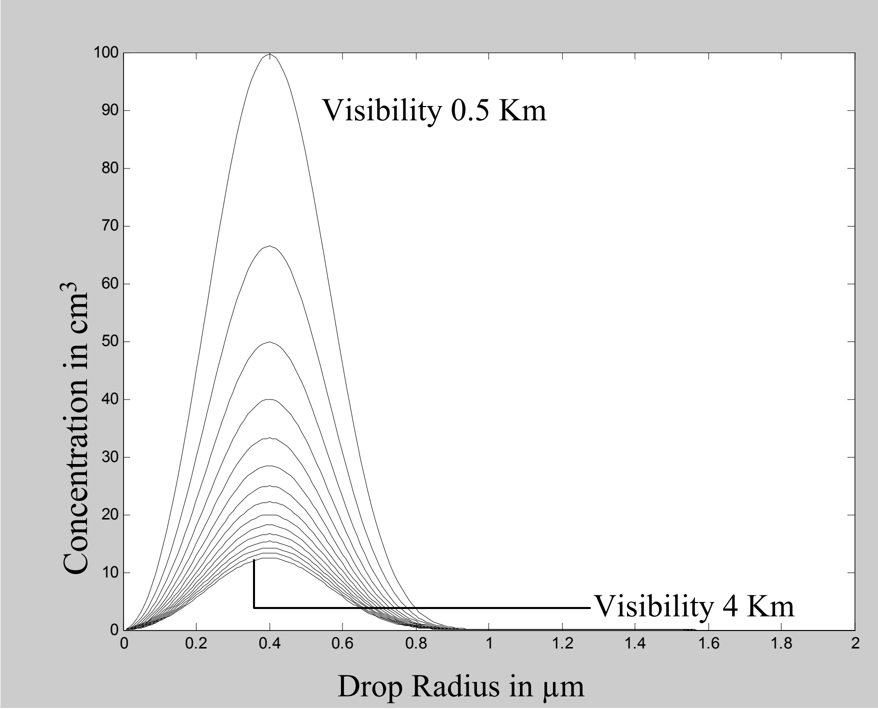


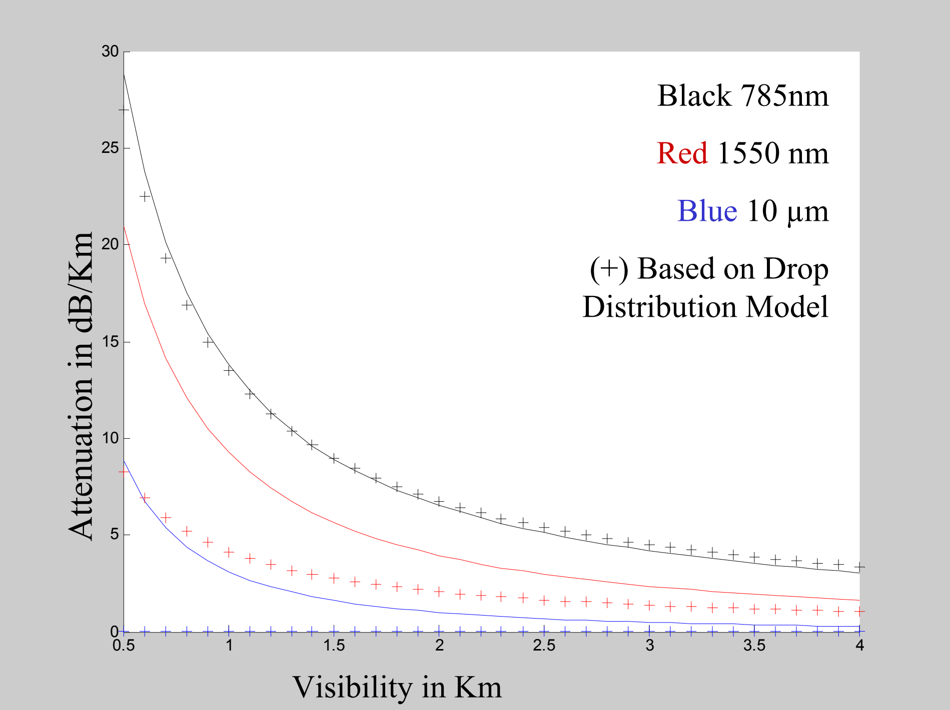


Mie Scattering

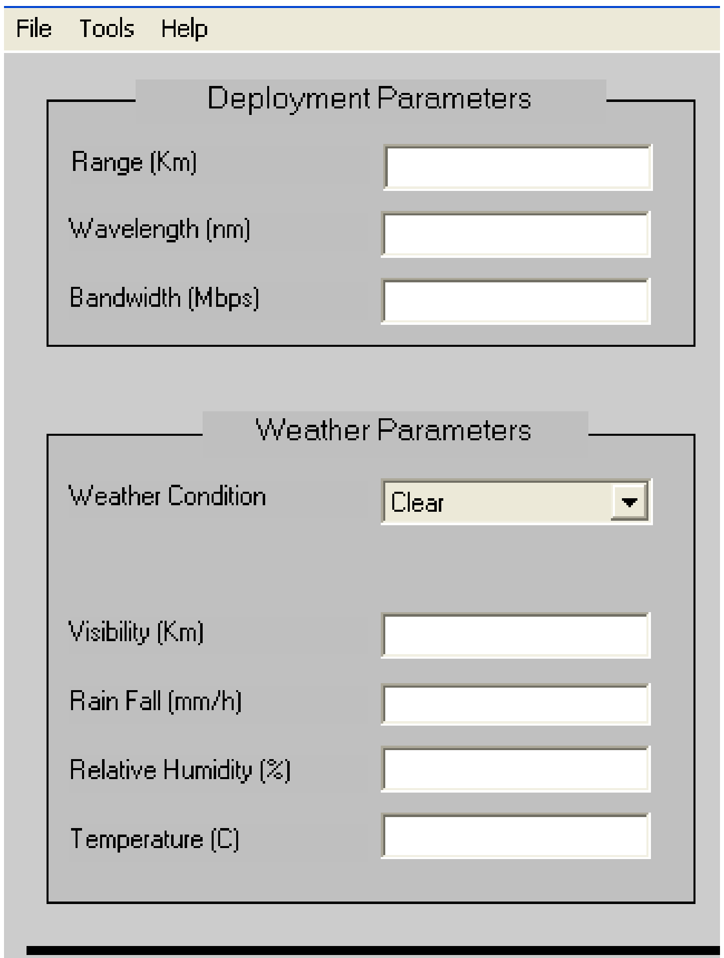
- Build a virtual fog/haze model that reproduces the same results as the equation below at λ = 850 nm:

$$\beta(\lambda) = \beta(\lambda = 0.55\mu)\left(\frac{\lambda}{550}\right)^{-0.585V^{1/3}} = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-0.585V^{1/3}}$$





Simulight™



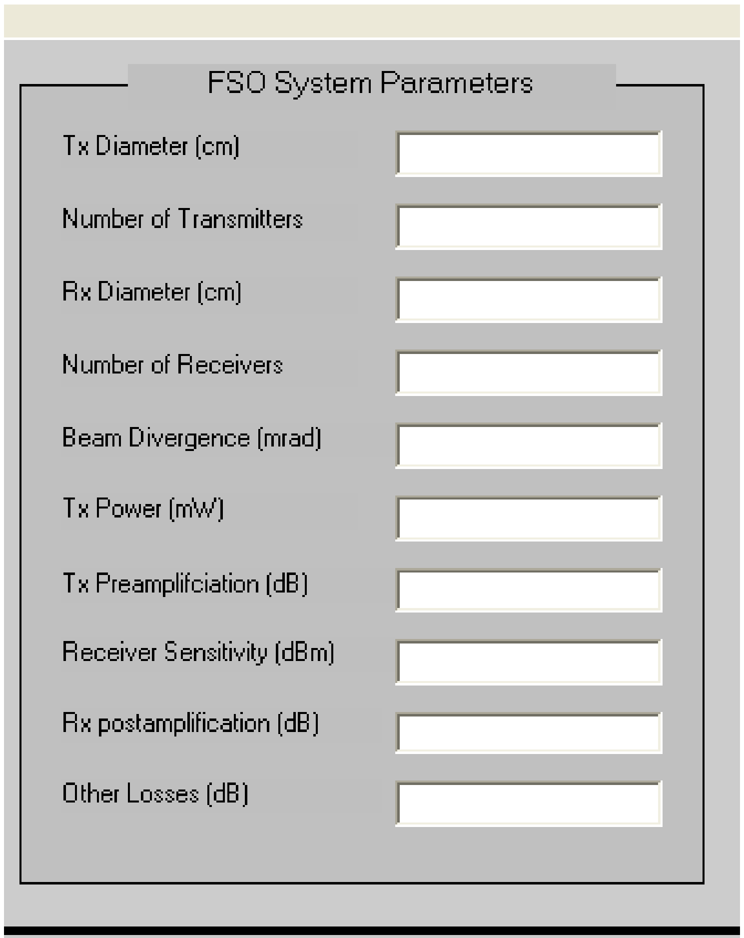
Weather Conditions:

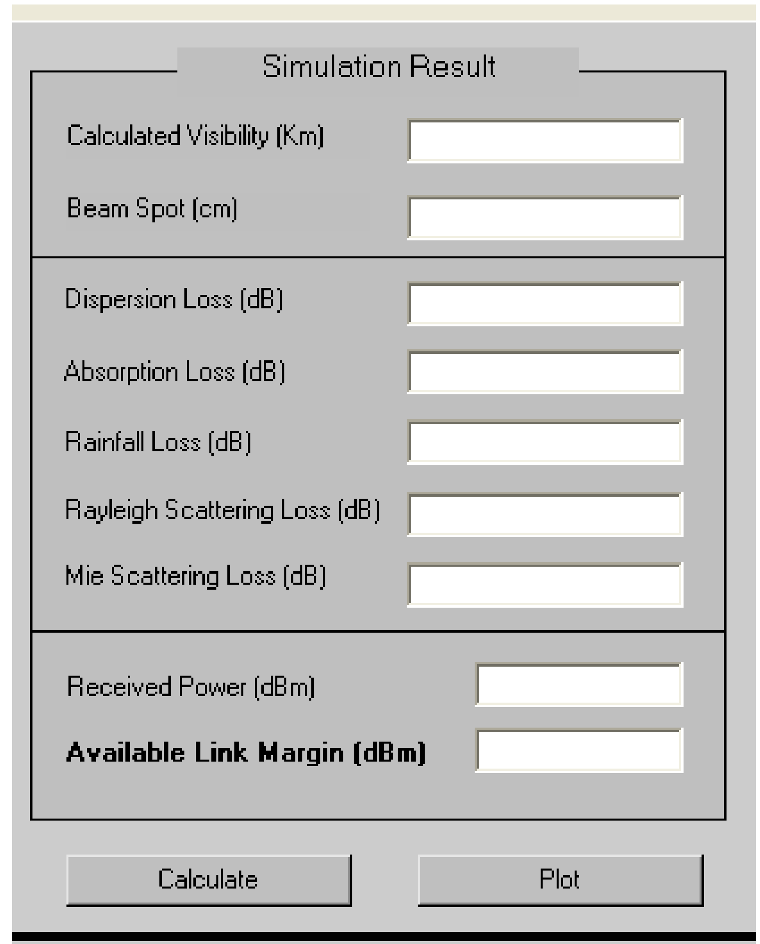
- Clear: including haze and light rain.
- Rainy: Calculate Visibility.
- Foggy: stable, evolving and selective.

Tool: Units conversion..

Help: Definitions, Errors and description..

Simulight™


FSO System Parameters
Tx Diameter (cm)
Number of Transmitters
Rx Diameter (cm)
Number of Receivers
Beam Divergence (mrad)
Tx Power (mW)
Tx Preamplifciation (dB)
Receiver Sensitivity (dBm)
Rx postamplification (dB)
Other Losses (dB)


Simulation Result
Calculated Visibility (Km)
Beam Spot (cm)
Dispersion Loss (dB)
Absorption Loss (dB)
Rainfall Loss (dB)
Rayleigh Scattering Loss (dB)
Mie Scattering Loss (dB)
Received Power (dBm)
Available Link Margin (dBm)
Calculate
Plot

Running examples directly from Simulight™

Concluding Remarks

• Simulight™ estimates FSO signal propagation in different weather conditions.

• Rain/Fog/Haze and Cloud models are based on *improved calculation of* most popular experimental published data.

• Those models need to be altered to fit other types of fogs depending on the geographical location and season.

• Haze/Fog drops of radius less than 0.5 μ are difficult to measure.

• Build the Model not only based on Visibility, but also on other wavelengths propagation characteristics!

Closing Bytes of Wisdom

"Obstacles are those frightful things you see when you take your eyes off your goal."

-- Henry Ford (1863-1947)

"If everything's under control, you're going too slow"

-- *Mario Andretti* (Car Racing Champion)

"I skate to where the puck is going to be, not to where it has been"

-- Wayne Gretzky (Best Hockey Player)