

Ontar 2021 Virtual Workshop

Our philosophy: To best teach the material, we are going to give you many models that you can modify for your own use, while doing your own calculations.

Session 1: Basic

Atmospheric Modeling Using PcModWin®/MODTRAN®

Learning Outcomes

PcModWin and MODTRAN

Why Use Introduction

MODTRAN® ?

MODTRAN® vs Koschmeider Equation Comparisons

MODTRAN®

The MODTRAN® Model

MODTRAN® Light Characterization

Most Important Parameters in Any Calculation

The MODTRAN® Spherical Refractive Geometry

MODTRAN Slant Path Observer Geometries

MODTRAN® Atmospheric Modeling

The MODTRAN® Built-In Databases

The MODTRAN® Atmospheric Profiles

The MODTRAN® Boundary Layer Aerosol Models (0-2 km)

The MODTRAN® Outputs

MODTRAN® Output Files

Limitation of MODTRAN®

Sources of Error in any MODTRAN® Calculation

Blackbody Radiation

Blackbody Radiation Sources

Spectro-Radiometric Conversions

Radiometry Entities

Radiant Parameters

Basis for the Spectral Transmittance Modeling of the Atmosphere

Degradation from Atmospheric Absorption and Scattering

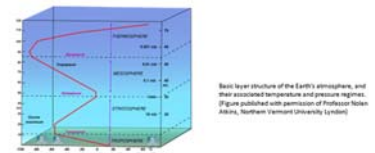
Spectral Transmittance for the Earth's Atmosphere

PcModWin Atmospheric Transmission Example

Session 2: Basic - Intermediate

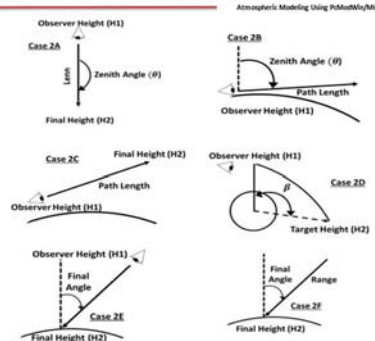
PcModWin Procedure for Modeling Spectral Transmittance

MODTRAN® Atmospheric Modeling



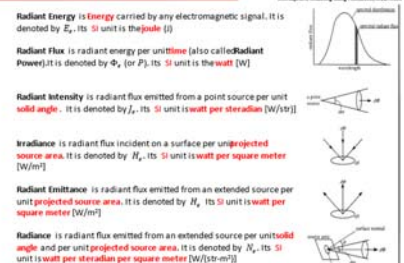
- MODTRAN® looks at the Earth's atmosphere as a layered structure
- MODTRAN® solves the Radiative Transfer Equations utilizing the *plane-parallel slab model* following the above to first order (It now handles a curved Earth)
- Each slab represents a layered atmospheric entity as the means to handle the vertical stratification as shown above.

MODTRAN Slant Path Observer Geometries



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Radiant Quantities



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Two Multiple Scattering Algorithms in MODTRAN®
Multiple Scattering / Wavelength Considerations
Multiple Scattering Rules of Thumb

Using PcModWin to Model Spectral Radiance

Spectral Radiance Calculation Way Ahead

PcModWin / MODTRAN Test Cases

(05vs1500mGround.ltn

PcModWin Test Case Directory

"Model Atmosphere" Screen for "05vs15nadirRAD.ltn"

"Surface Parameter" Screen for "05vs15nadirRAD.ltn"

"Solar Irradiance Parameter" Screen for "05vs15nadirRAD.ltn"

"Solar / Lunar Geometry" Screen for "05vs15nadirRAD.ltn"

Technical Report Figure for "05vs15nadirRAD.ltn"

Multiple Scattering Rules of Thumb

- Single-scattering (SS) always underestimates the scatter radiance when compared with multiple scattering (MS)
- Accuracy deteriorates with increasing optical depth and scattering albedo
- Observer in space: the ratio of MS/SS is 1.5 to 2.0 in window bands
- Observer on ground: SS is poor approximation for solar/observer zenith angles > 70°
- MS effects dominate clouds and thick fogs
- SS is good for early twilight; MS becomes significant in late twilight
- SS is good approximation when looking near the sun
- Scattering in the IR is less than it is in the visible bands.

Session 4: Intermediate

Advanced PcModWin Topics

New Model Atmosphere (NMA):

User Defined Properties

New Model Atmosphere

Example Calculation: AuxilSpecies.ltn

Exporting the Minor Species to Excel

Plotting the Minor Species

Another NMA Example (UserPath.ltn)

PcModWin Calculations Using Radiosonde Data

Characterization of the atmosphere is the MOST Important set of inputs.

Best Characterization of Aerosols

How to Obtain Atmospheric Data ?

How to Obtain More Realistic Atmospheric Data ?

PcModWin Radiosonde Downloads from the Internet

Use 05vs15nadirRad as an example

Configuring & Radiosonde Downloads

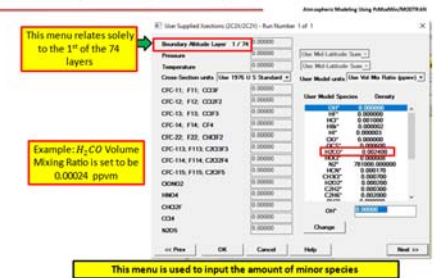
Calculation Comparing US Standard and Radiosonde Data

Correlated-k Calculations

Correlated k-Distribution

Correlated k Example

Example: AuxilSpecies.ltn (cont)



The Radiative Transfer Equation

- The transfer of the field radiance in particulate medium is given by

$$\frac{dN(z, \theta, \varphi)}{dz} = -cN(z, \theta, \varphi) + N_s(z, \theta, \varphi)$$

where

$$N_s(z, \theta, \varphi) = \int_0^{2\pi} \int_0^\pi \beta(\theta, \varphi; \theta', \varphi') N(z, \theta', \varphi') \sin \theta' d\theta' d\varphi'$$

- The first equation above is the *Radiative Transfer Equation*

• The first term in this equation represents the loss by attenuation

• The second term represents the gain by particulate scattering, sometimes called the *path function*

- Solutions to this integro-differential equation have been investigated by many researchers, most notably, Chandrasekhar, Lenoble, Duntley and Preisendorfer among others

- Let's look at the Preisendorfer solution

Session 5: Intermediate

Mapping MODTRAN Parameters Into PcModWin Screen Entries

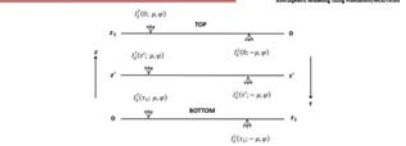
Model Atmosphere Screen

Atmospheric Column Parameters and Files Screen

Aerosol Model Screen

- Geometry and Spectral Band Screen
- Bi-Directional Reflectance Distribution Function
- Bi-Directional Reflectance Distribution Function (BRDF)**
- Surface Reflectance
- Bi-Directional Reflectance Distribution Function
- Specular Surfaces
- Diffuse Surfaces and Albedo
- Diffuse Surfaces and Lambert's Law
- PcModWin Lambertian Model Setup
- Spectral BRDF and Lambertian Options in MODTRAN
- Table of 49 Available "CSALB" (Variable) Spectral Curves
- Example Calculation (Lambertian.ltn)
- Spectral BRDF and Lambertian Options in MODTRAN (cont)
- Table of 20 Available BRDF Models
- Example Calculation Calculation (BRDF.ltn)
- Surface Parameter Screen for "BRDF.ltn"
- Modified Surface Parameter Screen for "BRDF.ltn"
- Example Calculation ("BRDFsavASC.ltn")
- Spectral Aerosol Profile**
- "Spectral Aerosol Profile" Selection
- Spectral Aerosol Profile (SAP) for "UserPathDistort.ltn" d
- Sample Calculation (UserPathDistort.ltn)

Plane-Parallel Slab Model (cont)



- This means that the RTE is written as

$$\mu \frac{dI_2(\tau; \mu, \varphi)}{d\tau} = I_2(\tau; \mu, \varphi) - J_2(\tau; \mu, \varphi),$$

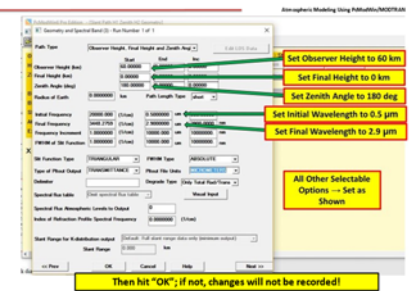
using the fact that

$$d\tau = dz / \cos \theta \equiv dz / \mu$$

and $J_2(\tau; \mu, \varphi)$ is the sum of thermal emission and the scattering of radiation incident from other directions

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Example Spectral Transmittance Calculation (cont)



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Session 6: Advanced

Line-By-Line Calculations

Descriptions of Case AnLBLTemplate.ltn: input parameters, graphical and text output files

Navy Maritime Model

Descriptions of Case NavyMaritime.ltn: input parameters, graphical and text output files

Multiple-Line-of-Sight (MLOS)

Descriptions of Case ElevAngMWRTthm.ltn: input parameters, graphical and text output files

Another MLOS Example - Lut01thm.ltn

Descriptions of Case Lut01thm.ltn : input parameters, graphical and text output files

Session 7: Advanced

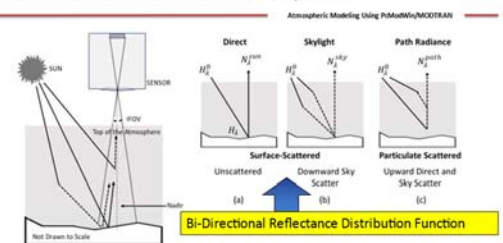
User Defined Cirrus Test Case

Descriptions of Case UserDefinedCir.ltn : input parameters, graphical and text output files

User Defined Cloud Test Case

Descriptions of Case UserDefined Cld.ltn : input parameters, graphical and text output files

Reflected and Scattered Radiance Components



- Three light components that reach a sensor:
 - Direct Light Component is unscattered from source
 - Skylight Light Component is scattered down onto a surface (explain why shadows are not totally black)
 - Path Radiance Light Component is scattered along the path up into the sensor

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Cirrus Profile Test Case

Descriptions of Case CirrusProfile.ltn : input parameters, graphical and text output files
Ice Present in the Upper Atmospheric Layers

Ångström Law

Discussion of Angstrom's Law

Descriptions of Case AngstromLaw.ltn: input parameters, graphical and text output files

Session 8: Optical Signal Detection I

Electro-Optical Systems**Background-Limited Optical Communications****Signal-to-Noise Ratio**

Key System Design Metric – Signal-to-Noise Ratio

The Electrical Signal-to-Noise Ratio Used in Optics

The Electrical Signal-to-Noise Ratio Used in Imaging

Optical Imaging Sensors

Responsivity

The Electrical Signal-to-Noise Ratio Used in Optics

Noise Equivalent Power

The Radiometry of Images

SNR for a Point Source Using a System-Noise-Limited

Receiver

Extended Background Radiance -Sensor Geometrical

Layout

Received Background noise Current at the Center-Pixel

Other Forms of the Received Background Noise Current

SNR for an Extended Background Source Using a System-Noise-Limited Receiver

Imaging SNR for a Received Point Source and Extended Background Radiation under

System-Noise-Limited Conditions

Imaging SNR Under System-Noise-Limited Conditions

Example #1 Sensor Geometry, point source

MODTRAN Transmittance Calculation

MODTRAN Scattered Radiance Calculation

Key System Characteristics @ 0.85 μm

System Calculation

Calculation

Atmospheric Modeling Using PMODWIN/MODTRAN

- Inserting the previous parameters into Eq. (20) for $\lambda = 0.85 \mu\text{m}$ gives

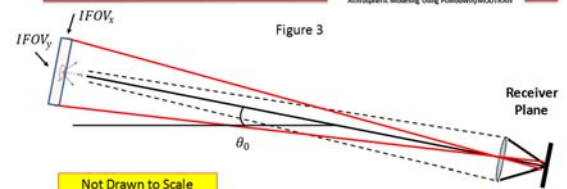
$$\begin{aligned} OSNR_{\text{contrast}} &= \left(\frac{A^{\text{img}}}{R^2} \right) \left(\frac{Y_{\text{opt}}}{\sqrt{B_{\text{e}}}} \right) \int_0^\infty F(\lambda) L_a(\lambda; \theta) \left(\frac{I_s(\lambda) - N_b(\lambda) A^{\text{det}}}{NEP(\lambda)} \right) d\lambda \\ &\approx (2.4 \times 10^{-15} \text{ str} - \mu\text{m}) F_{\text{aviriz}} L_a(30^\circ) \left(\frac{I_s(\lambda) - N_b(0.93 \text{ nm}^2)}{2.15 \times 10^{-15} \text{ W}} \right) \\ &\approx \left(1.1 \frac{\text{str} - \mu\text{m}}{\mu\text{W}} \right) F_{\text{aviriz}} L_a(30^\circ) \left(I_s - \left(20.2 \frac{\mu\text{W}}{\text{str} - \mu\text{m}} \right) \right) \end{aligned}$$

- If $I_s = 100 \mu\text{W}/\text{str} - \mu\text{m}$, then $OSNR_{\text{contrast}} \approx 88.8$ (19.4 dB)
- If $I_s = 50 \mu\text{W}/\text{str} - \mu\text{m}$, then $OSNR_{\text{contrast}} \approx 33.3$ (15.2 dB)
- If $I_s = 30 \mu\text{W}/\text{str} - \mu\text{m}$, then $OSNR_{\text{contrast}} \approx 10.88$ (10.4 dB)

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Extended Background Radiance -Sensor Geometrical Layout

Atmospheric Modeling Using PMODWIN/MODTRAN



- Square-Pixels in Focal Plane, each with detector area A^{det} , given by

$$A^{\text{det}} = d_x^{\text{det}} \times d_y^{\text{det}} \quad (7)$$

- Background radiance N_b from an extended-area source is assumed to fill the entire pixel's IFOV as we have a point source target

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Session 9: Optical Signal Detection II

Normalized Spectral Detectivity

Noise Equivalent Temperature Difference

Example calculations: Horizontal link near the earth's surface

Example calculations: NETD for a lossy atmosphere in LWIR using Koschmeider Eu.

Example calculations: NETD in MODTRAN "Rural-Vis=23 km"

Remote Sensing Example

Two Channel-Spectral Processing

Target Blackbody Curves

Notional Data Set

Multi-Spectral/Multi-Frame Processing

ORIGINAL MWIR and LWIR TAHOE IMAGES

40 Frame Averaged Weighted Differenced Images

Airborne Wireless Communications

How the FSOC System Works

Compensation for Turbulent Fade

FSOC Received Power Model

Noise Equivalent Temperature Difference (cont)

- The Spectral Exitance is given by

$$W_\lambda(\lambda) = \frac{C_1}{\lambda^5} \left[\frac{1}{e^{C_2/\lambda T} - 1} \right]$$

with

$$C_1 = 3.741832 \times 10^8 \text{ [W} \cdot \mu\text{m}^4 / \text{cm}^2]$$

and

$$C_2 = 1.438786 \times 10^4 \text{ [\mu m} \cdot \text{K}]$$

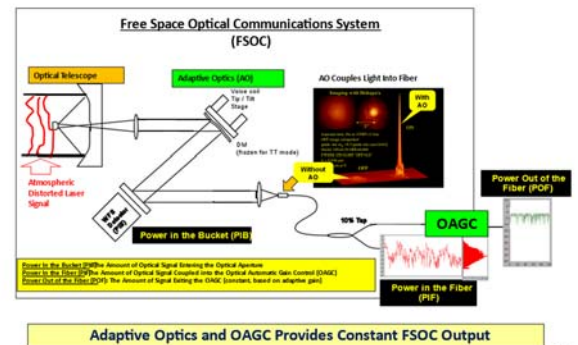
- Dividing by ΔT , we have

$$\frac{\Delta OSNR_{img}}{\Delta T} \approx \frac{\pi \sqrt{A_{det}}}{4[F\#]^2 \sqrt{B_e}} \int \gamma(\lambda) L_a(\lambda; \theta_0) D^*(\lambda) \frac{\partial W_\lambda(\lambda)}{\partial T} d\lambda$$

- If we let $\Delta OSNR = 1$ be the definition of the NETD, then we have

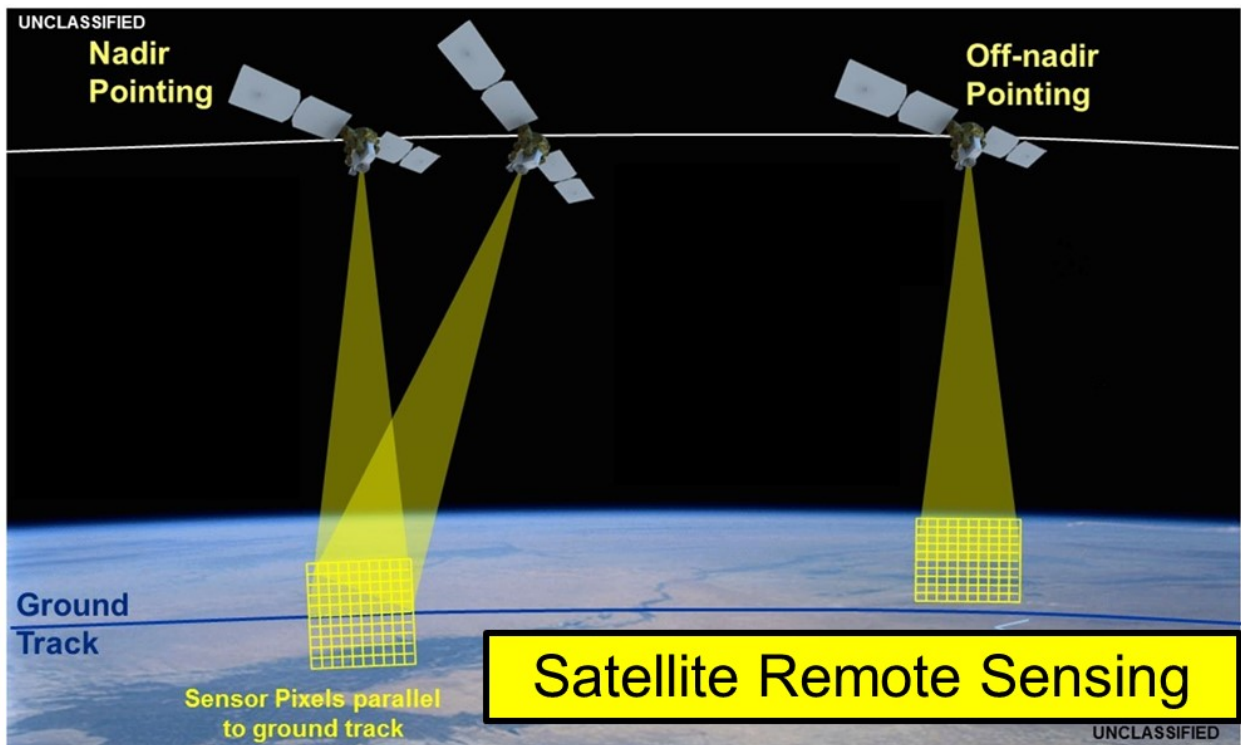
$$NETD \equiv \Delta T_{min}^{\Delta OSNR=1} = \frac{4[F\#]^2 \sqrt{B_e}}{\sqrt{A_{det}} \int \gamma(\lambda) L_a(\lambda; \theta_0) D^*(\lambda) \frac{\partial W_\lambda(\lambda)}{\partial T} d\lambda}$$

How the FSOC System Works



PSD[•] Point Source Detection

New Software



Systems engineers design sensors to detect targets at ranges from tens to hundreds of kilometers using both single detectors and focal plane arrays.

Ontar's new PSD (Point Source Detections) software calculates OSNR and other metrics needed by systems designers using Target, Scenario, Atmospheric, Sensor Optics and Sensor Detector parameters.

Scenario: **PsdDefault** Open... Save As... Run Basic Run PcModWin Results >>

Target Parameters Target Temperature: 500.00000000 K Target Emissivity: 0.850000000 W/(cm² str) Point-Source Radiant Intensity (PSRI): 4.350000000 W/(str - μm)		Sensor Parameters Optics Sensor Lens Focal Length (SLFL): 0.950000000 m Sensor Lens Diameter (SLD): 0.100000000 m Optical Transmittance of the Sensor (OTS): 0.800000000 Sensor Spectral Transmission (SST): 1.000000000 Sensor Filter Response (SFR): 8.150000000 Average In-Band Filter Function (FIIF): 0.950000000 Delta Omega Lens (DOL): 1.000000000 Detector Electronics Detector Quantum Efficiency (DQE): 0.990000000 Detector Responsivity (RESP): 6.500000000 Use Calculated Detector Responsivity: ☐ Sensor Detector Diameter (SDD): 0.100000000 cm² Detector's Noise Equivalent Power (SNEP): 2.150000E-015 W/Hz Sensor's Electrical Bandwidth (SEB): 500.000000000 Hz	
Scenario Parameters Altitude of Point-Source Height 2 (H2): 0.000000000 km Altitude of Sensor Height 1 (H1): 2.500000000 km Max Range [Link Range + H2 H1] (MaxR): 80.000000000 km ☐ Range Increment (RI): 2.500000000 km ☐ >> Initial Wavelength (IW): 7.000000000 μm Final Wavelength (FW): 9.300000000 μm		Atmospheric Parameters Average In-Band Transmission (Atran): 1.000000000 Background Spectral Radiance (Bsr): 0.010522000 Target Spectral Radiance (Tsr): 0.010522000	

OSNR for Point-Source Background Noise
OSNR:

PSD • Main Screen

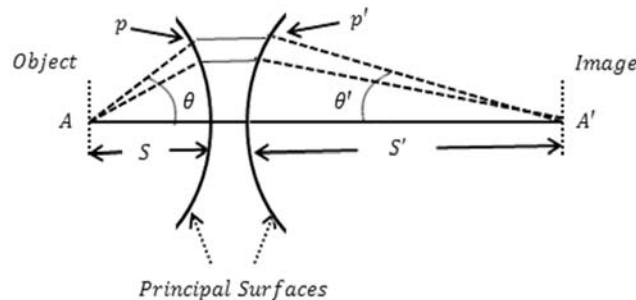
PcModWin Launch Status:

ONTAR CORPORATION

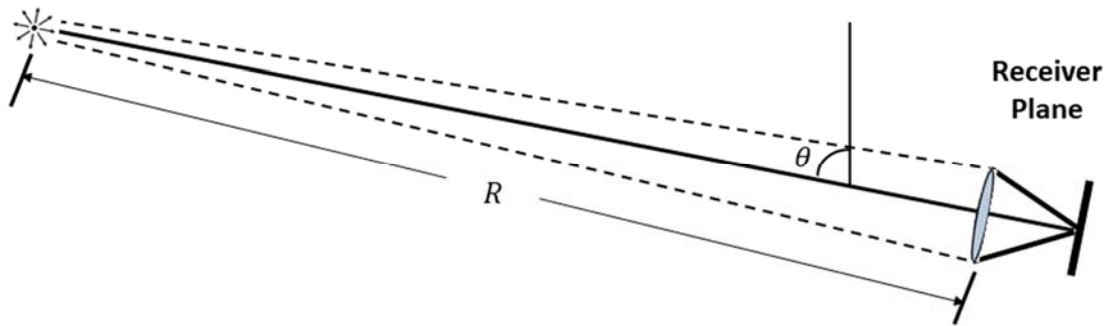
parameters.

It executes as both a stand-alone software package **and** integrated with our **NEW PcModWin – Scenario** software in the Run Basic and Run PcModWin modes depicted by the ↑s in the figure.

This figure is the main PSD input screen showing the input parameters and run modes. The software was developed cooperatively with Dr. Larry B. Stotts.



When a radiation source is imaged by an optical system, the observed image only captures radiance within the solid angle subtended by the clear aperture of said optical system and zero, elsewhere as depicted in the figure above.



The figure above depicts the sensor geometry for a point source detection scenario. The point source is at Altitude H_2 illuminating a sensor at the Observer Altitude H_1 from a distance R away at a zenith angle θ . The point-source has radiant intensity $I_s [W/str]$. The sensor uses a lens of diameter d_{lens} and focal length f

For example, the Optical Signal to Noise Ratio for this scenario is approximated by:

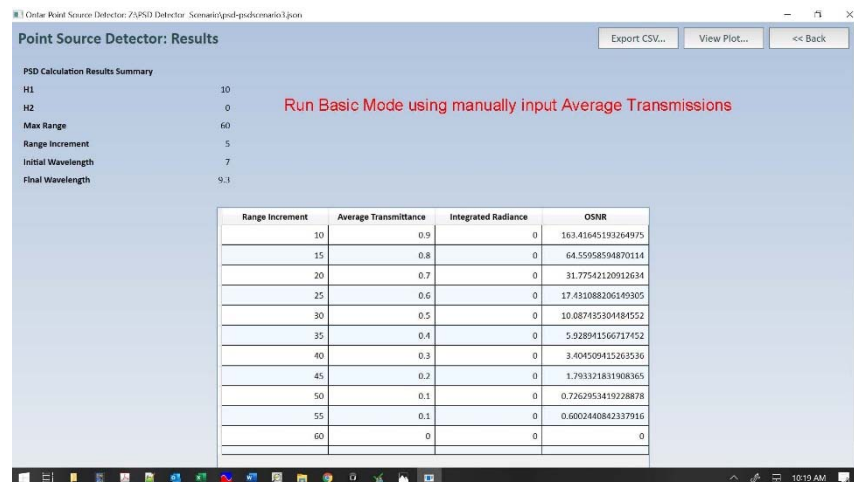
$$OSNR = \frac{\mathcal{R}_\lambda P_s}{\sqrt{B_e} NEP} \approx \frac{\gamma_{sensor} L_a I_s \Delta\Omega_{lens} \Delta\lambda}{\sqrt{B_e} NEP} \approx \frac{\gamma_{sensor} L_a I_s \Delta\lambda}{\sqrt{B_e} NEP} \left(\frac{A^{lens}}{R^2} \right)$$

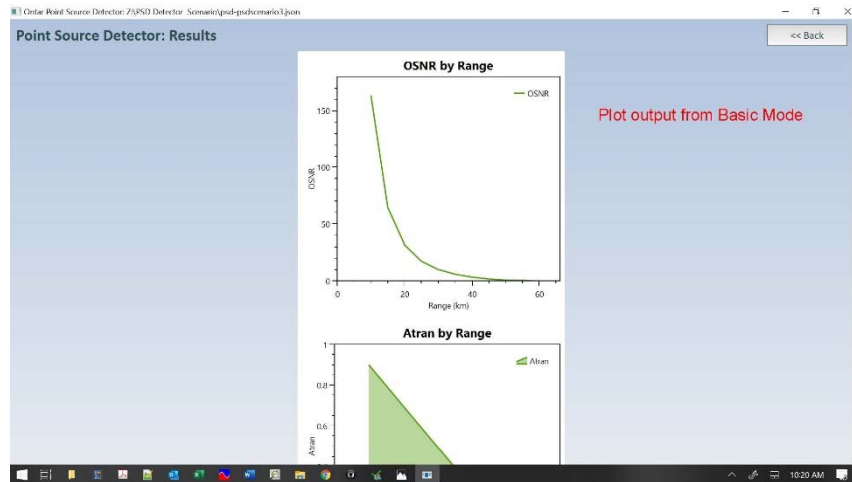
Also Contrast, Detection Range, and other metrics are calculated.

RUN Basic Mode:

In the stand-alone mode the user inputs the parameters in the Main Screen as well as the atmospheric transmission, target, and background signatures.

Tabular output for a down viewing scenario at ranges from 10 to 60 Kms in 5 Km increments.

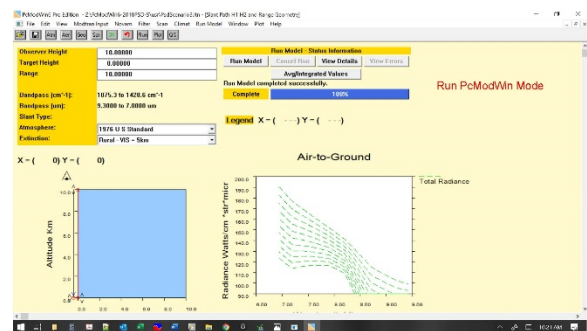
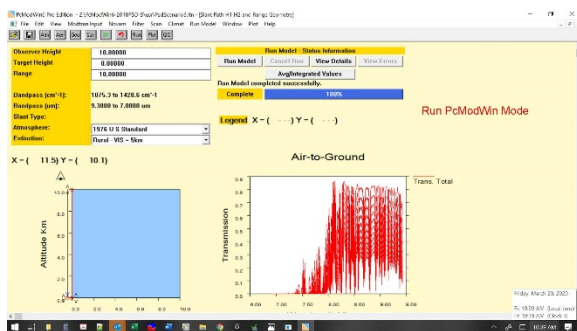




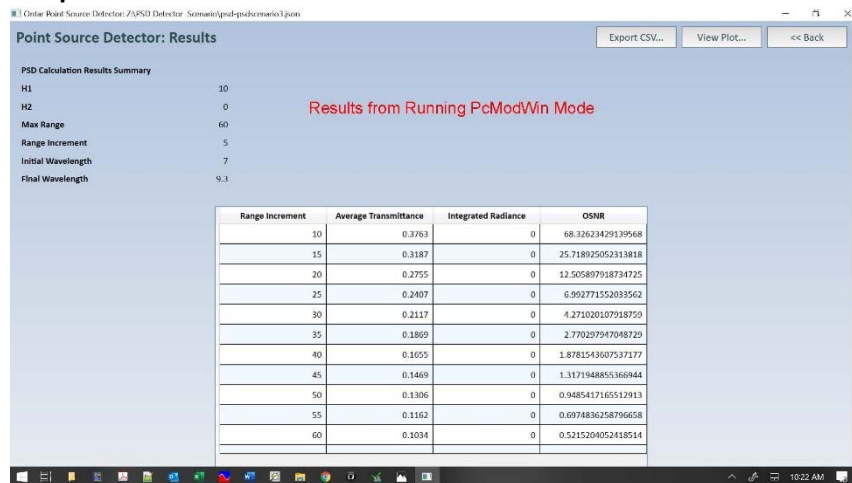
Run PcModWin Mode:

In this mode the user inputs the scenario and system parameters on the main screen. At execution, the PSD software is interrupted and transmits parameters to PcModWin – Scenario. This is like the interface Ontar’s designed for NVESD’s NVTherm-IP to interface PcModWin5 with NVTHERM.

The user has the capability to change any MODTRAN® parameters except those specified on the main screen such as wavelength interval, altitudes, ranges, zenith angle etc. Hence the user has access to ALL other parameters such as aerosols, scattering, atmospheric profiles, radiosonde etc.

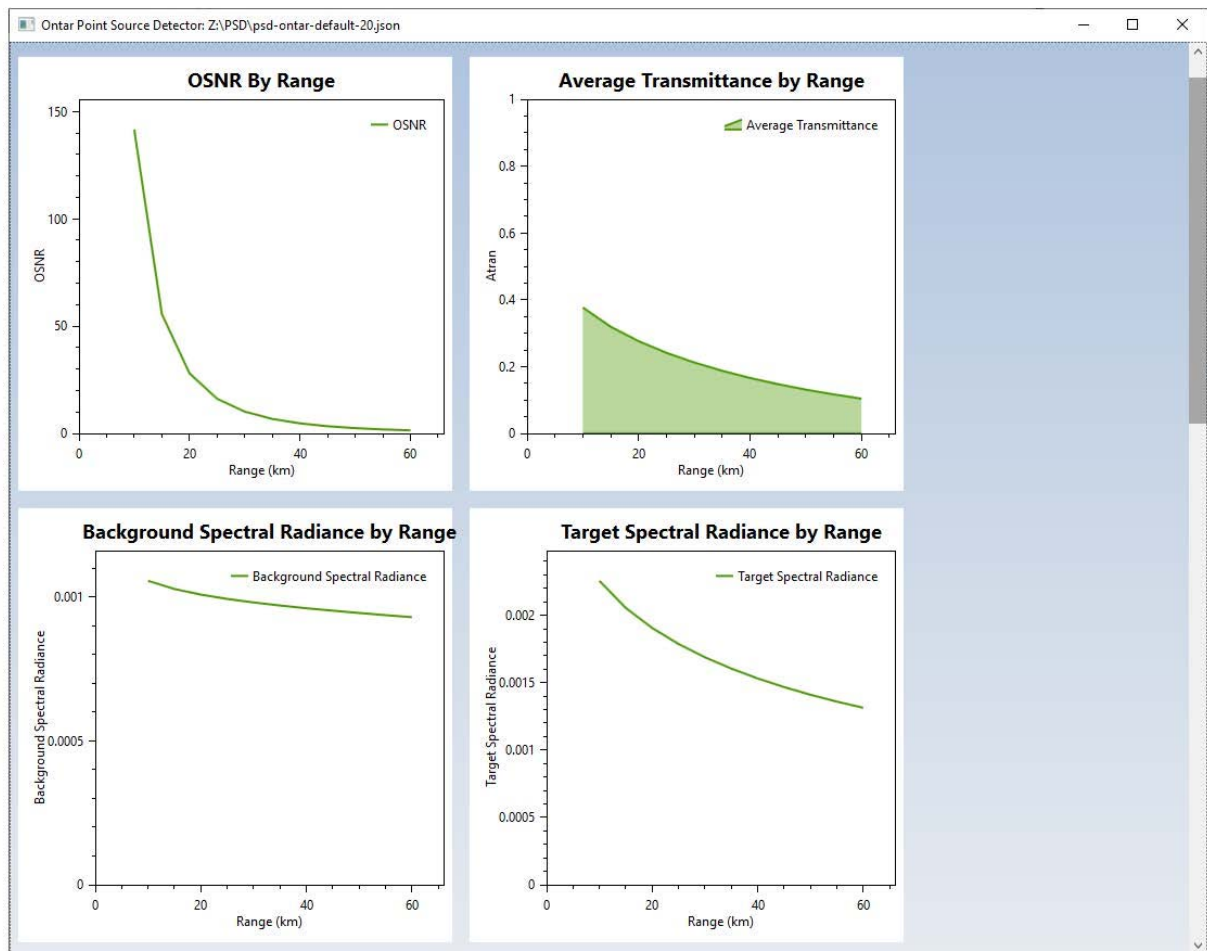


Atmospheric Transmissions and Radiance for the scenario described about.



Excel sheet from PcModWin mode

Current Range Increment	Average Transmittance	Integrated Radiance	OSNR
10	0.3763	0	68.32623429
15	0.3187	0	25.71892505
20	0.2755	0	12.50589792
25	0.2407	0	6.992771552
30	0.2117	0	4.271020108
35	0.1869	0	2.770297947
40	0.1655	0	1.878154361
45	0.1469	0	1.317194886
50	0.1306	0	0.948541717
55	0.1162	0	0.697483626
60	0.1034	0	0.521520405



PSD outputs for the scenario described above.