

# 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

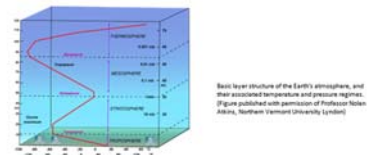
#### Basis for the Spectral Transmittance Modeling of the Atmosphere

- Degradation from Atmospheric Absorption and Scattering
- Spectral Transmittance for the Earth's Atmosphere
- PcModWin Atmospheric Transmission Example

## Session 2: Basic - Intermediate

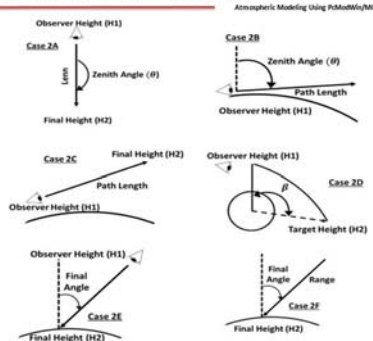
### PcModWin Procedure for Modeling Spectral Transmittance

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



#### Radiant Quantities

**Radiant Energy** is energy carried by any electromagnetic signal. It is denoted by  $E_e$ , its SI unit is the **joule (J)**

**Radiant Flux** is radiant energy per unit **time** (also called **Radiant Power**). It is denoted by  $\Phi_e$  (or  $P_e$ ), its SI unit is the **watt (W)**

**Radiant Intensity** is radiant flux emitted from a point source per unit **solid angle**. It is denoted by  $I_e$ , its SI unit is **watt per steradian (W/sr)**

**Irradiance** is radiant flux incident on a surface per unit **unprojected source area**. It is denoted by  $H_e$ , its SI unit is **watt per square meter (W/m²)**

**Radiant Emittance** is radiant flux emitted from an extended source per unit **projected source area**. It is denoted by  $M_e$ , its SI unit is **watt per square meter (W/m²)**

**Radiance** is radiant flux emitted from an extended source per unit **solid angle and per unit projected source area**. It is denoted by  $L_e$ , its SI unit is **watt per steradian per square meter (W/(sr·m²))**

- Directory Structure of PcModWin
- Example Spectral Transmittance Calculation
- “Edit Options” via File Menu
- Atmosphere and Path
- Aerosols
- Geometry and Spectral Band
- Calculation Overview
- How to Know when Calculation has successfully run
- Plotting results
- Editing plot (advanced)
- Export Results to Excel Spreadsheet
- Export to Matlab
- Importance of Ground Altitude on Aerosol Effect In

MODTRAN

- “1500mGround.ltn” test case
- Long Range Refraction and Surface Meteorological Range
- 57-km Long Range Refraction Calculation
- Basic Setup for 57 km Long Range Refraction Calculation Demo
- Refractive Path Details from TAPE6, created by “DesertTest.ltn”

PcModWin – Enhanced for Custom Atmospheres

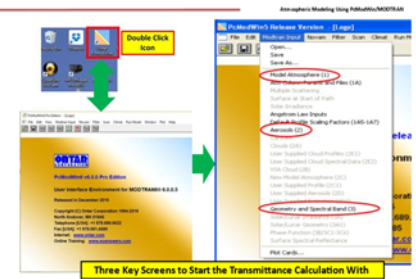
- Enhanced for Custom Atmospheres for China
- 29 Profiles + 6 US Profiles
- MODTRAN® Default Atmospheres
- Setup Custom Profiles Steps
- Comparison Calculations for Custom Atmospheres

## Session 3: Intermediate

### Spectral Radiance Components

- Reflected and Scattered Radiance Components
- Example Multiple-Scattering Effects on Spectral Radiance
- Radiative Transfer Equation
- Essential Concepts in Radiative Transfer
- The Radiative Transfer Equation
- Preisendorfer Solution
- Henyey-Greenstein Scalar Phase Function
- MODTRAN® Radiative Transfer Equation Calculations
- The Radiative Transfer Equation (RTE) in MODTRAN®
- Solving the Radiative Transfer Equation in MODTRAN®
- Plane-Parallel Slab Model

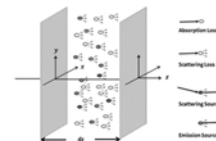
Example Spectral Transmittance Calculation



Geometry and Spectral Band Screen

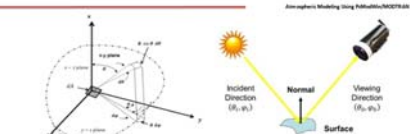


The Radiative Transfer Equation (RTE) in MODTRAN®



- In MODTRAN®, the RTE is treated as the fundamental equation describing the propagation of specific intensity (radiance from a point source) in a scattering and absorbing homogeneous medium
- Specifically, the change in the spectral specific intensity  $I_\lambda(z; \theta, \varphi)$  at a given pointz, as the wave traverses a distancez in the direction  $(\theta, \varphi)$ , will be affected as follow

Bi-Directional Reflectance Distribution Function ( cont)



- The BRDF is the ratio of the radiance in the outgoing direction to the incident irradiance
  - The BRDF has units of inverse steradians (1/sr)
- This implies that if the surface cited above is to emit radiance  $N_e(r, t; \theta_e, \varphi_e; \lambda)$ , its BRDF would be given by

$$P_{BR}(r, t; \theta_e, \varphi_e; \theta_i, \varphi_i; \lambda) = \frac{N_e(r, t; \theta_e, \varphi_e; \lambda)}{I_i(r, t; \theta_i, \varphi_i; \lambda)}$$

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

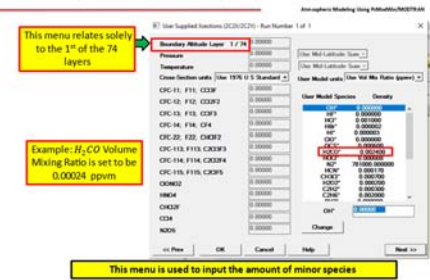
Calculation Comparing US Standard and Radiosonde Data

**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

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

where

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

- 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**

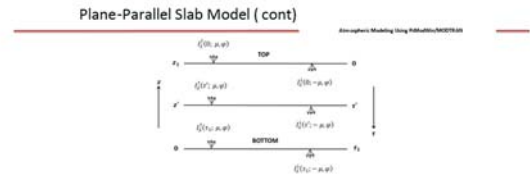
**Mapping MODTRAN Parameters Into PcModWin Screen Entries**

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)



This means that the RTE is written as

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

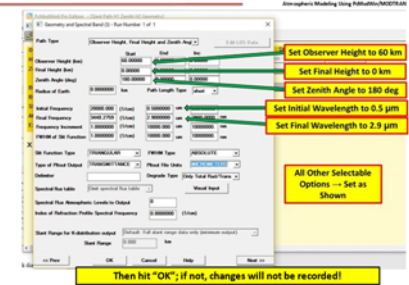
using the fact that

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

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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- Spectral Aerosol Profile**
- "Spectral Aerosol Profile" Selection
- Spectral Aerosol Profile (SAP) for "UserPathDistort.ltn" d
- Sample Calculation (UserPathDistort.ltn)

## 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 ElevAngMWRTtthm.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

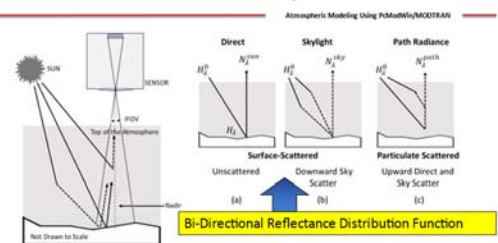
### User Defined Cirrus Test Case

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

$$OSNR_{contrast} = \left( \frac{A^{img}}{R^2} \right) \left( \frac{Y_{opt}}{\sqrt{B_e}} \right) \int_0^\infty F(\lambda) L_a(\lambda; \theta) \left( \frac{I_s(\lambda) - N_b A^{det}}{NEP(\lambda)} \right) d\lambda$$

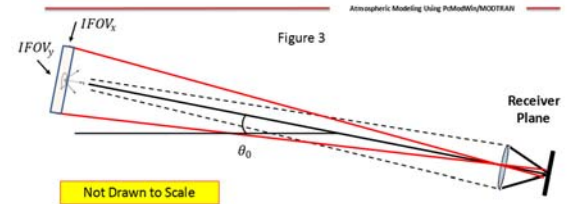
$$\approx (2.4 \times 10^{-15} \text{ str} - \mu\text{m}) F_{aviriz} L_a(30^\circ) \left( \frac{I_s(\lambda) - N_b (0.93 \text{ mm}^2)}{2.15 \times 10^{-15} \text{ W}} \right)$$

$$\approx \left( 1.1 \frac{\text{str} - \mu\text{m}}{\mu\text{W}} \right) F_{aviriz} L_a(30^\circ) \left( I_s - \left( 20.2 \frac{\mu\text{W}}{\text{str} - \mu\text{m}} \right) \right)$$

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

**Extended Background Radiance -Sensor Geometrical Layout**

Atmospheric Modeling Using PMODWIN/MODTRAN



- Square-Pixels in Focal Plane, each with detector area  $A^{det}$ , given by
- $$A^{det} = d_x^{det} \times d_y^{det} \tag{7}$$

- 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



# 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

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

and

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

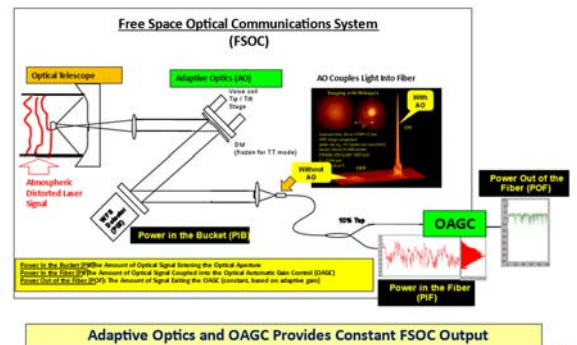
- Dividing by  $\Delta T$ , we have

$$\frac{\Delta OSNR_{img}}{\Delta T} \approx \frac{\pi \sqrt{A_{det}}}{4|F\#|^2 \sqrt{B_e}} \int \gamma(\lambda) L_a(\lambda; \theta_0) D'(\lambda) \frac{\partial W_{\lambda}(\lambda)}{\partial T} d\lambda$$

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

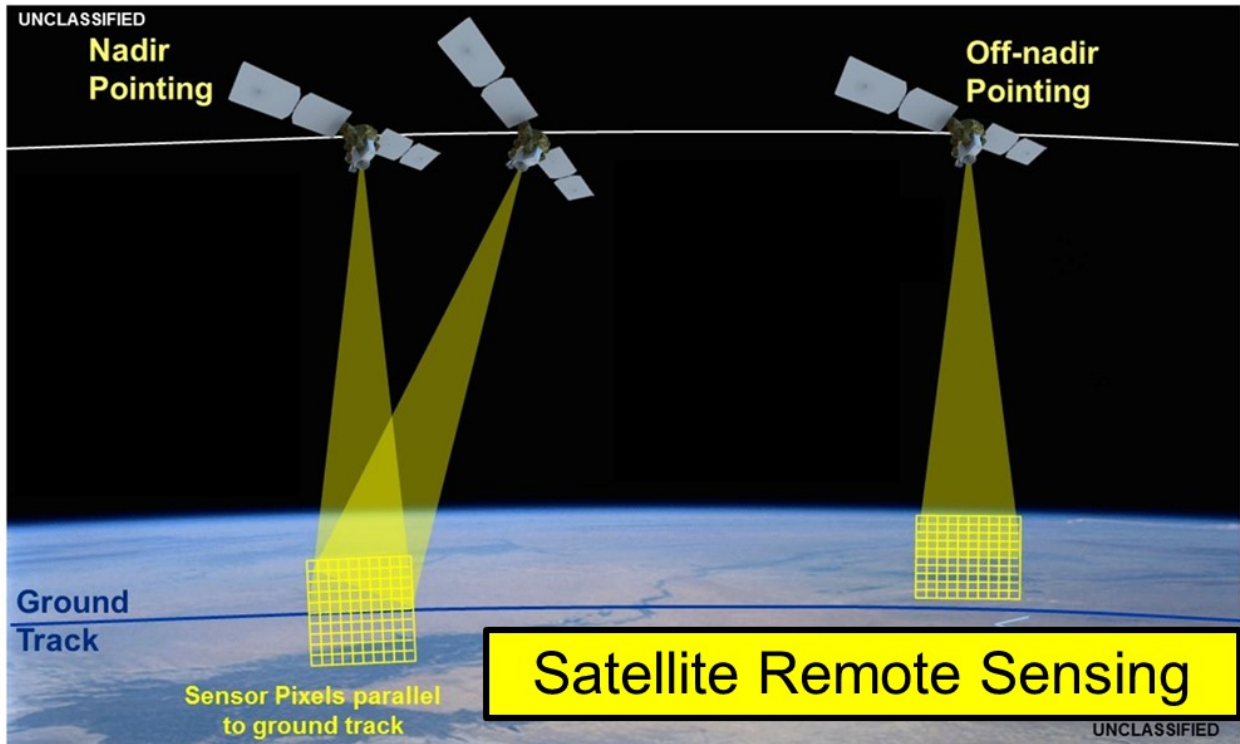
$$NETD \equiv \Delta T_{min}^{\Delta OSNR=1} = \frac{4|F\#|^2 \sqrt{B_e}}{\sqrt{A_{det}} \int \gamma(\lambda) L_a(\lambda; \theta_0) D'(\lambda) \frac{\partial W_{\lambda}(\lambda)}{\partial T} d\lambda}$$

## How the FSOC System Works



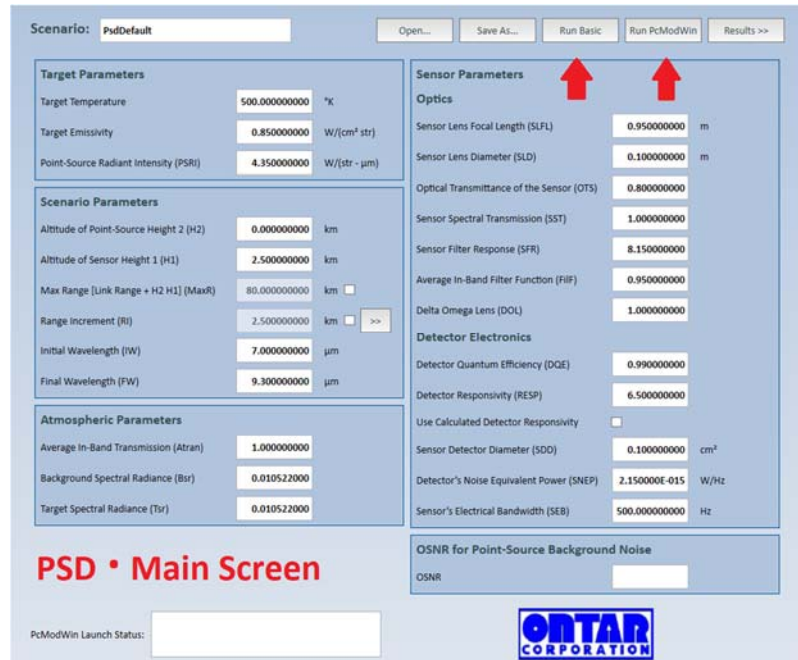
# PSD<sup>•</sup> Point Source Detection

## New Software



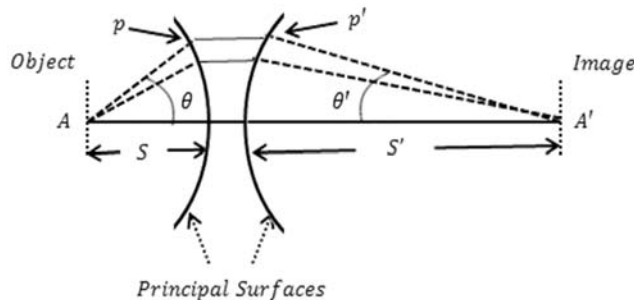
Systems engineers design sensors to detect targets at ranges from tens to hundreds of kilometers using both single detectors and focal plane arrays.

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.



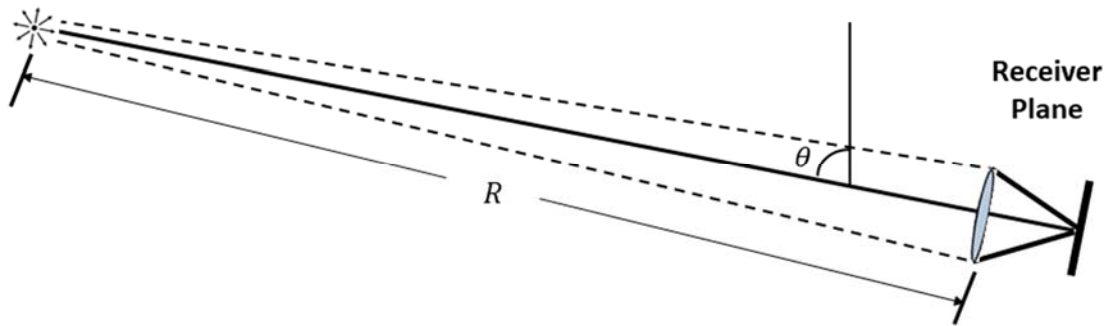
It executes as both a stand-alone software package **and** integrated with our **NEW PcModWin – Scenario** software in the Run Basic and Run PcModWin modes depicted by the ↑s in the figure.

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  $\theta$ . 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:

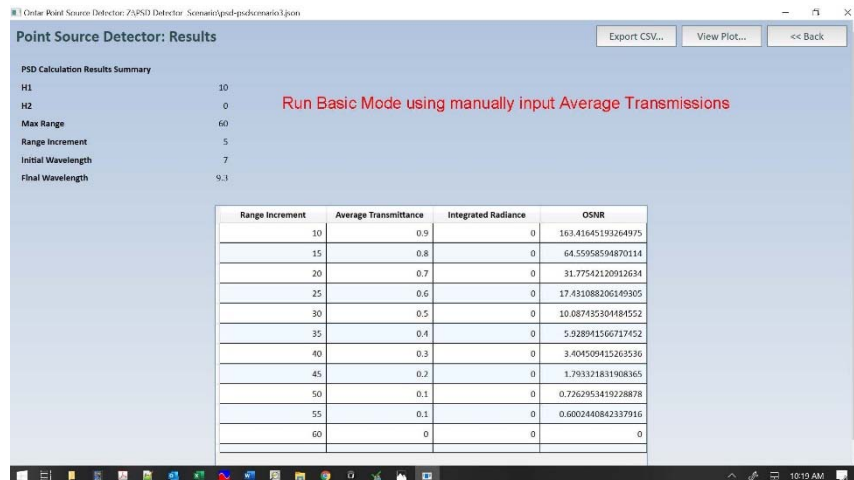
$$OSNR = \frac{\mathcal{R}_\lambda P_s}{\sqrt{B_e} NEP} \approx \frac{\gamma_{sensor} L_a I_s \Delta\Omega_{lens} \Delta\lambda}{\sqrt{B_e} NEP} \approx \frac{\gamma_{sensor} L_a I_s \Delta\lambda}{\sqrt{B_e} NEP} \left( \frac{A^{lens}}{R^2} \right)$$

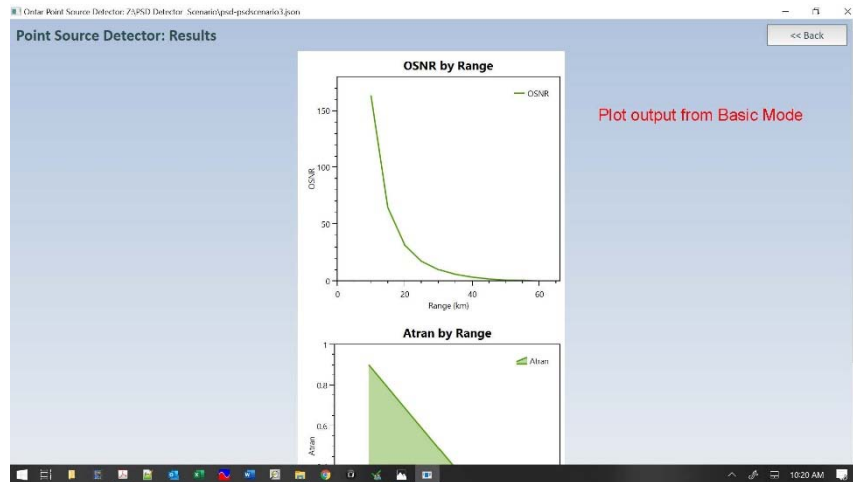
Also Contrast, Detection Range, and other metrics are calculated.

**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.

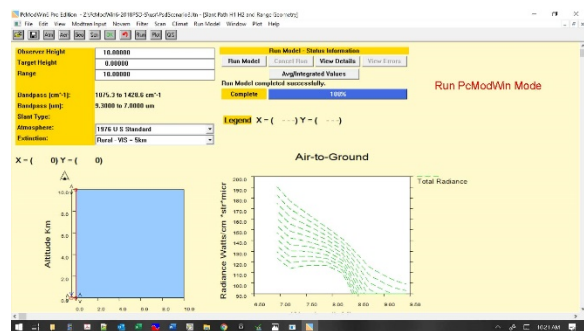
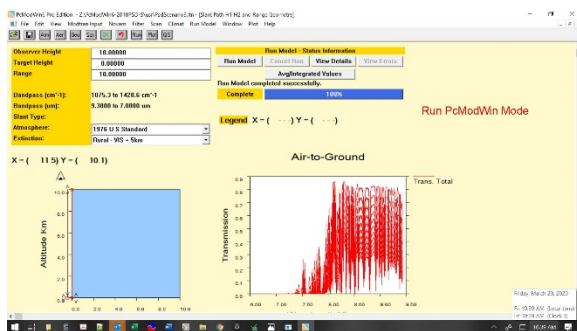




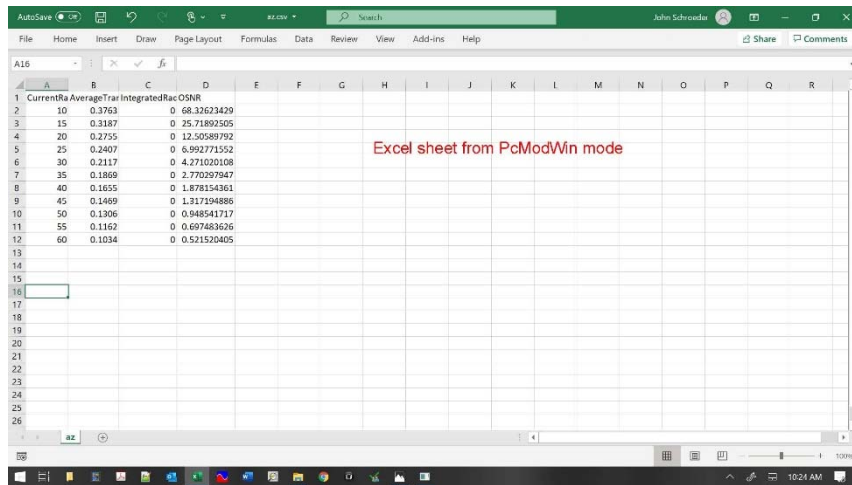
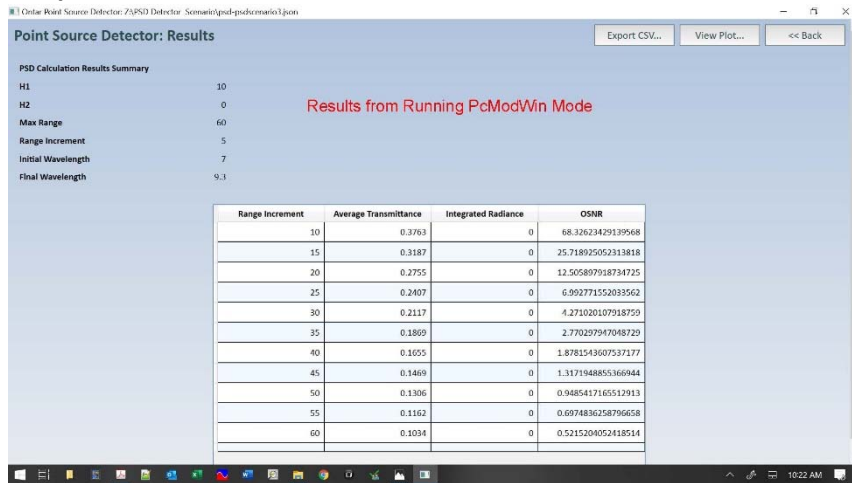
**Run PcModWin Mode:**

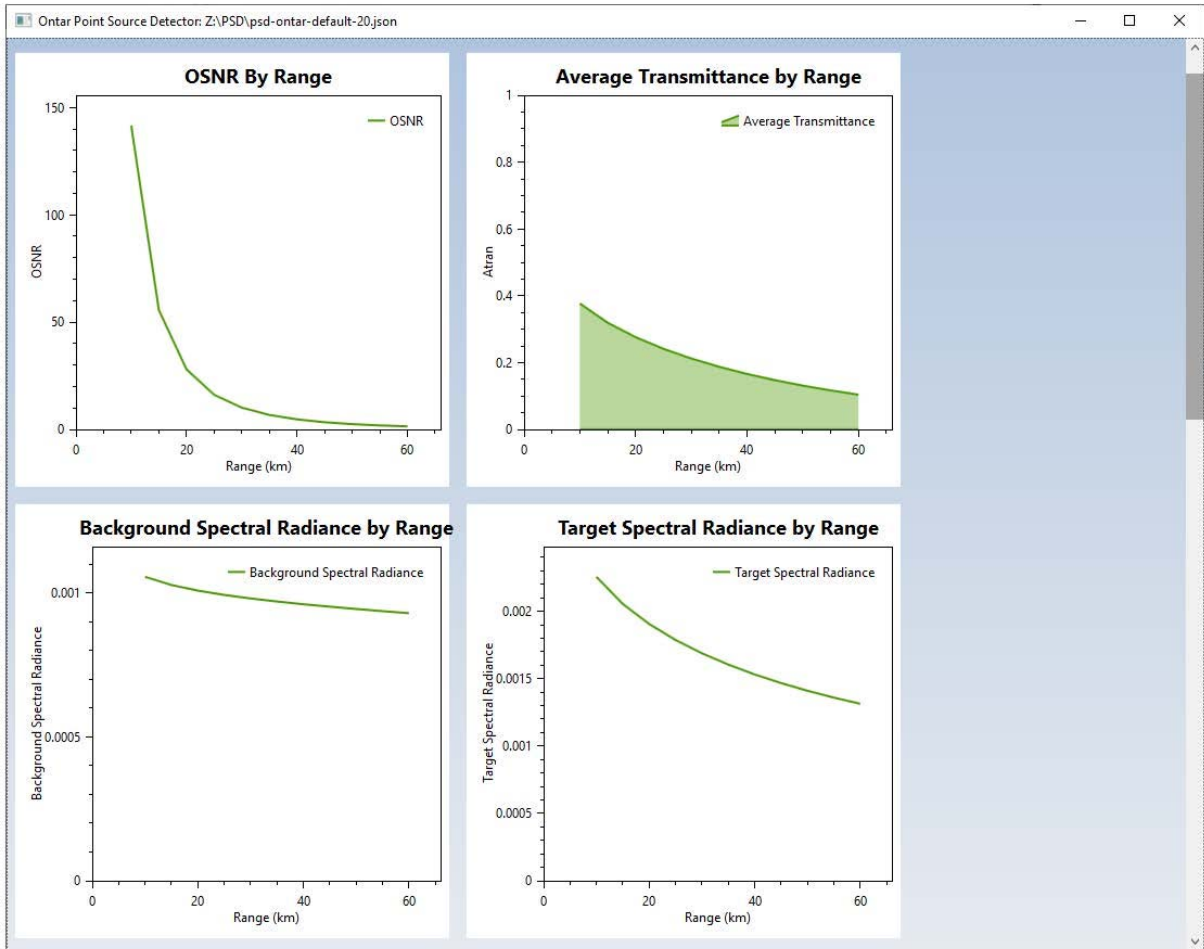
In this mode the user inputs the scenario and system parameters on the main screen. At execution, the PSD software is interrupted and transmits parameters to PcModWin – Scenario. This is like the interface Ontar’s designed for NVESD’s NVTherm-IP to interface PcModWin5 with NVTHERM.

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.**





PSD outputs for the scenario described above.