EOIR Sensor Radiance Predictions using MuSES and MODTRAN

Corey Packard, Mark Klein, Dr. David Less, Pete Rynes*

ThermoAnalytics, Inc. (USA)

Atmospheric Transmission Models | Modeling in Remote Sensing

ATM-MIRS Meeting

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Agenda

Motivation for Sensor Radiance Prediction

Summary of Workflow & Process

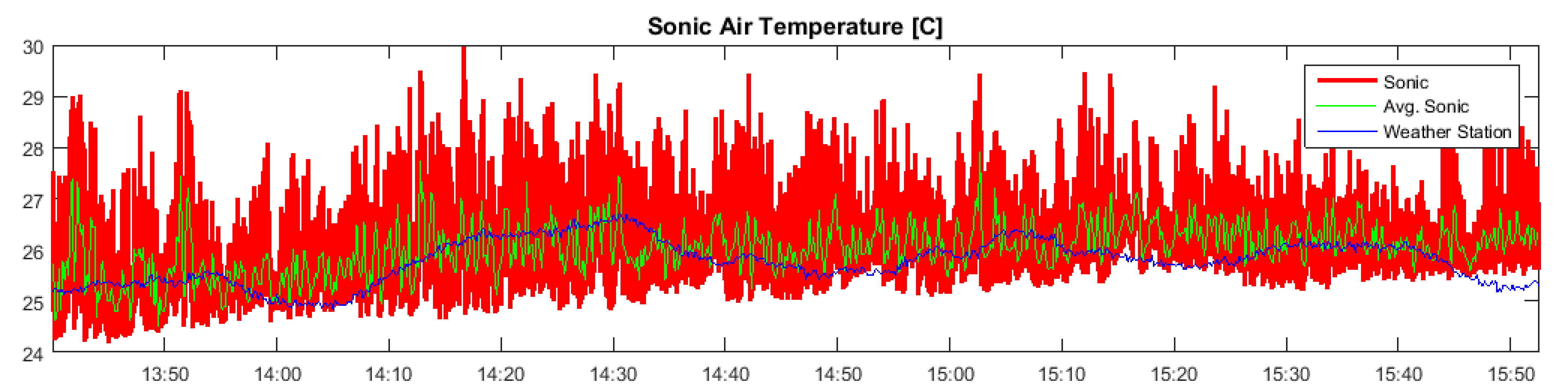
MuSES Imaging Chain

Incorporation of MODTRAN results

Future Direction

Motivation for EOIR Scene Simulation

- Many defense agencies require the ability to predict scene radiances for target vulnerability studies and detection analysis
  - GOAL: Simulate any weather, mission profile, target scenario
  - BENEFIT: Minimizes expensive, complex data collections which measure only limited weather conditions and target/background configurations



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  - GOAL: Simulate a wide range of sensor wavebands/resolutions, advanced sensor platforms (e.g. moving airborne sensor)
  - BENEFIT: Avoid having to own imagers of interest, predict characteristics of imager required for various activities, avoid complex test campaigns with finite vantage points

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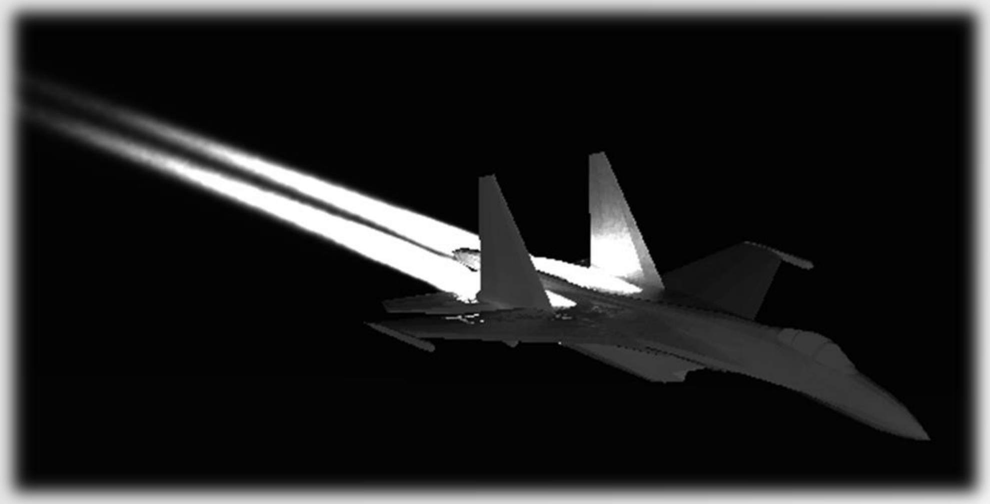
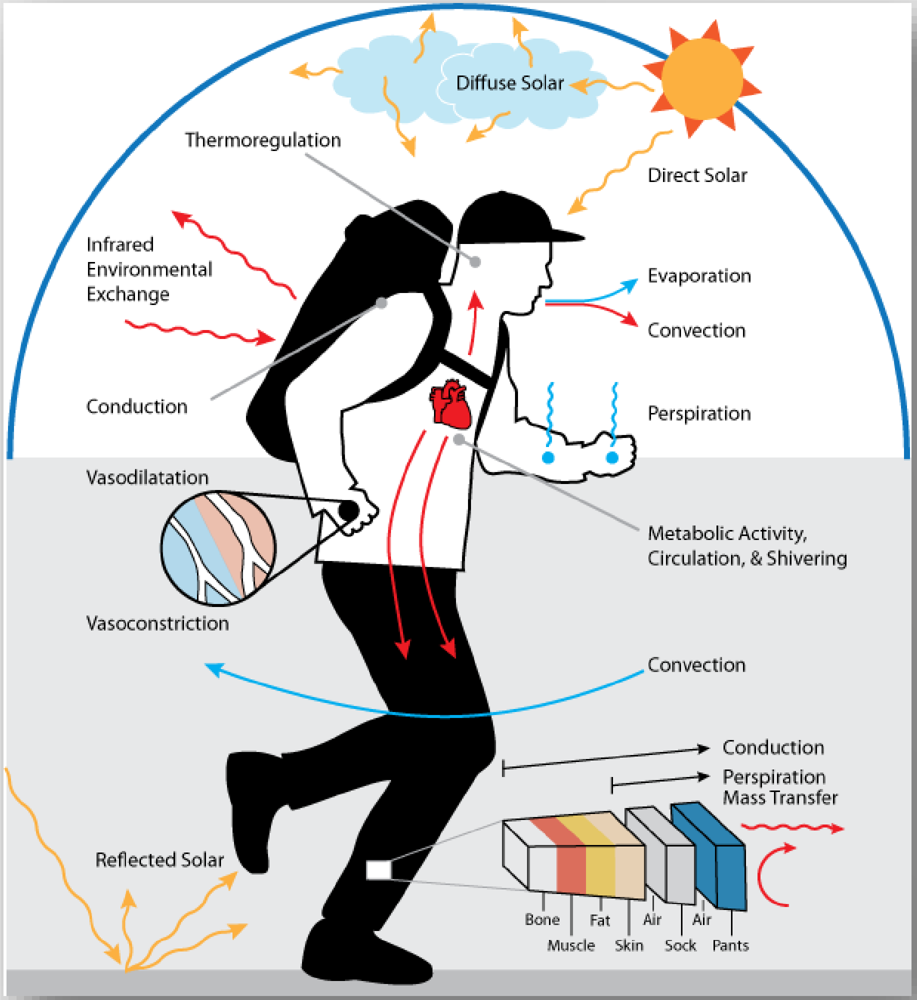
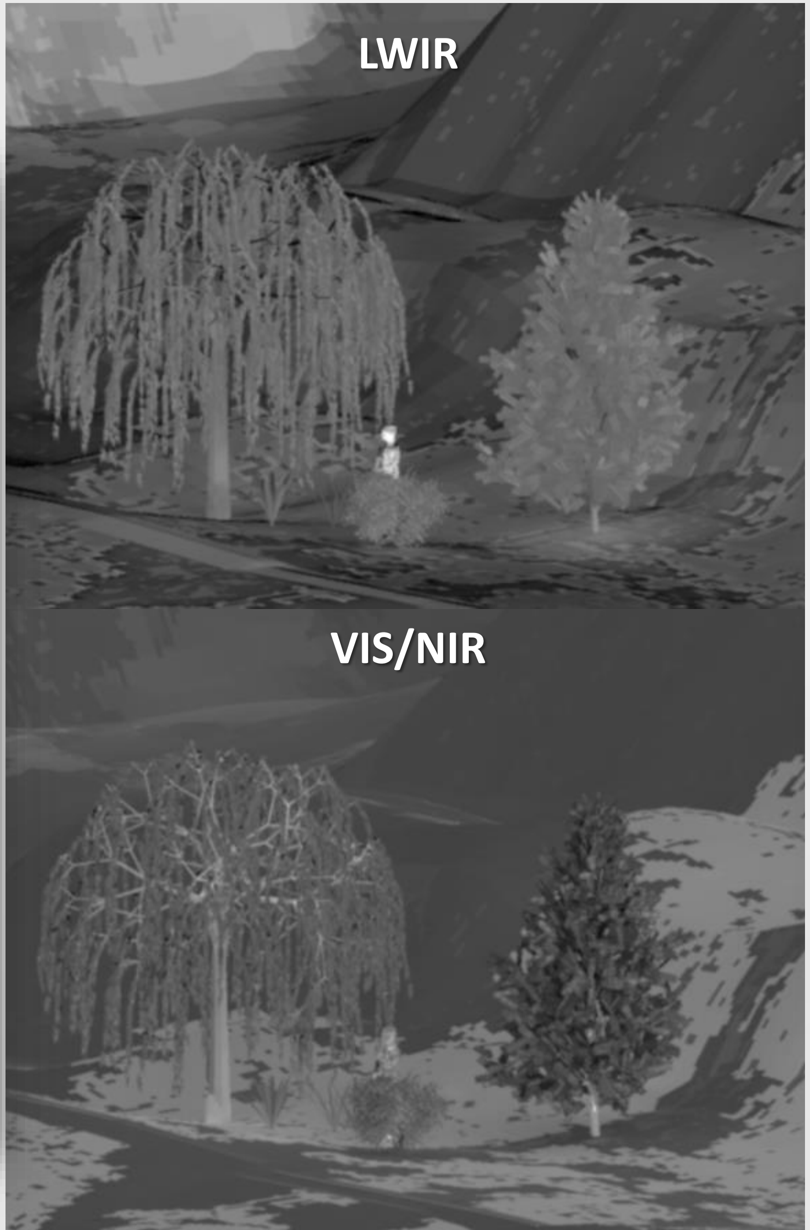
  - GOAL: Render hyperspectral scene radiances to evaluate/exploit wavelength-dependent and narrow-band target and background signatures
  - BENEFIT: Generate data for automatic target detection (ATR) algorithm development, scene content classification algorithms, etc.

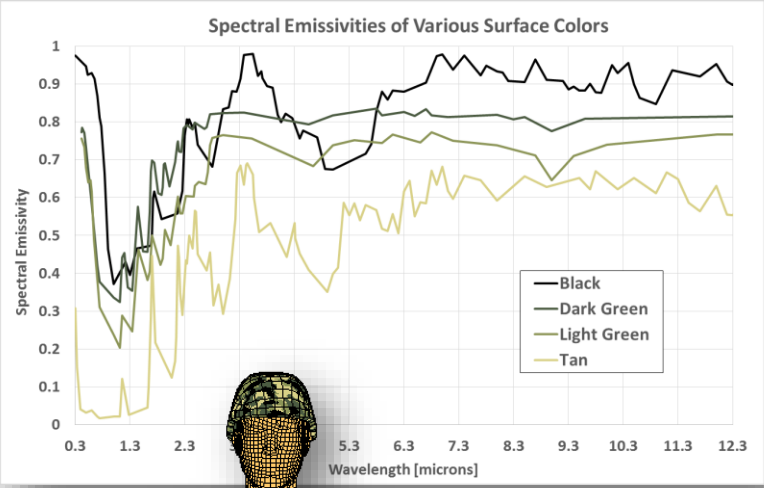
MuSES Sensor Radiance Rendering Examples

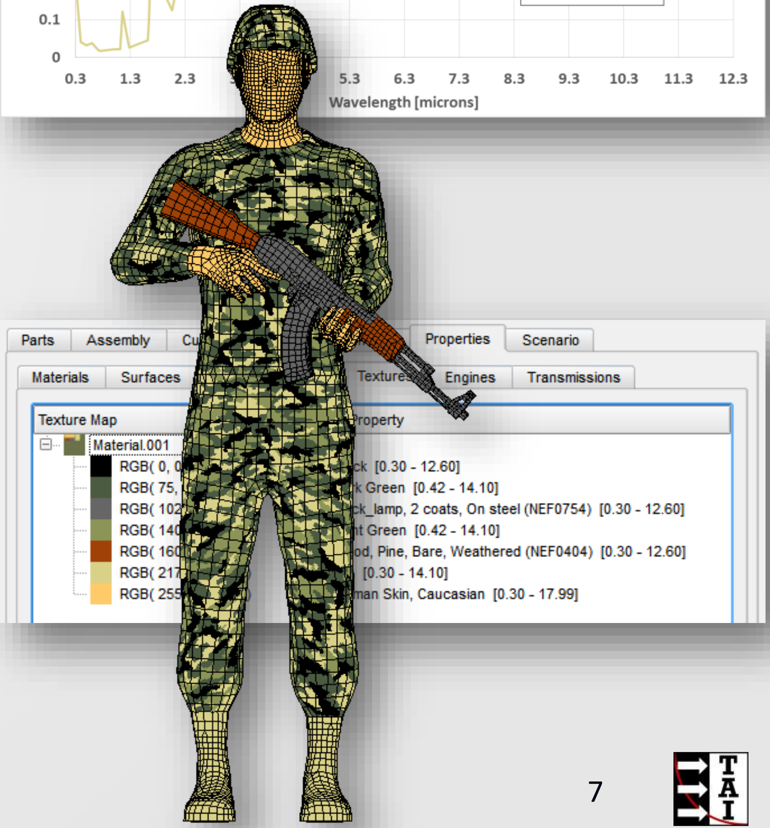


MuSES Sensor Radiance Rendering Examples





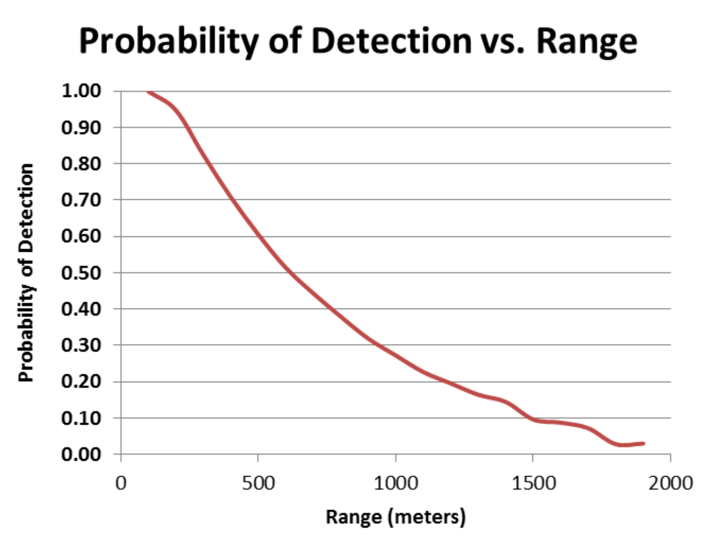




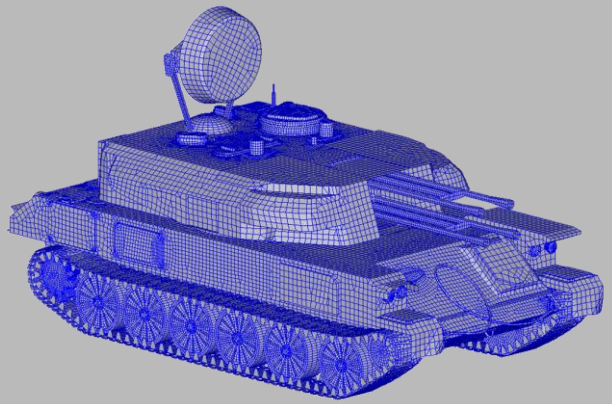
Overview of MuSES EOIR simulation process

Target Information

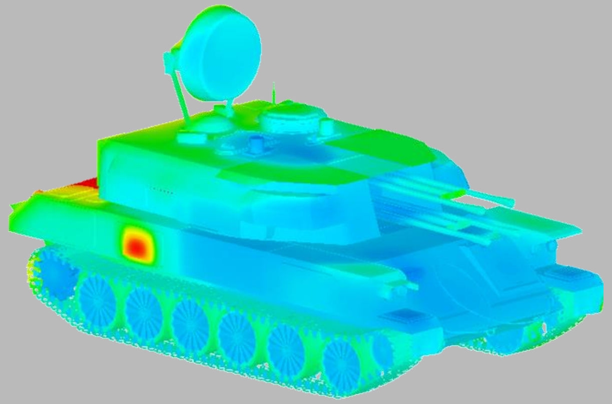
EO/IR Simulation Process



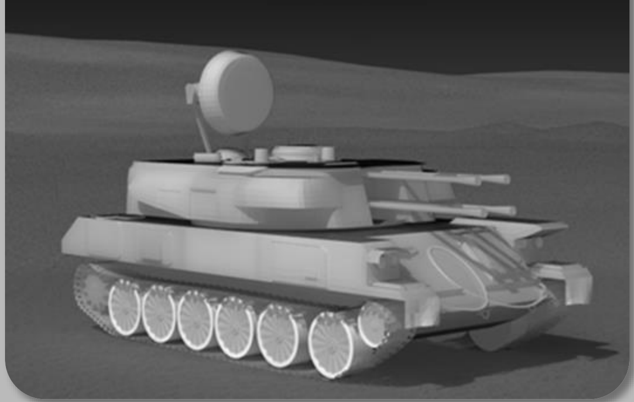
Meshed Target Geometry



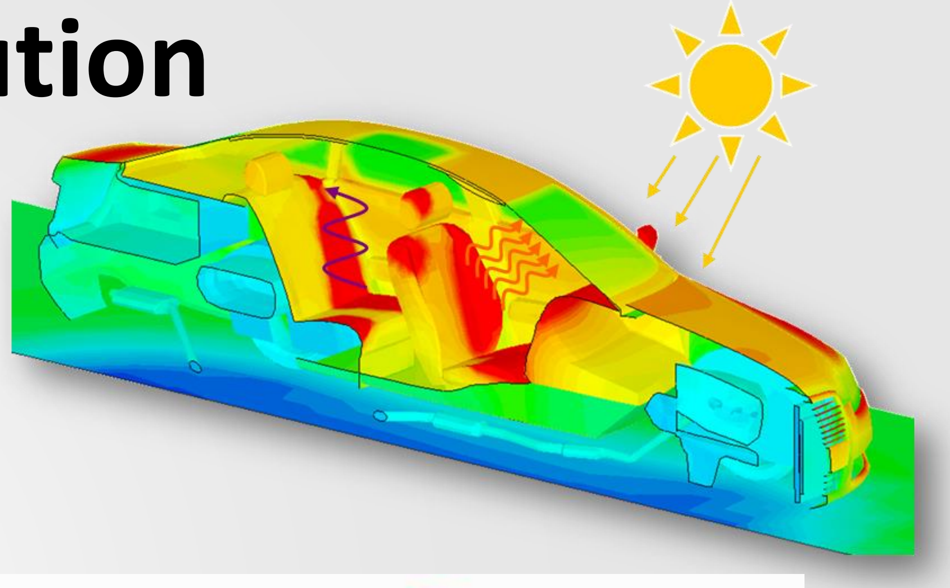
Transient Thermal Solution



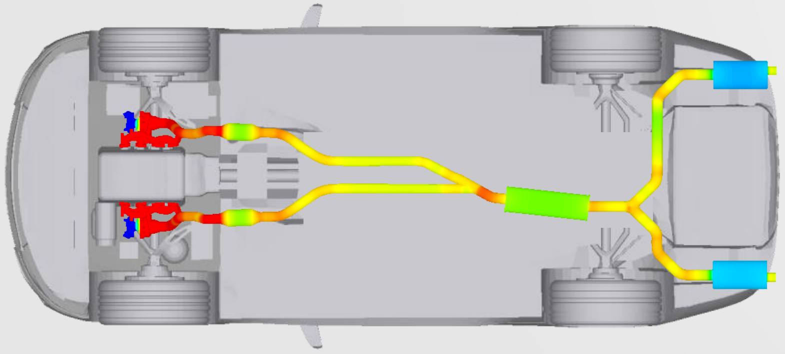
Radiance Rendering

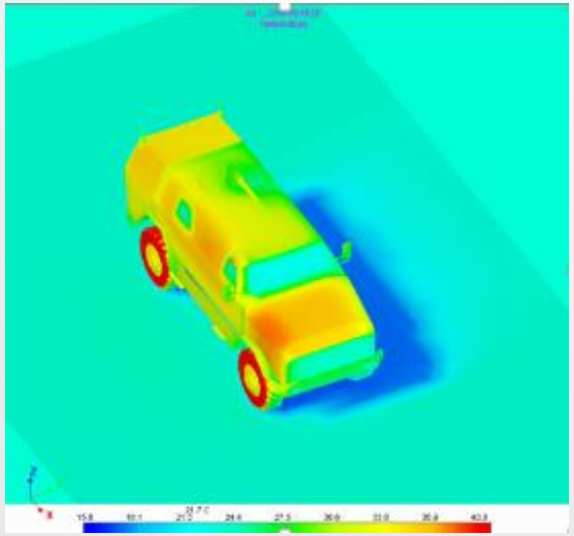


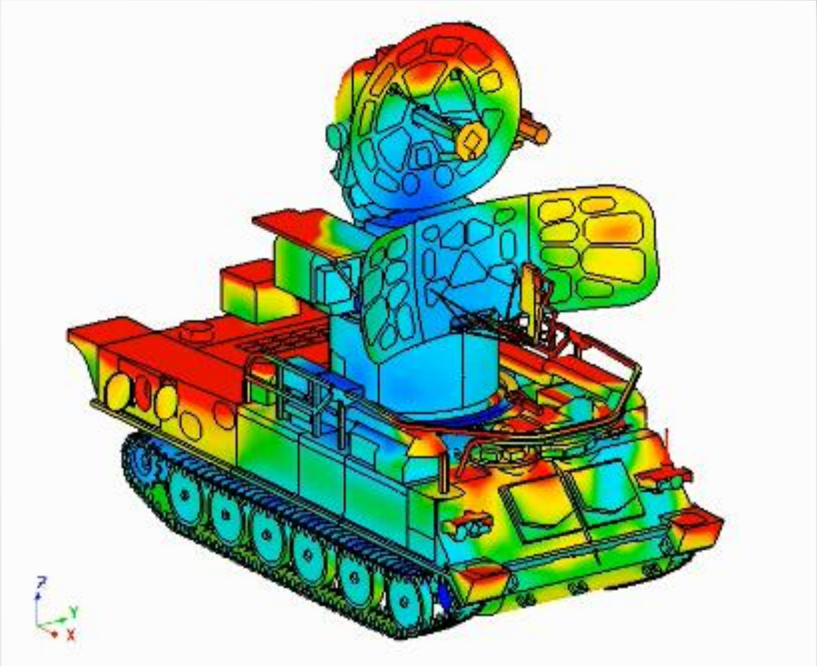
Comprehensive Thermal Solution



- MuSES, developed by ThermoAnalytics, includes:
  - **Transient Thermal Solver (physical temperatures)**
    - Dual-band (solar and thermal)
    - Radiation, convection and conduction
    - Weather effects (solar, clouds, sky, wind, etc.)
    - Active heat sources







- MuSES™: **M**ulti-**S**ervices **E**lectro-optics **S**ignature

Thermal & EO/IR Simulation with MuSES™

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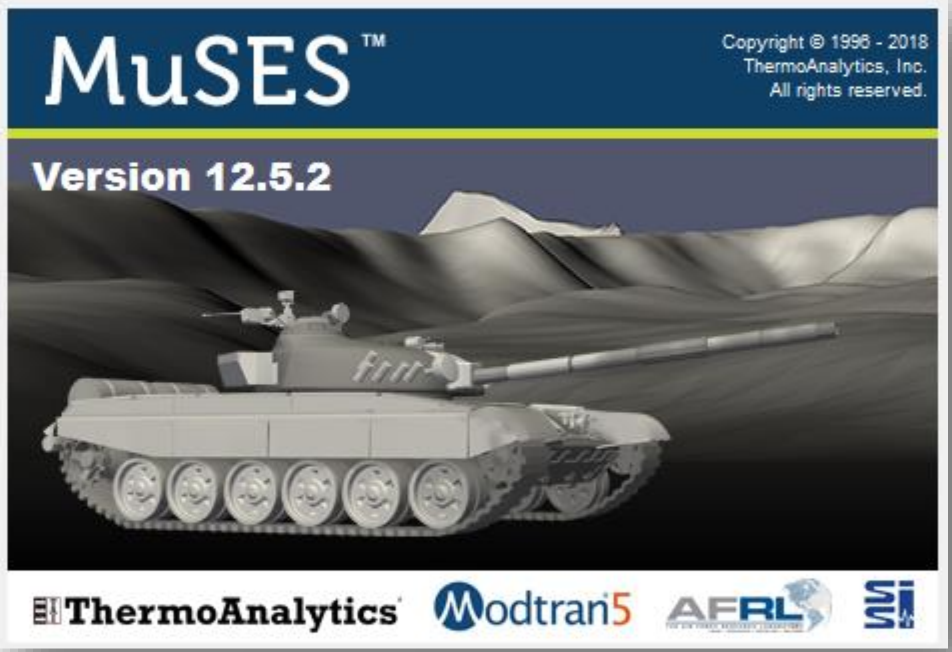
  - Transient Thermal Solver (physical temperatures)
    - Dual-band (solar and thermal)
    - Radiation, convection and conduction
    - Weather effects (solar, clouds, sky, wind, etc.)
    - Active heat sources
  - Sensor Radiance Image Rendering
    - Spectrum covers VIS through LWIR
    - Hyperspectral & Band-Integrated Renderings
      - Ray-traced from sensor to scene
      - Sandford-Robertson BRDF model
    - *Atmospheric effects incorporated via MODTRAN*
    - Radiance and Apparent Temperature, Image Metrics



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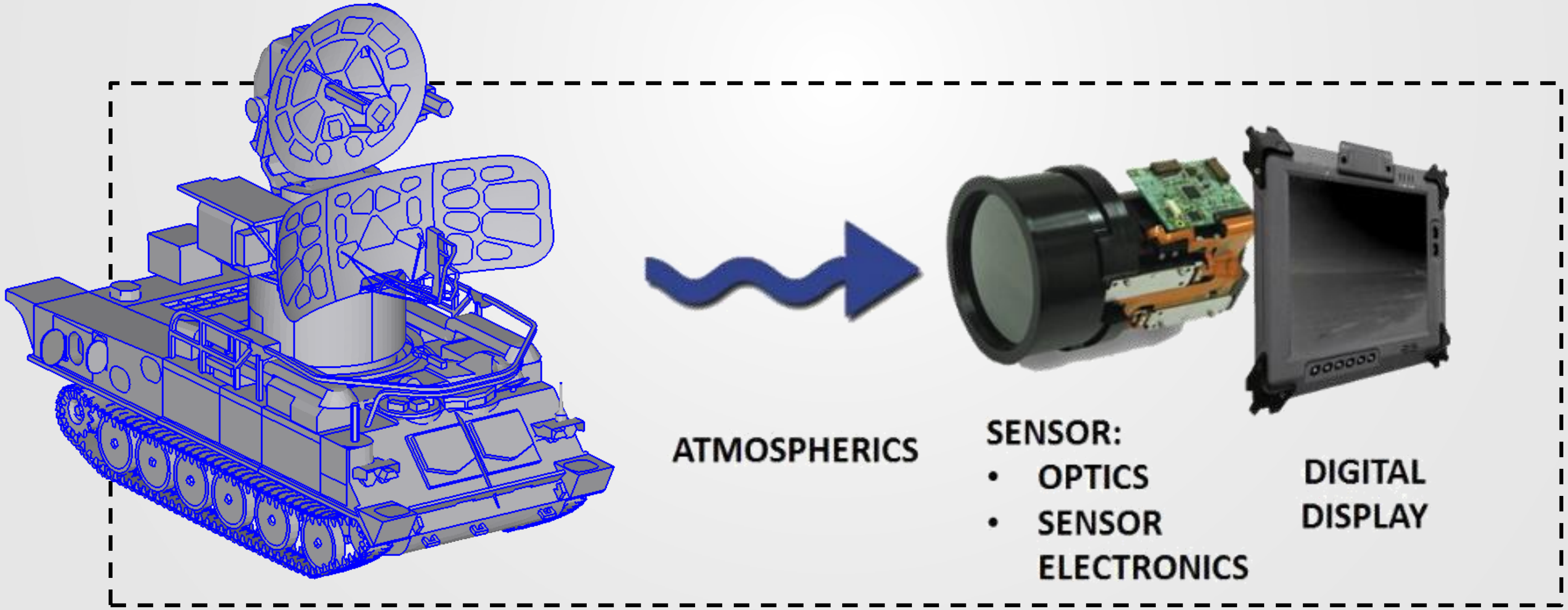
Simulating the Imaging Chain with MuSES

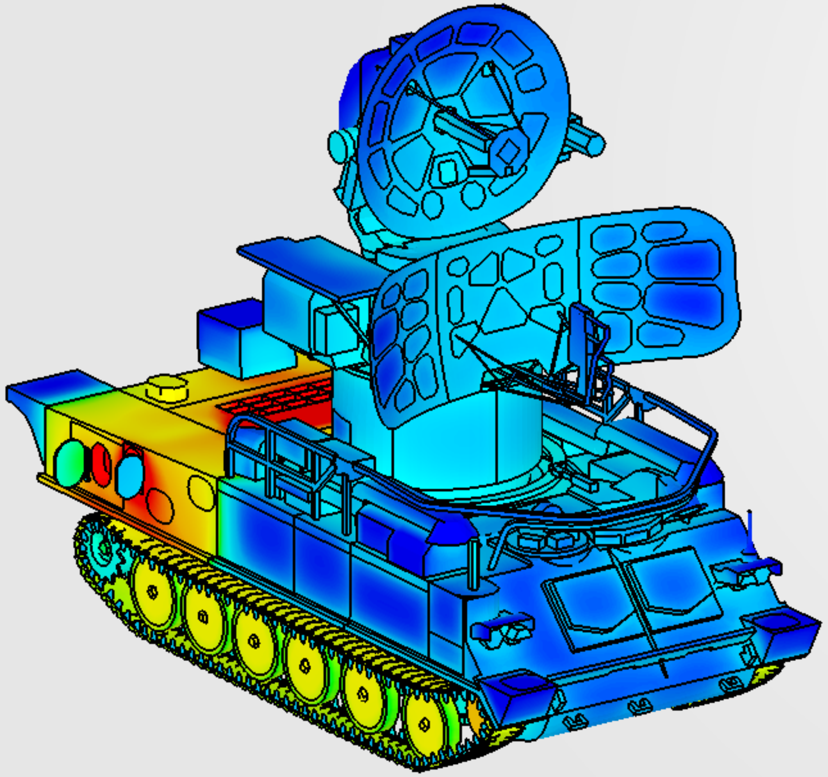
Scene Radiance → Atmospheric Path Effects → Sensor Effects → Human Vision Effects



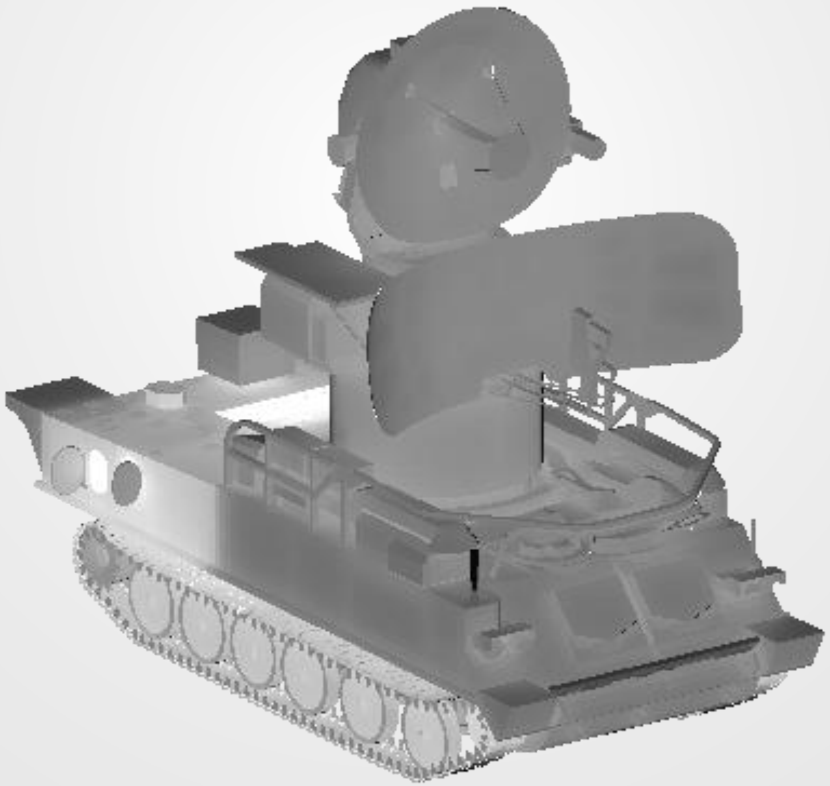
Representation of MuSES Imaging Chain

Simulating the Imaging Chain with MuSES

Scene Radiance → Atmospheric Path Effects → Sensor Effects → Human Vision Effects



Physical Temperatures

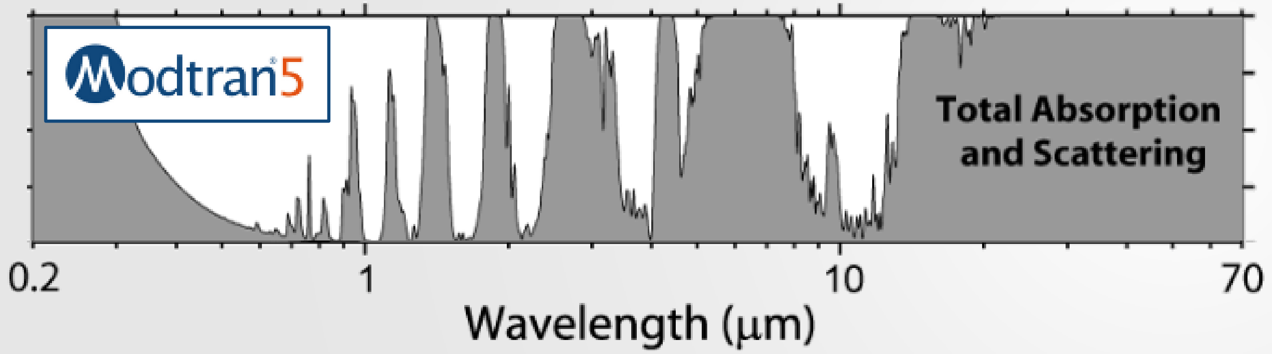


Source Radiance

- Transient physical temperatures are predicted, which results in scene ***emissions***
- MODTRAN is used to prediction reflections from sky off the scene
- Sandford-Robertson BRDF properties are used to model specular and diffuse reflections
- Result of this step is scene radiance ***at the source***, not at the sensor

Simulating the Imaging Chain with MuSES

Scene Radiance → **Atmospheric Path Effects** → Sensor Effects → Human Vision Effects



- Atmospheric transmission is computed via MODTRAN runs that are performed “behind-the-scenes”
- *Source* scene radiances are modified to incorporate extinction (absorption and scattering) and path radiance
- Result of this step is scene radiance ***at the sensor entrance***

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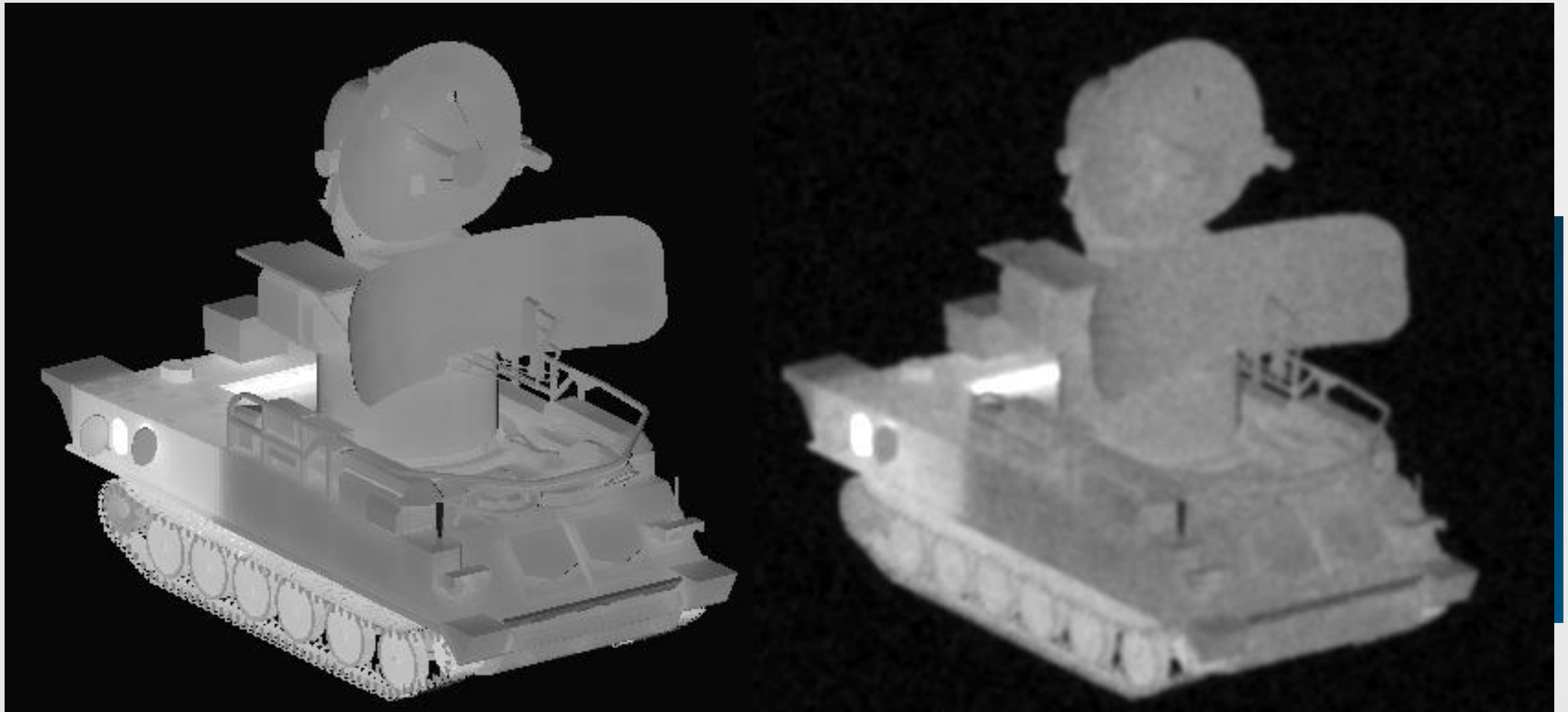
Simulating the Imaging Chain with MuSES

Scene Radiance → Atmospheric Path Effects → **Sensor Effects** → Human Vision Effects



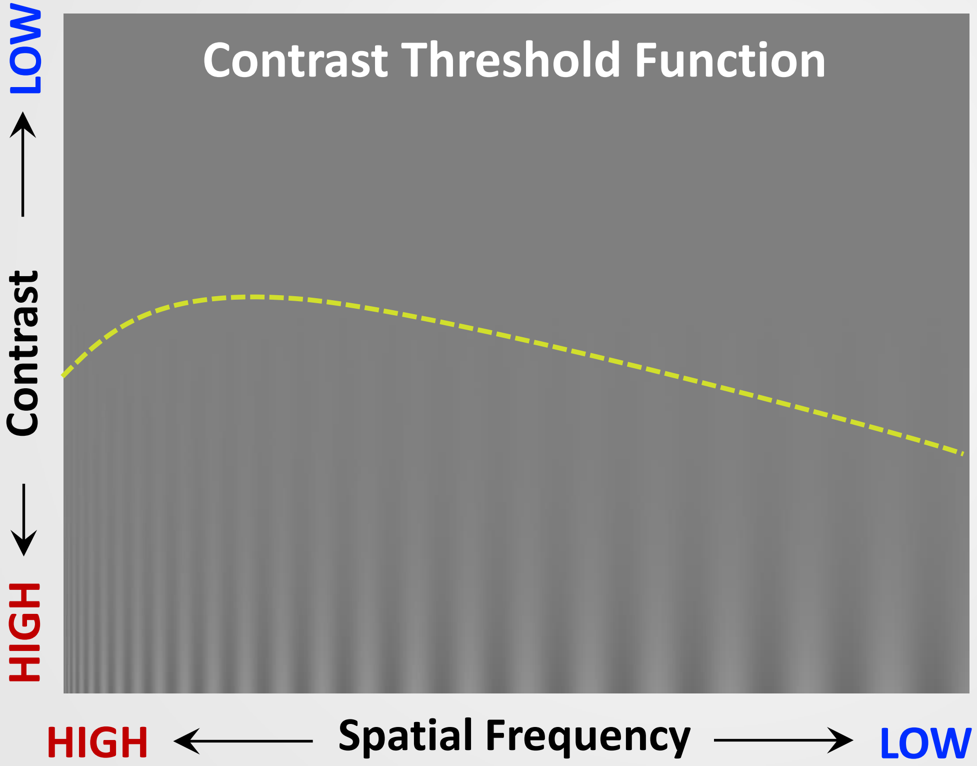
Pristine Sensor Radiance | **Sensor Effects Incorporated**

- Pristine image can be modified to incorporate wavelength-dependent optical blurring from the lens aperture
  - Photon noise can also be included
- This improves realism of rendered sensor image and increases accuracy of image-derived metrics
  - Contrast, Pd

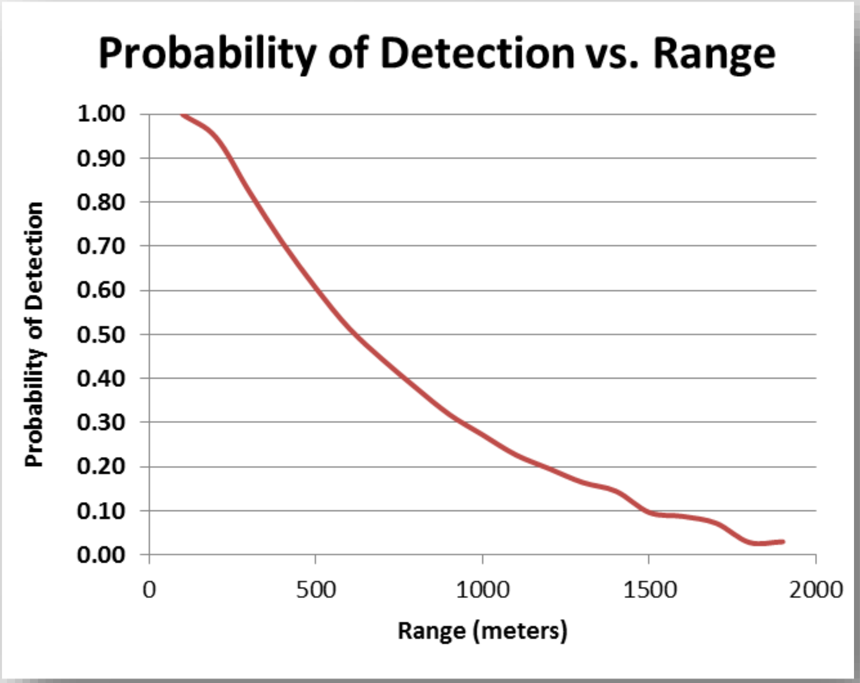
Simulating the Imaging Chain with MuSES

Scene Radiance → Atmospheric Path Effects → Sensor Effects → **Human Vision Effects**

Night Vision Integrated Performance Model



$$TTP_{H/V} = \int \sqrt{\frac{C_{tgt}}{CTFSYS(\nu)}}\, d\nu$$



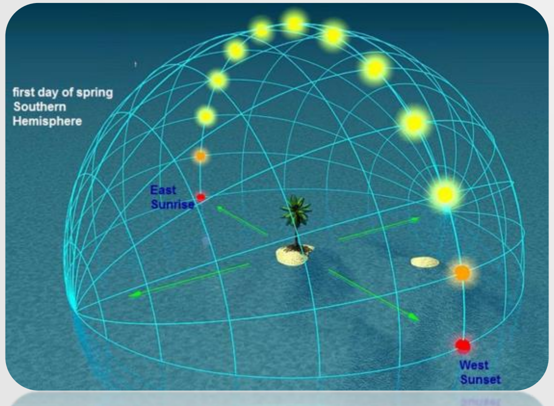
Incorporating MODTRAN results

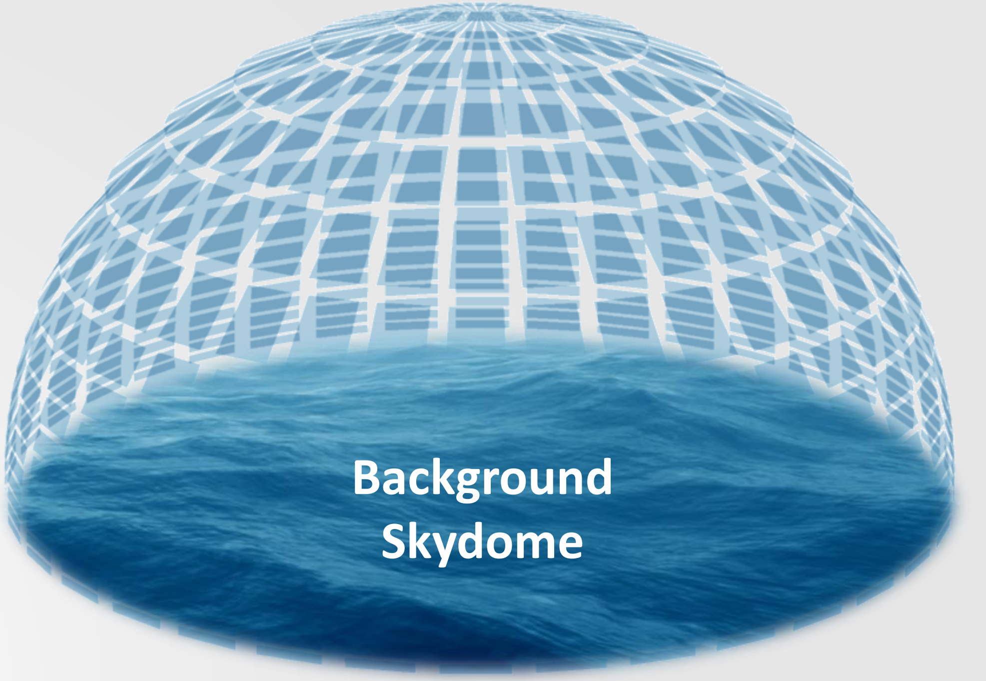
MuSES uses MODTRAN in numerous ways:

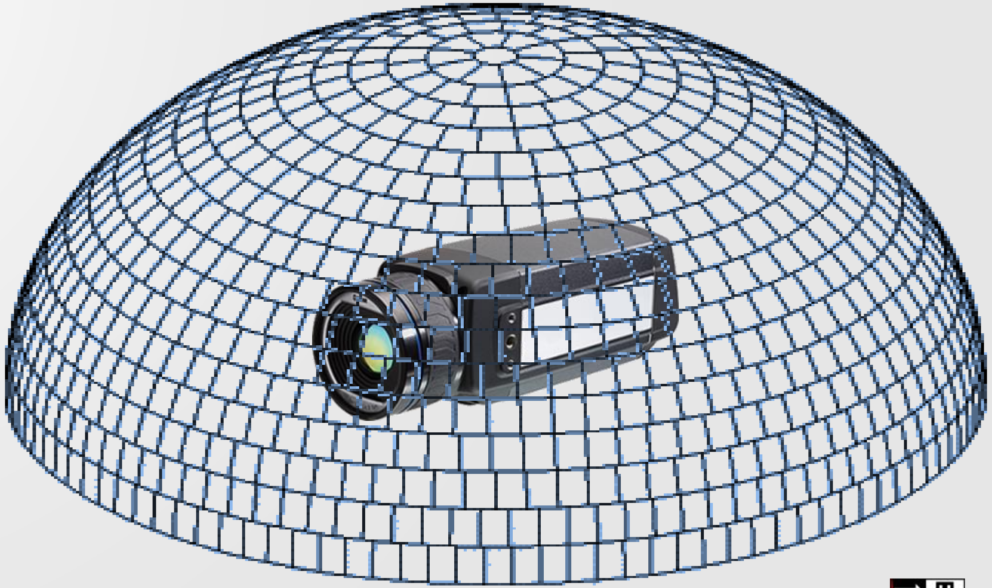
- Solar and lunar illumination for renderings
- Sky radiance for scene reflections and above-horizon FOV pixels
- Atmospheric propagation paths between sensor and scene
- This is all done automatically for the user, avoiding the need for MODTRAN expertise

MODTRAN Sky Calculations

- MODTRAN is used to calculate sky radiances at many hemispherical positions
  - Clear and cloudy sky radiances are calculated **spectrally** for each hemispheric position
    - These radiances are mixed (if necessary) for partially overcast skies, otherwise either the clear or cloudy results are used
  - Target view factors are used to interpolate from this “skydome” (radiance grid)
    - Skydome interpolation is used for target & background reflections and for rendering the sky in the field of view above horizon
- MODTRAN is used to calculate solar illumination



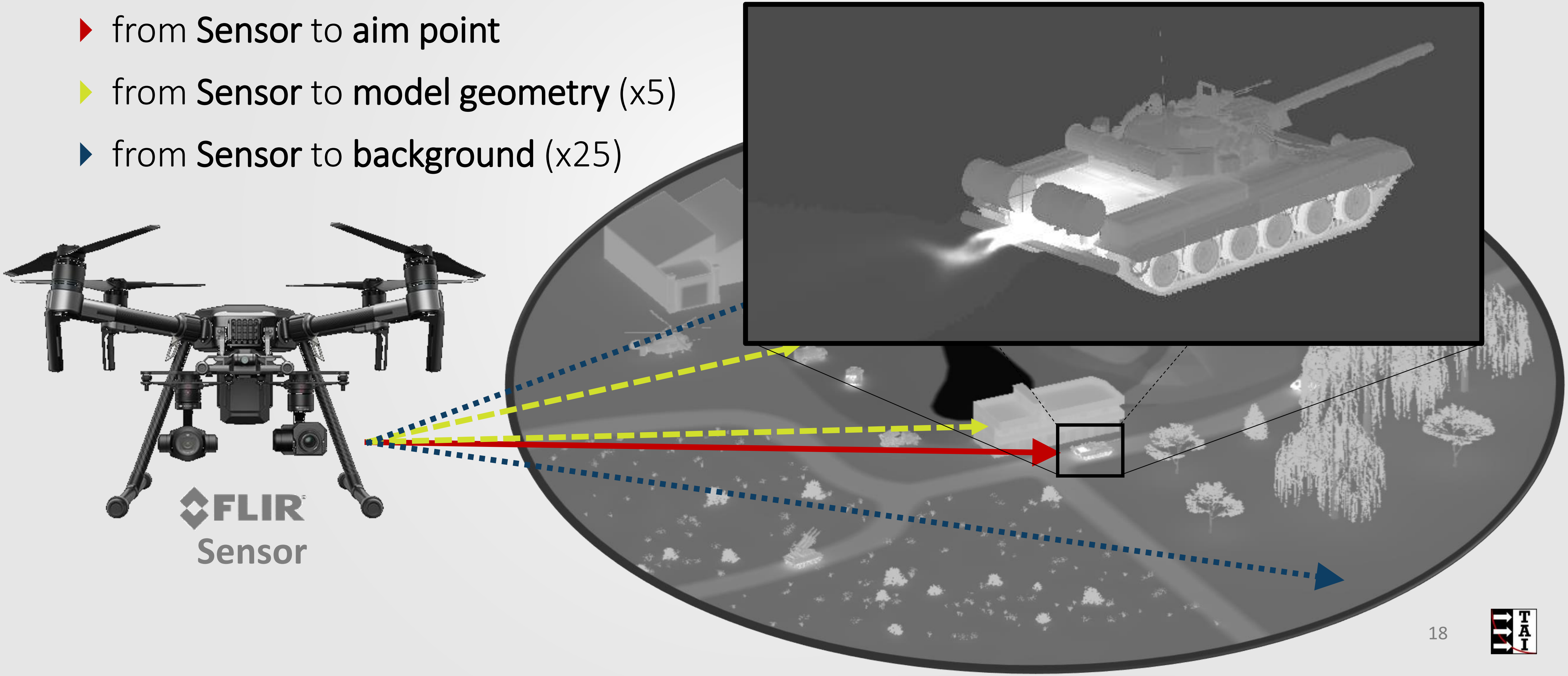




Sensor Skydome

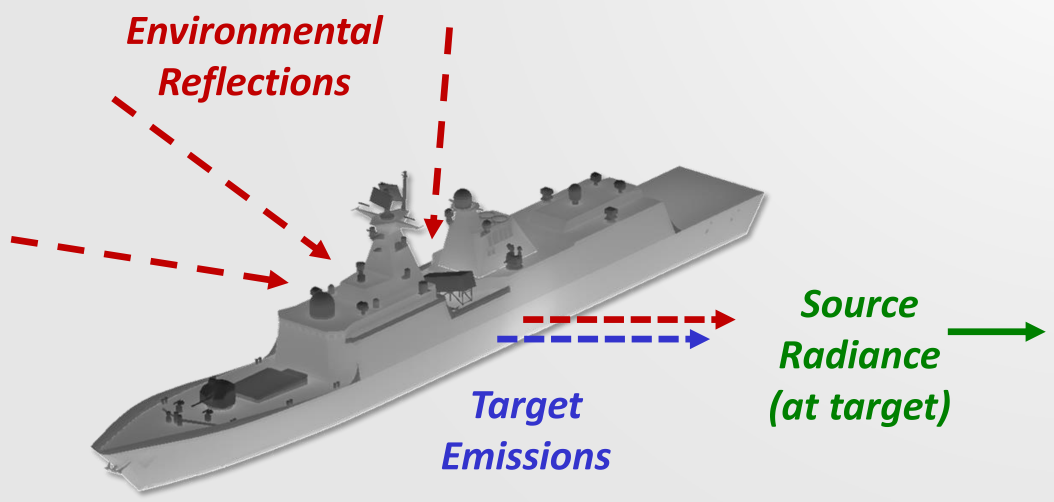
MODTRAN Paths: From Sensor to Scene

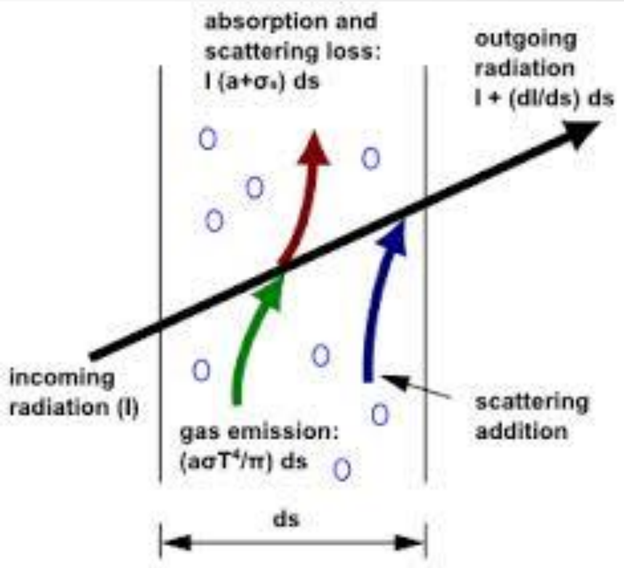
- What MODTRAN runs are performed to calculate extinction and path radiances?
  - from **Sensor** to **aim point**
  - from **Sensor** to **model geometry** (x5)
  - from **Sensor** to **background** (x25)



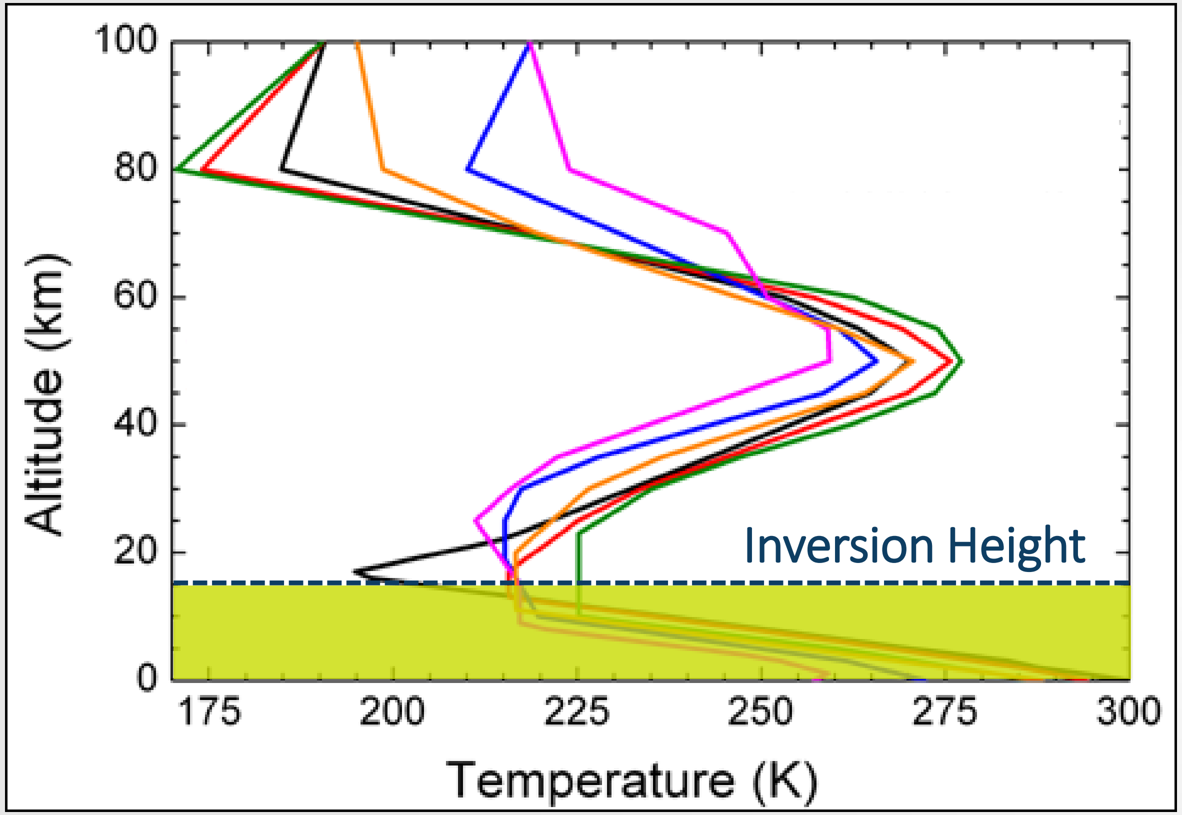
ATM Path Calculations

- Source radiance is defined, in MuSES and TAIThermIR, as the emitted + reflected radiation ***at its source***
  - For a target this is the (emitted + reflected) radiance at the target
  - For pixels intersecting the target's background, it is the total radiance at the background location
- Atmosphere along propagation path between source and sensor modifies radiance detected by a sensor (***at range***, relative to source)



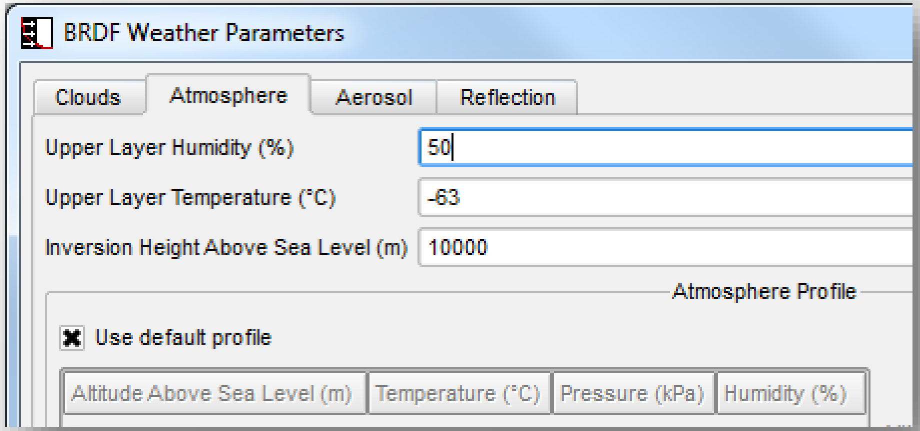


Default Atmospheric Profile for MuSES



Latitude	Day of Year	MODTRAN Atmosphere Model
> -24 to < 30 degrees	Any	1 (Tropical atmosphere)
>= 65 degrees	Summer (Day 109 through 291)	4 (Sub-Arctic summer)
	Winter (Day <109 or > 291)	5 (Sub-Arctic winter)
<= -65 degrees	Winter (Day 109 through 291)	4 (Sub-Arctic summer)
	Summer (Day <109 or > 291)	5 (Sub-Arctic winter)
>= 30 and < 65 degrees	Summer (Day 109 through 291)	2 (Mid-Latitude summer)
	Winter (Day <109 or > 291)	3 (Mid-Latitude winter)
<= -24 and >-65 degrees	Winter (Day 109 through 291)	4 (Sub-Arctic summer)
	Summer (Day <109 or > 291)	5 (Sub-Arctic winter)

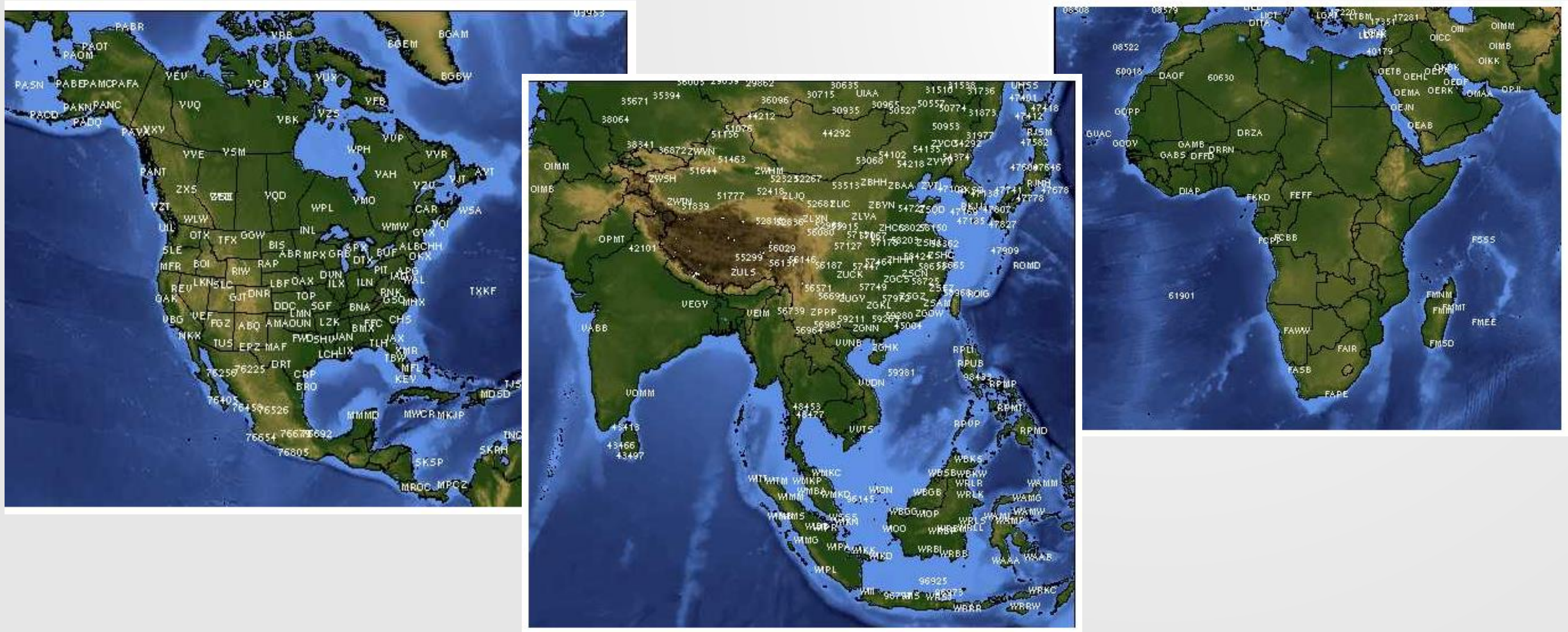
- Latitude and Day-of-Year are used to select appropriate MODTRAN atmosphere model
  - Most appropriate MODTRAN default molecular species concentration profile is used
  - Atmospheric pressure is calculated by MODTRAN
- Upper layer inversion height can be user-supplied
  - Along with corresponding Tair and RH values

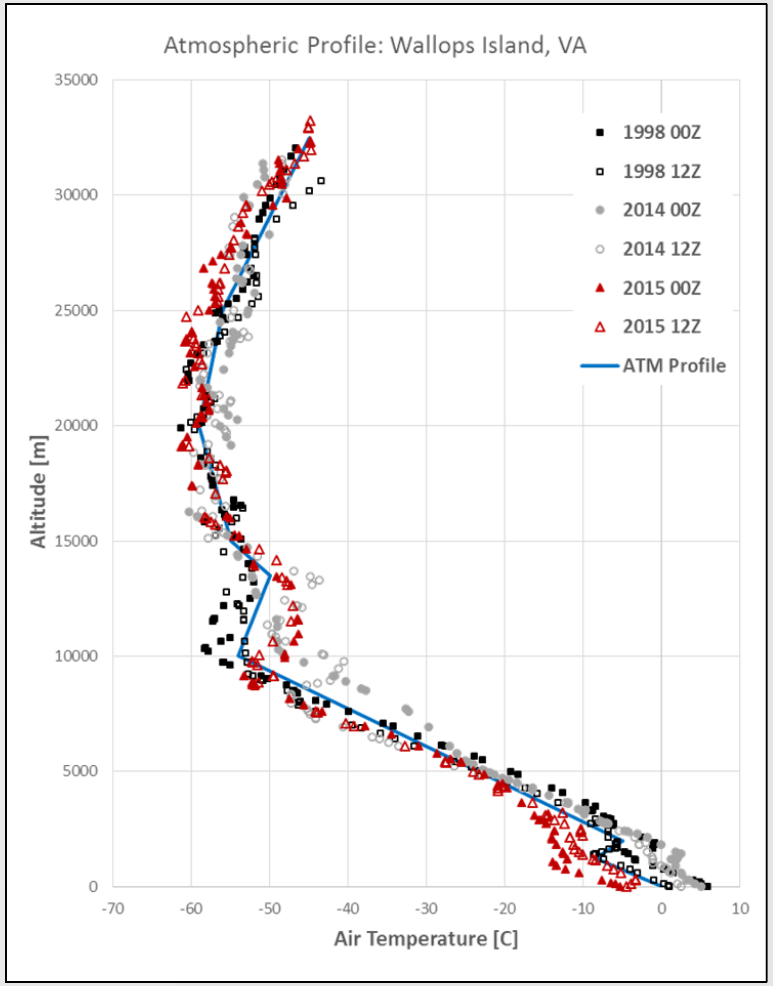


- Below inversion height, lapse rate of -7°C/km assumed
  - Ground-level RH is used for altitudes below USL
- Above this, MuSES-selected MODTRAN model atmosphere is used

Custom Atmospheric Profile for MuSES

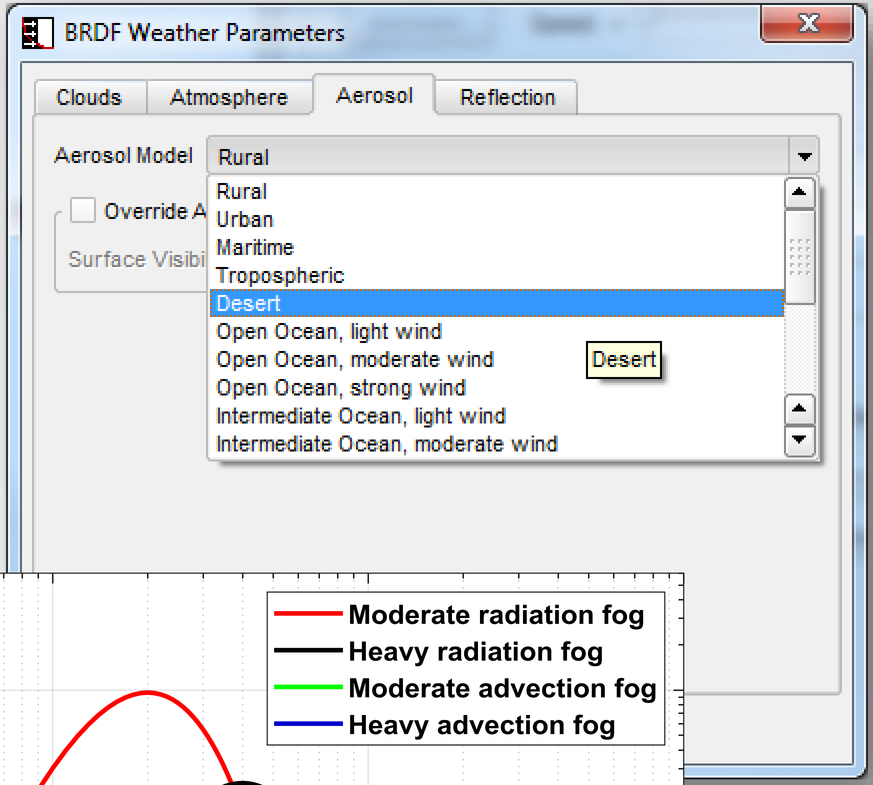
- MuSES allows users to enter a custom ATM profile to define altitude-dependent characteristics of the atmosphere
  - Inputs: Air temperature, pressure and relative humidity
- Custom atmospheric profiles can be downloaded
  - e.g., http://weather.uwyo.edu/upperair/sounding.html

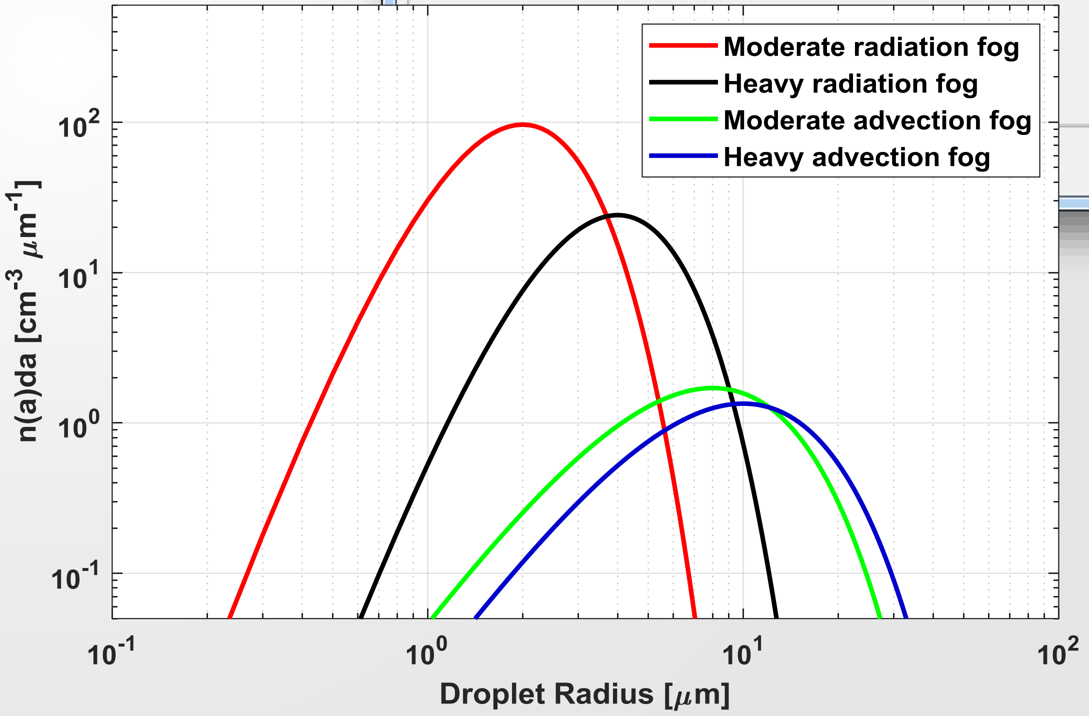




Aerosol Models

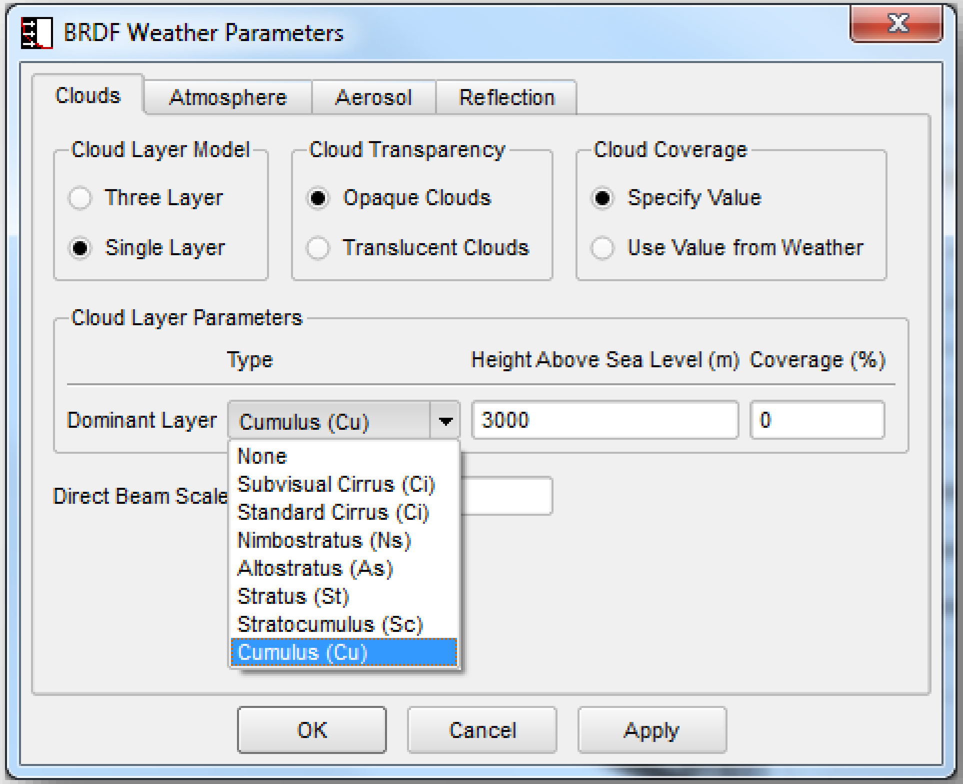
- MuSES users can choose from numerous MODTRAN aerosol models
  - “Desert”, “Urban”, “Rural”
  - Has both “Maritime” & “Navy Maritime”
  - Various fog models
- This controls the particle size distribution function used to compute impact on atmospheric propagation paths
  - Extinction (absorption, scattering)
  - Path radiance





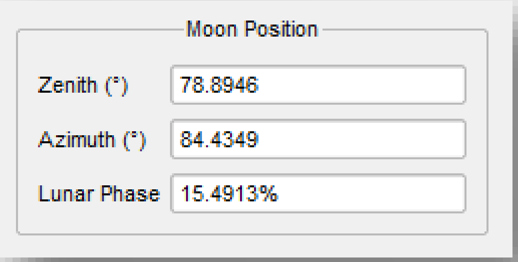
Cloud Deck Parameters

- Users can specify cloud deck parameters
  - Cloud layer type (e.g., cumulus, stratus)
  - Cloud base height (above sea level)
  - Cloud coverage (0-100% overcast)
    - Clear and cloudy sky radiances are calculated **spectrally** by MODTRAN for each position of the hemisphere
    - These radiances are mixed for partially overcast skies, otherwise either clear or cloudy results are used
  - Opaque or Translucent
    - Opaque: Assumes cloud is a black-body emitter at altitude-dependent air temperature
    - Translucent: User-specified thickness can be used to vary transparency for VIS/NIR wavebands where light (not temperature) dominates
- Direct (solar or lunar) beam scale factor exists

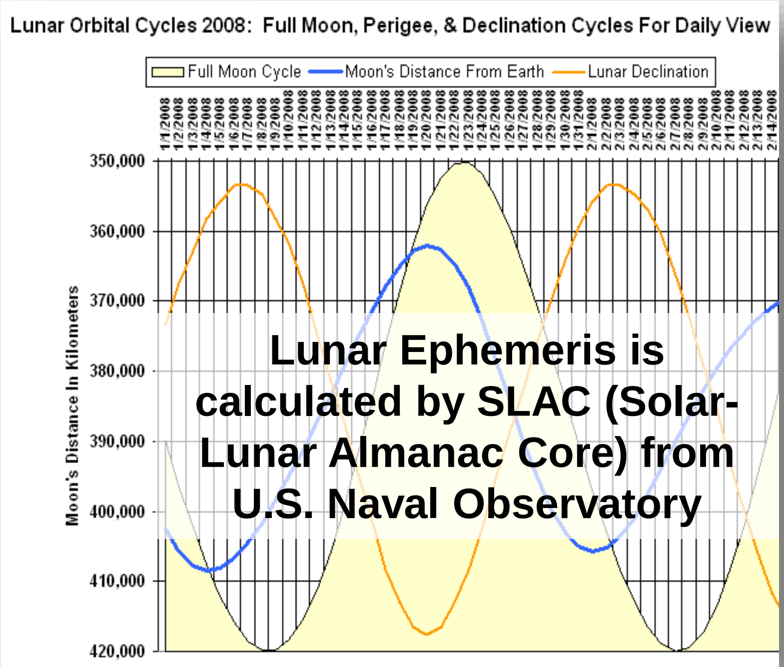


Lunar Source Modeling with MuSES

- Lunar illumination can be incorporated with MuSES/MODTRAN
  - MuSES calculates position and phase angle of the moon with U.S. Naval Observatory lunar ephemeris routine (SLAC)
    - Lunar phase and position are reported in MuSES

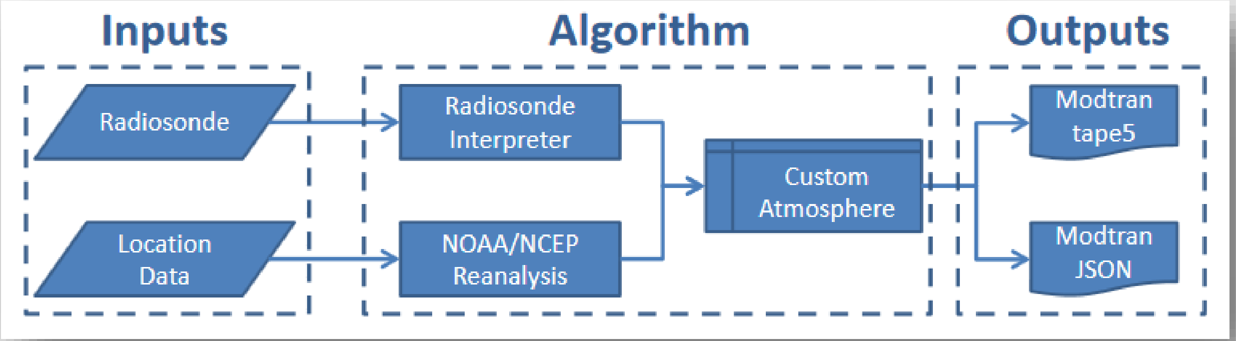


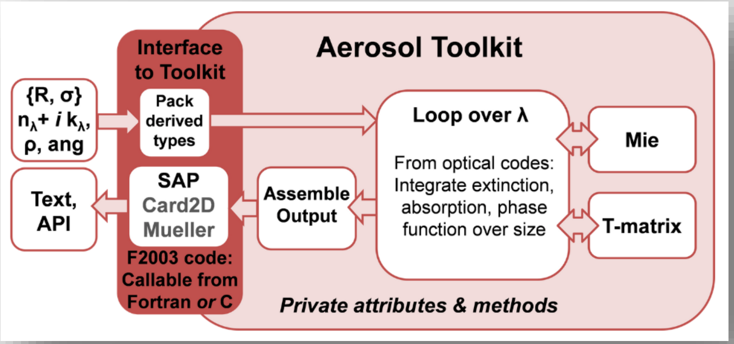
  - MODTRAN models lunar radiance as exponential function of MuSES-supplied phase angle of moon
  - MuSES incorporates lunar illumination calculated by MODTRAN into sensor radiance renderings



Automating MODTRAN for MuSES users

- MuSES GUI is intended for novice MODTRAN user, not MODTRAN expert
  - Simplifies MODTRAN inputs, runs it in the background & incorporates results
  - User doesn’t need to know how to set up MODTRAN runs; MuSES creates input files for the user
- MuSES automatically uses ground weather temperature, combined with lapse rate and standard MODTRAN profile
- MuSES automatically computes sun & moon position based on GPS location and date/time
- We plan to incorporate MODTRAN6 into MuSES
  - API/GUI would allow expert users to adjust advanced MODTRAN parameters
  - Revised radiosonde data import into MODTRAN (Atmosphere Generator Toolkit, AGT)
  - Import user aerosol specifications (via Aerosol Toolkit, ATK)





Questions?

Thanks for your attention!

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