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Infrared Scene Simulation for Chemical Standoff Detection System Evaluation

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Why Synthetic Scene Simulation?

- Evaluation of New System/Sensor Designs and Concepts
- Evaluation of New Data Exploitation Algorithms
- Evaluation of New ConOps for Existing Systems

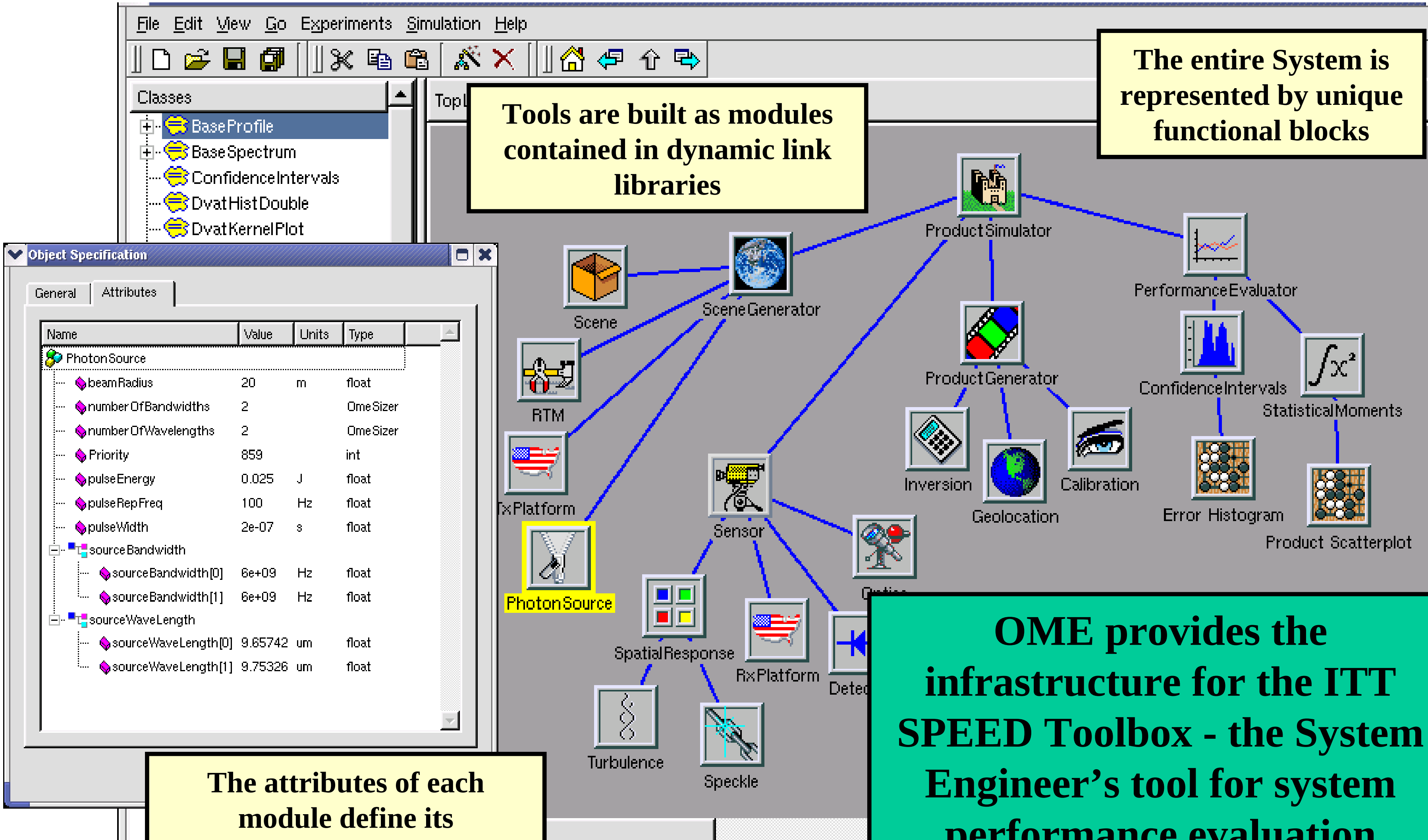
Issues Regarding Scene Simulation

- Background Clutter
  - Do simulated spatial distributions match reality?
  - Is simulated spectral variation realistic?
- Target Insertion
  - Are target absorption properties correct?
  - Insertion techniques
  - Interaction with other naturally occurring gases
- Horizontal Radiative Transfer
  - Problem using MODTRAN to calculate the atmospheric transmission for horizontal and near horizontal geometries
    - MODTRAN horizontal mode assumes constant pressure, therefore slant path mode must be used.
    - Large ranges resulting from a line of sight nearly tangential to the earth's surface caused MODTRAN to fail on computing the layer thicknesses required for the transmission calculations.

Scene Simulation Plan for Sensor Evaluation

- Scenarios
  - Downlooking Scene Using Simulated Backgrounds
  - Horizontal Scene Using Simulated Backgrounds
  - Downlooking Scene Using Measured Backgrounds
- Scene Specifications
  - Pixel size: 1 m
  - Image size: (1000 - 2000 m) x (4000 - 5000 m)
  - Spectral resolution: 2 cm^{-1}
  - Wavelength range = 700 - 1400 cm^{-1}
  - Radiance units = W/cm^2 sr cm^{-1} or uW/cm^2 sr cm^{-1}
  - Cloud size = 30 m height, 300 m width, 100 m length
  - Cloud concentration lengths: 0 - 1000 mg/m^2
  - Vapor target: GB
  - Mean ΔT: 5K

The SPEED Toolbox Provides the Foundation for Scene Simulation



Tools are built as modules contained in dynamic link libraries

The entire System is represented by unique functional blocks

The attributes of each module define its characteristics.

OME provides the infrastructure for the ITT SPEED Toolbox - the System Engineer's tool for system performance evaluation

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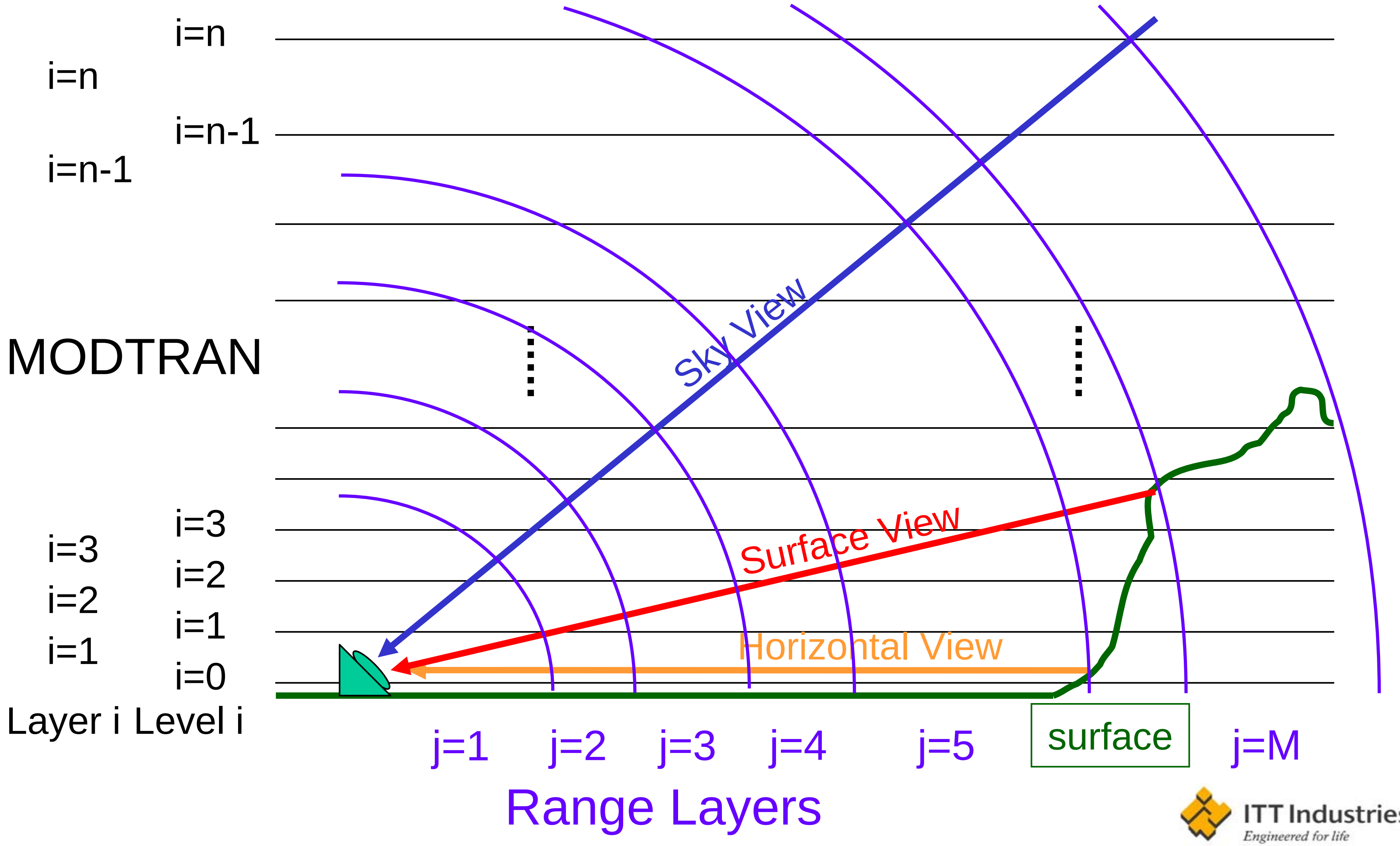
Radiative Transfer Method for Scene Simulation

- Plane-parallel, down-welling only, non-scattering
- Vertical Layer spectral transmission from MODTRAN
  - User defined atmosphere (not just US std or MLS)
    - Number of levels
    - Temperature, water vapor, pressure, and ozone profiles specified on vertical (height) levels
    - Background aerosols (rural, urban, etc)
  - Layer transmission is converted to layer mass extinction for use in SPEED model
- Agent cloud spectral absorption from PNNL IR library
- Background data from DIRSIG or hyperspectral sensor
- Agent cloud and interferent concentrations are user specified in any range layer
- Range layer coordinate system used for radiative transfer

Radiative Transfer Geometry



Radiative Transfer Model in Range Coordinates

$$t_j = \exp\left[-\sum_{k=1}^{K} \sigma_k \rho_k l_j\right] \qquad T_M = \prod_{j=1}^{M} t_j$$

$$L = \varepsilon_s B(\theta_s) T_M + \sum_{j=1}^{M} (1 - t_j) B(\theta_j) T_{j-1}$$

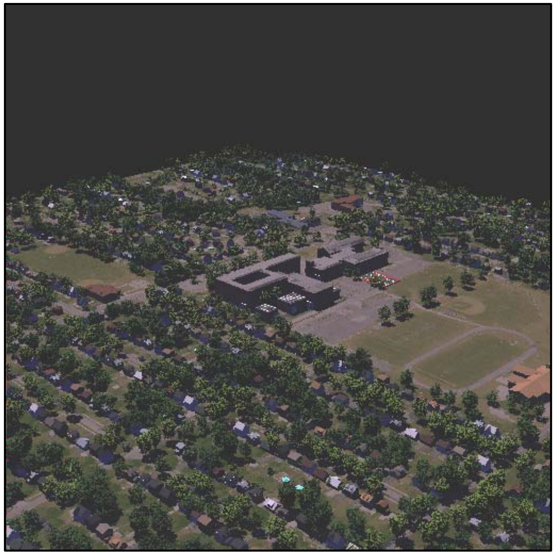
t_j is layer transmission
σ_k is mass extinction coefficient
ρ_k is density for k^th constituent
l_j is layer thickness of Range layer j
T_M is sensor to surface transmission

M specifies the number of layers between the sensor and the surface

B is the Planck function
θ_j is the temperature of layer *j*
ε is the emissivity of the surface
θ_s is the temperature of the surface
L is the at aperture radiance

Surface Properties via Simulation - DIRSIG

- Surface properties of the scenes can be generated using the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool provided by the Rochester Institute of Technology
  - DIRSIG provides rendering and thermal modeling of complex, 3D scenes
  - Spectral data in DIRSIG is supplemented by the Advanced Spaceborne Thermal Emission and Reflection (ASTER) Radiometer Spectral Library (provided by Johns Hopkins University, the Jet Propulsion Laboratory, and the United States Geological Survey)
  - Each material file contained between 5 and 100 different emissivity curves to complicate the background spectra.

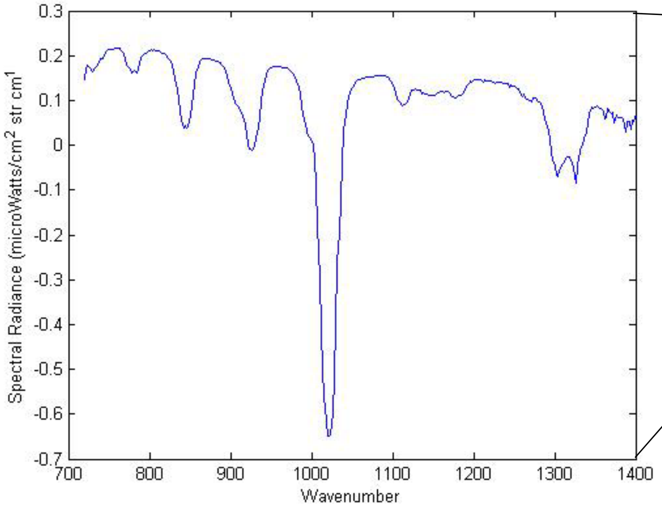


Surface Properties via Data Collections - SPARSE

- SPARSE algorithm – Surface Properties and Atmospheric State Estimator
- SPARSE does not depend on the presence of blackbodies in the scene
  - It estimates the atmospheric transmission spectrum in an optimal manner using the passive hyperspectral observations and *a priori* information about the surface and atmosphere
  - In addition to retrieving the atmospheric transmission spectrum for use in spectral matched filter applications, the SPASE also retrieves surface spectral emissivity and surface temperature
- SPASE is based on well-established work used in a variety of atmospheric retrieval applications
  - The primary difference between previous Bayesian atmospheric remote sensing methods and this implementation is that SPASE retrieves the transmission spectrum and not the geophysical state variables (along with model parameters) that describe it
  - Since one is only interested in the atmospheric transmission to generate obtain surface property signatures, there is no need to retrieve the atmospheric gas concentration profiles
  - The state variables necessary to describe the radiative transfer model are: atmospheric transmission spectrum, atmospheric temperature, surface emissivity spectrum, and surface temperature
    - Additionally, local variations of water vapor and carbon dioxide are accounted for by retrieving their a concentration-lengths (CLs)
    - These were included in order to get a better fit but may not be necessary for most applications.

Scenario 1 - Downlooking Simulated Scene Using DIRSIG MegaScene

Difference Spectra – Off plume (blue) – On plume (red)



Composite Scene Showing Plume Locations

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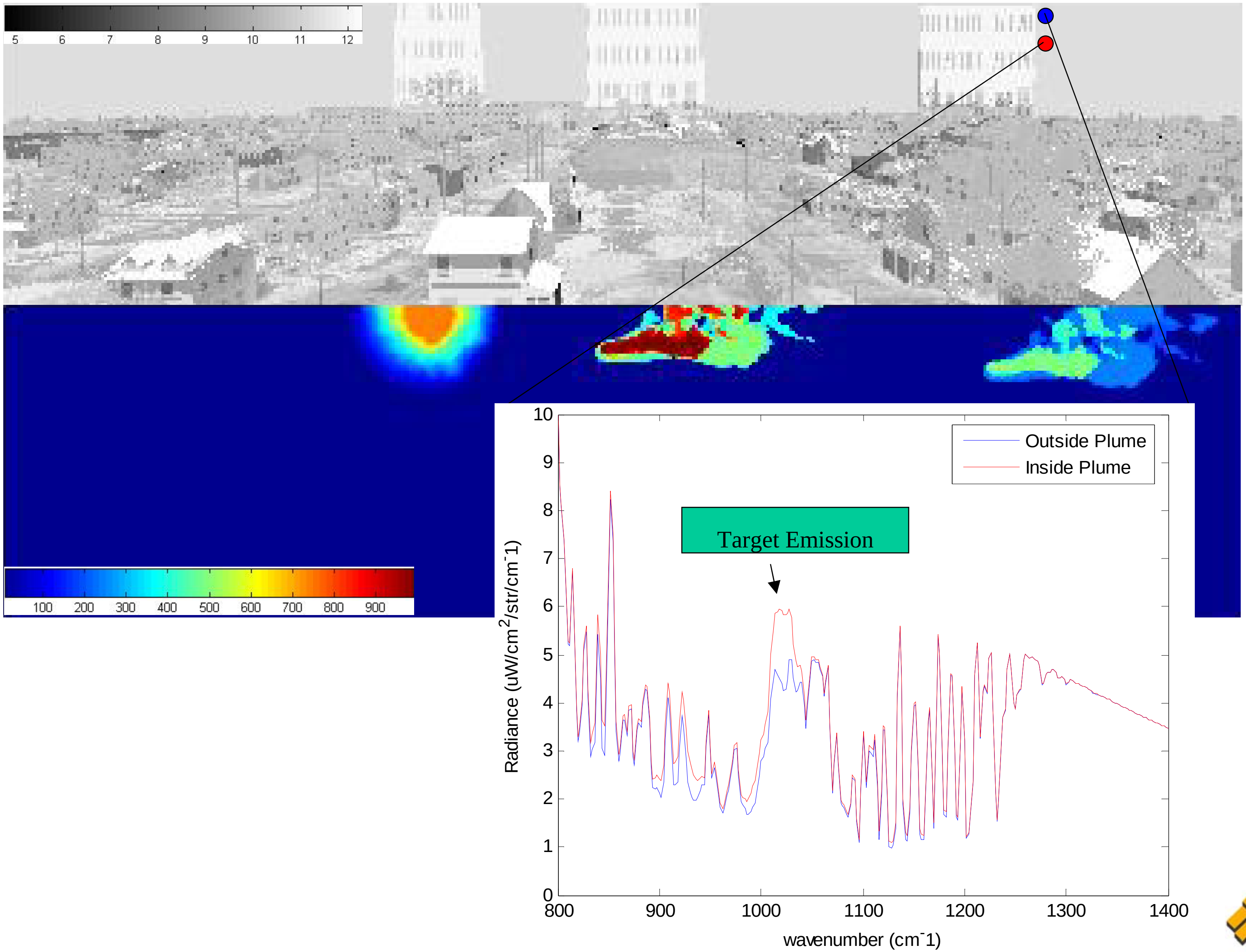
Discussion of Scenario 1 Simulation

- DIRSIG Did Not Have LWIR Spectra for Twelve (12) Materials in the Scene
  - We used spectra from ASTER database to supplement
  - Did not supply sufficient spectral variability
- Plume insertion looked realistic
  - Plumes were in absorption over a hot background; emission over cooler background
- Clear evidence of atmospheric water lines
- No ozone lines
  - Scene was developed as if the sensor was flying at 1 kilometer
  - Not enough atmospheric path to create a strong ozone signature

Scenario 2 - Horizontal Simulated Scene Using DIRSIG MegaScene



Single Band Image of Scene

Plume Mask (mg/m^2)

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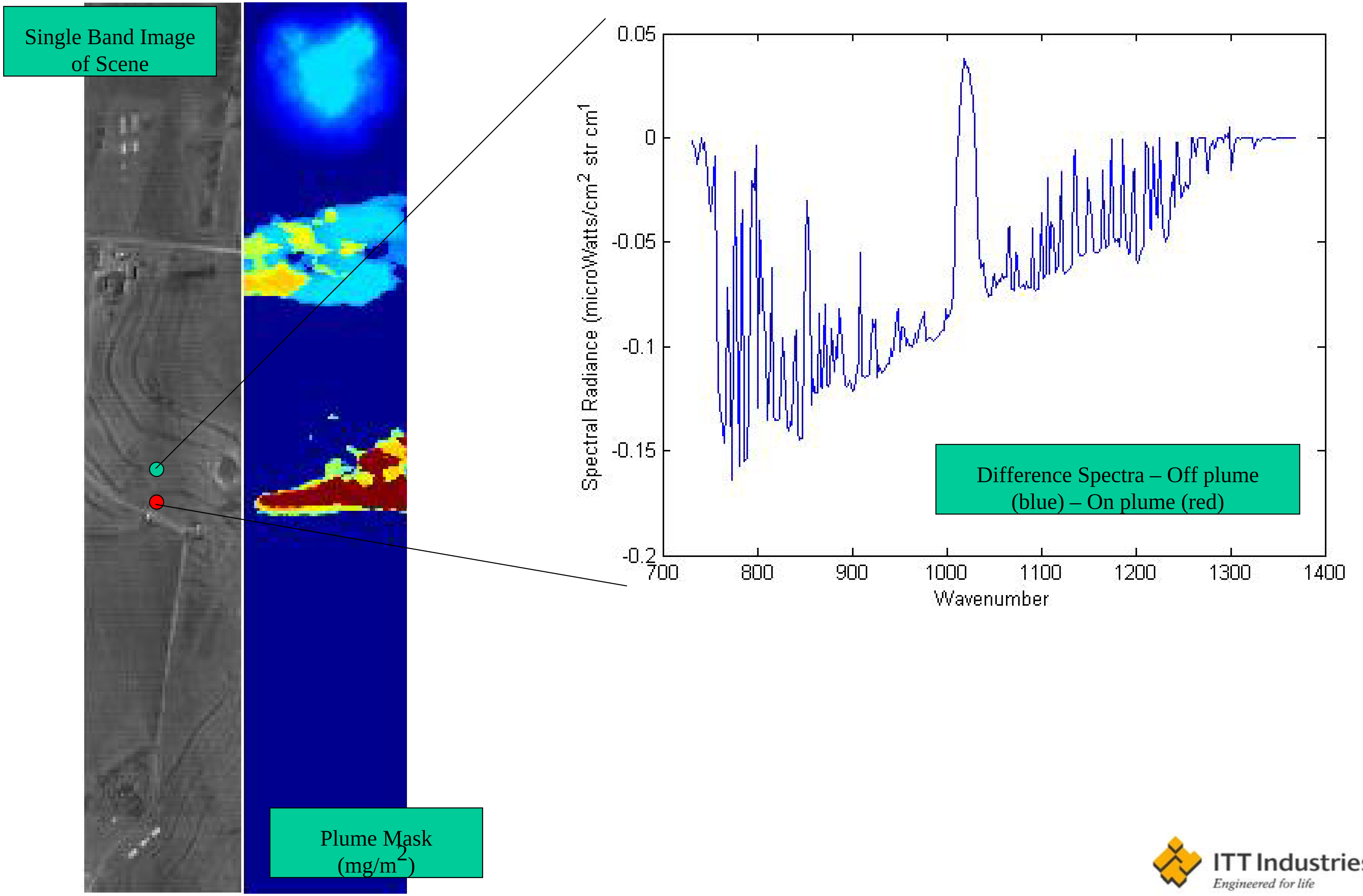
Discussion of Scenario 2 Simulation

- Difficulties Accurately Computing Radiative Transfer for Long Paths
  - Code was modified for horizontal geometries
  - Calculated the atmospheric layer attenuation using a vertical path
  - Applied the layer optical depths to the longer ranges required for the horizontal geometry
- Same Spectral Property Issues in LWIR Described in Scenario 1
- Significant Ozone Absorption for Low Elevation Angles / Long Ranges

Scenario 3 - Simulated Scene Using SPARSE Method to Define Background Properties from Measured Data



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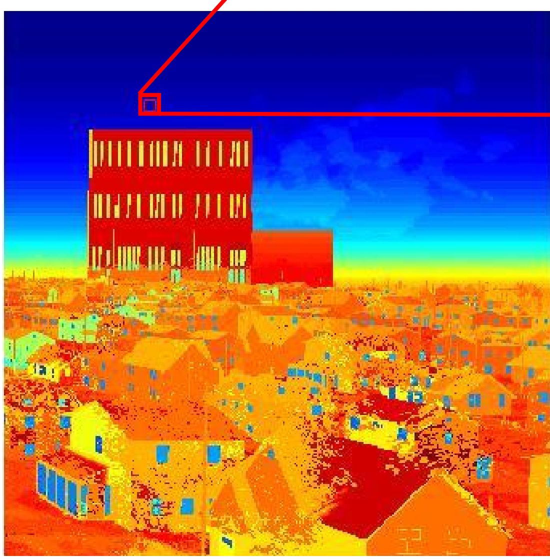
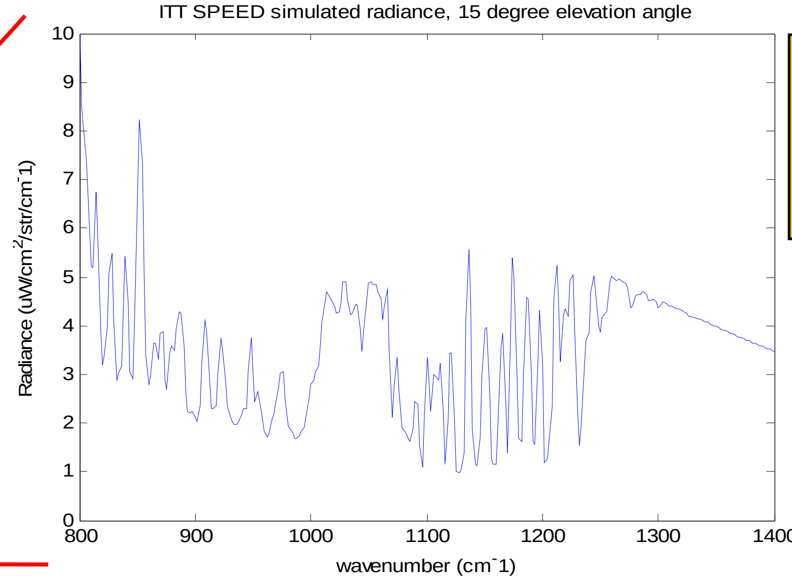
Discussion of Scenario 3 Simulation

- Surface Emissivity and Surface Temperature Retrieval is an Offline Process That Requires Human Interaction
- Sensor Noise and Weak Sensor Response can Affect the Retrieval
- This Method Provides the Most Realistic Background Clutter
- Simulated Atmosphere and Target Insertion Allows fro Different Scenarios to be Built from Same Input Deck

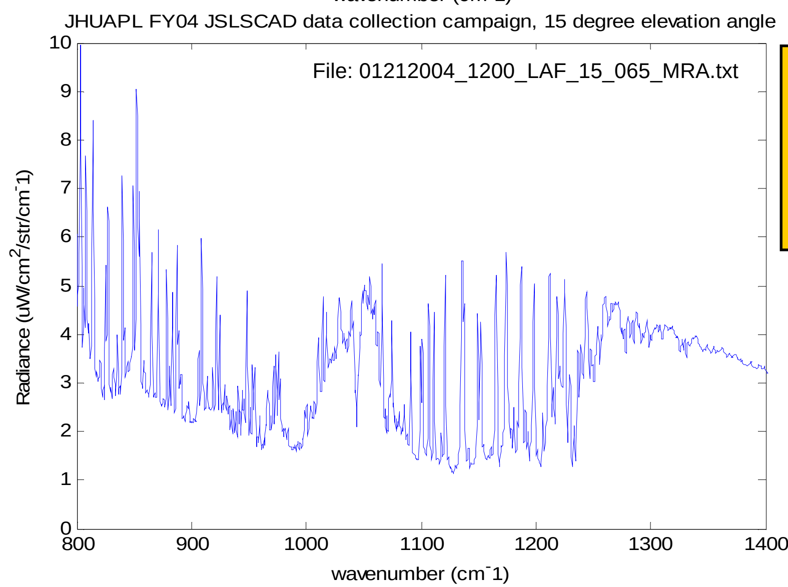
Comparing Simulated Horizontal Radiance to Measured Horizontal Radiance

SPEED Simulated
Hyperspectral
Horizontal Scene





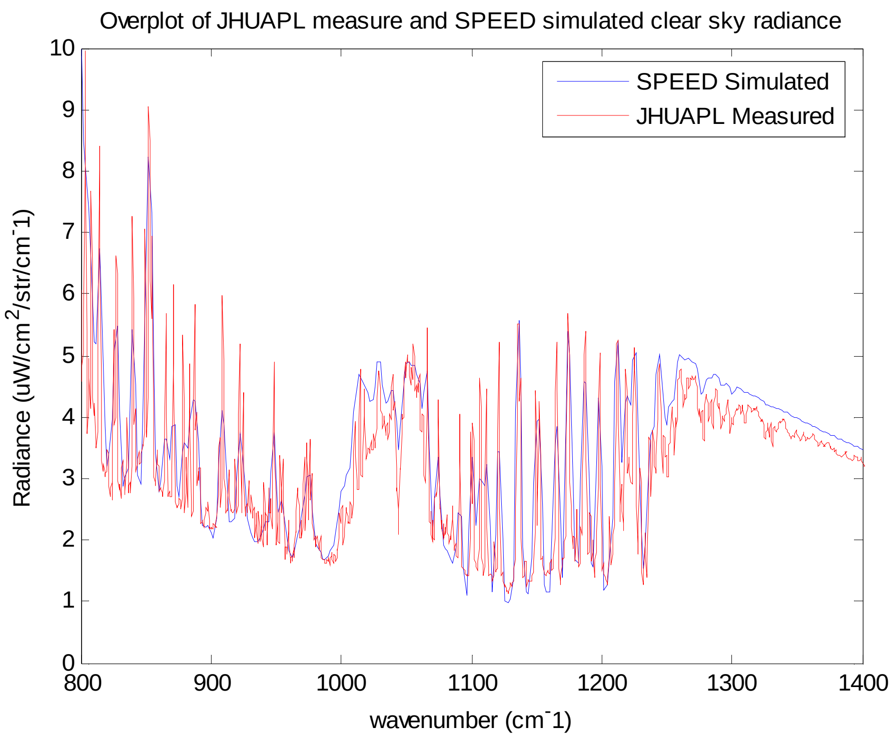
SPEED Simulated
15 Degree Elevation
Clear Sky Radiance
(2 cm^{-1} resolution)



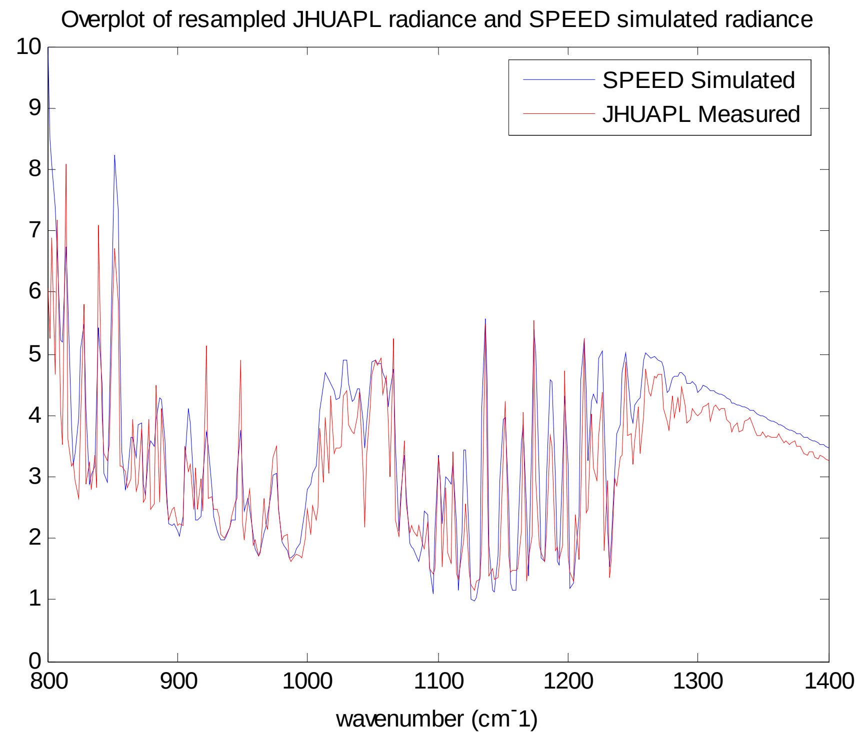
JHUAPL Measured
15 Degree Elevation
Clear Sky Radiance
(0.5 cm^{-1} resolution)

Measured vs Modeled Spectral Radiance at Consistent Resolution

Spectral Radiance Comparison
Native Resolution



Spectral Radiance Comparison
JHUAPL Data Resampled to 2 cm^{-1}



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Conclusions

- Simulated Scenes Can Be Used to Support Algorithm/System Development
- More Validation is Required to Define Accuracy of Simulation Processes
- Mixture of Simulations Methods Should be Utilized
  - Fully Simulated Backgrounds
    - Most Flexibility
    - Least Realistic
  - Background Properties Retrieved from Measured Data
    - Most Realistic Clutter
    - Limited by Data Sources