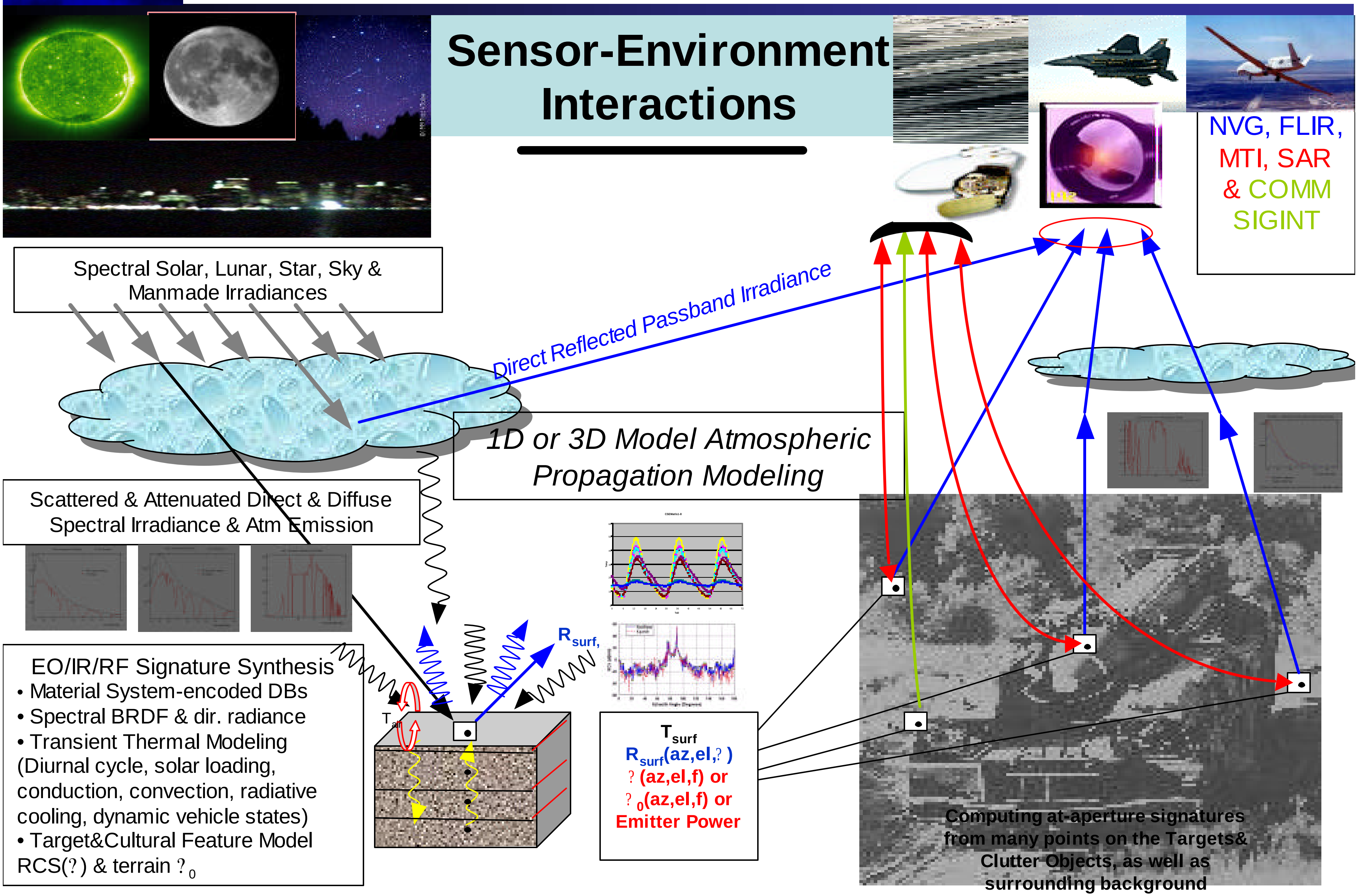
Emerging Technologies for Sensor Simulation

Sensor Simulation Challenges



Sensor Simulation Challenges

- Material & Property-attributed Environmental DBs
- Credible real-time signatures & atmospherics
- Consistent/Correlated Modeling for EO, IR & RF
- Credible Optical Sensor Effects Simulation
- CGF-virtual sensor model interoperability
- Rapidly-composing Sensor-oriented Federations

Material System Modeling Captured in EDCS

Material System Concept

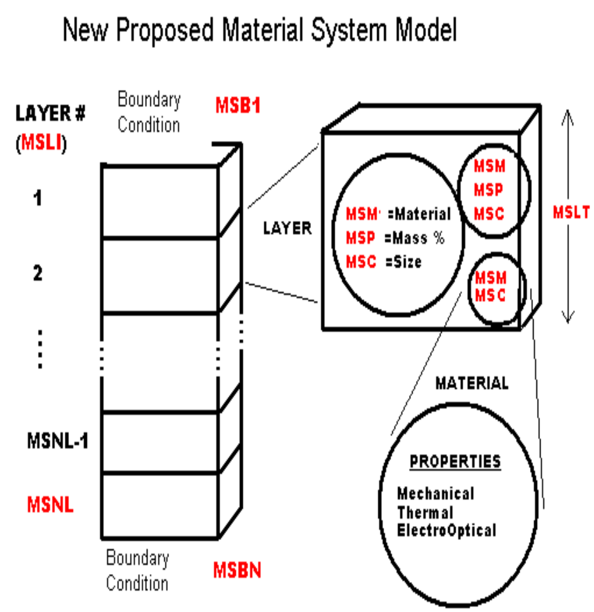
MATERIAL = Homogenous composition of matter with specific values of ***intrinsic*** (context-independent) physical properties

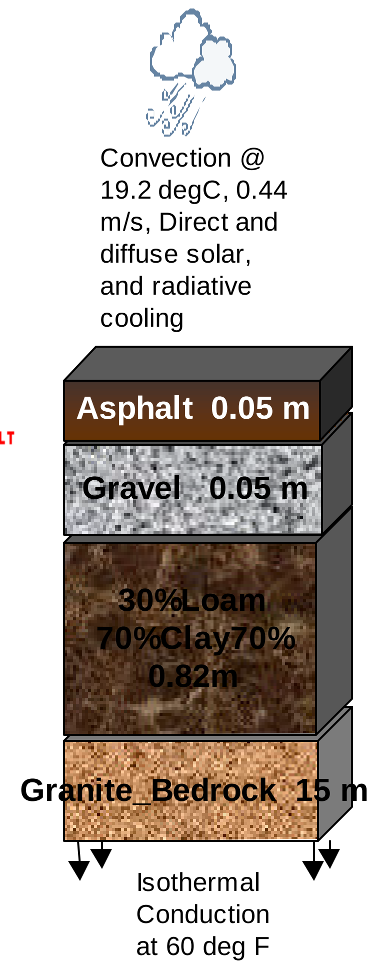
LAYER = is 1 or more materials, each of arbitrary aggregate mass % in the layer.

1D MATERIAL SYSTEM = Set of layers of arbitrary thickness, with ***context-dependent*** boundary conditions.

Provides "hook" for physical property attributions throughout the terrain.

Concept incorporated in EDCS





EDCS MATERIAL EA

Developed an initial list of 307 homogeneous Materials, their associated definitions, EAs, labels, and names for the following categories

- *carbon and petroleum materials*
- *grasses*
- *tree leaves, barks, woods*
- *marine life*
- *minerals and monomolecular solids*
- *non-elemental metals*
- *papers and textiles*
- *plastics, rubbers, and other composites*
- *rocks and building materials*
- *soils and particulates*
- *water states*
- *all elemental materials*

Over 200 *Material Systems* using these EAs in use by our customers.

SigSim Material System Modeling Captured in EDCS

1D Material System

• **Thermal Solver Mode** (energy balance, transient)

• **Thermal Boundary Conditions** at Top and Bottom (Convective, Conductive, Insulating, etc..)

• **Number of Layers**

• **Material ID, Thickness** of each layer

Material

• **Bulk Properties:** Density, Thermal Conductivity, Specific Heat, Latent Heats of Fusion, Evaporation, & Sublimation, Solar Absorptivity, Lambertian Emissivity, BRDF model to use, Angle at which DHR measured, RF sigma0 model parameters

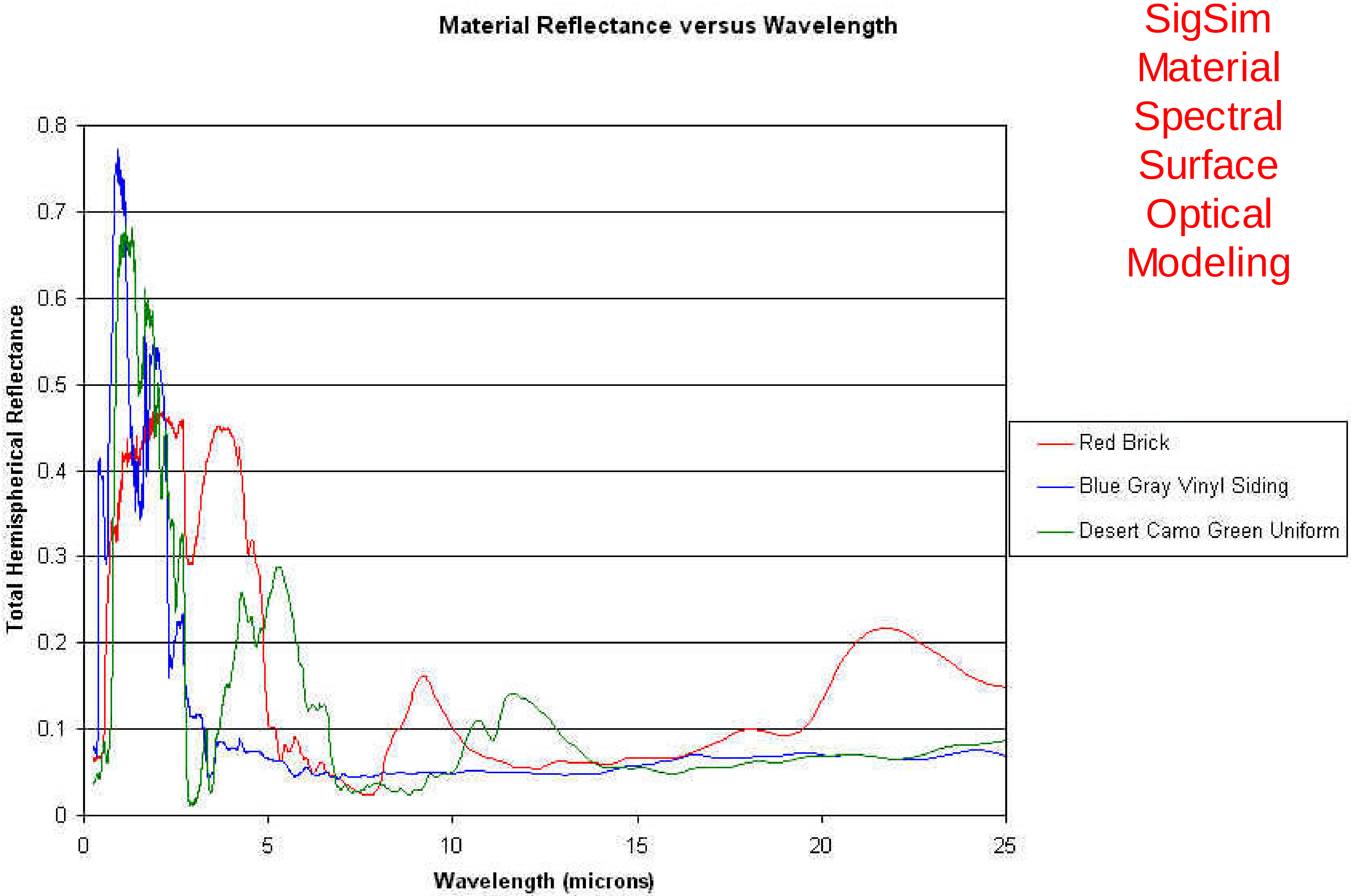
• **Spectral Properties:** BRDF parameters such as DHR, % Specular, Lobe Width, Shininess

SAMPLE MATERIAL SYSTEM FILE

Material_System	Top_Surface_Boundary				Bottom_Surface_Boundary					Surface_Normal				
Name	BC1	T1	V1	Q1	BCn	Tn	Vn	Qn	Tinit	i	j	k	Num_Layers	
Yellow_Asphalt	1	0	0	0	0	15	0	0	28	0	0	1	3	Asphalt
Bare_Ground	1	0	0	0	0	15	0	0	28	0	0	1	1	Ground_S

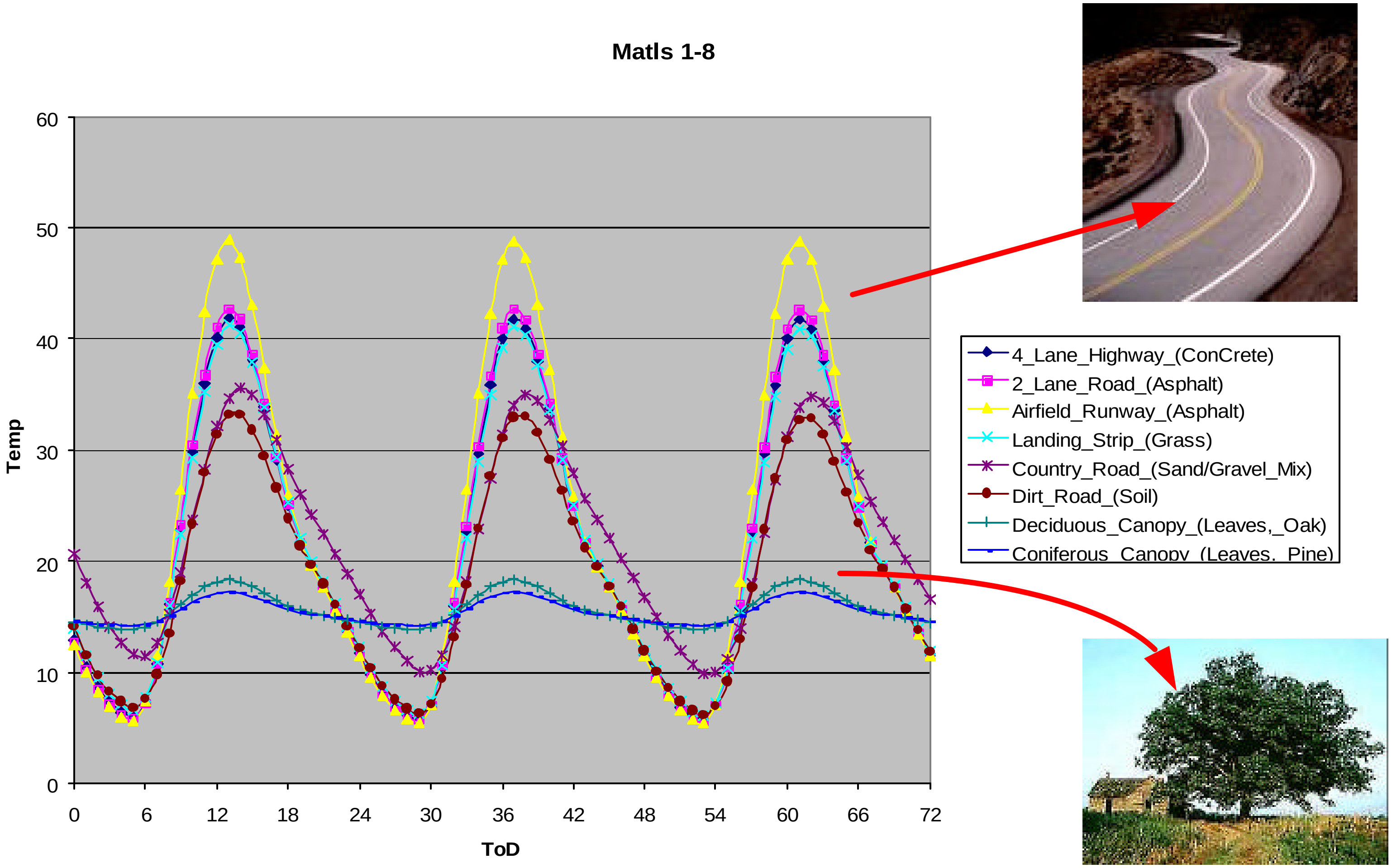
SAMPLE MATERIAL FILE

Bulk_Properties													
p	k	Ch	Lhf	Lhs	Lhv	Stan	r-type						
2115	0.062	920	-1	-1	-1	1	1						
Spectral_Surface_Optical													
SigSim_BRDF_F	Sanford-F	Phong_BRDF_Parameters											
Lambda	Flag	Polarizatio	Param1	Param2	Param3	Param4	Parar	Param6	Param7	Param8	Param9	F	
0.35	IO	UN	0.5	50	160.38	-1	-1	-1	-1	0.567672	0.25		
0.45	IO	UN	0.5	50	160.38	-1	-1	-1	-1	0.567672	0.25		
0.55	IO	UN	0.5	50	160.38	-1	-1	-1	-1	0.567672	0.25		
0.65	IO	UN	0.5	50	160.38	-1	-1	-1	-1	0.567672	0.25		
0.75	IO	UN	0.1	50	160.38	-1	-1	-1	-1	0.113534	0.05	0.117392	13
1.00E+04	RF	HH	-94.9	99	0.694	30	1.34	-1.718	7.151	-5.201	0.778		
1.00E+04	RF	VV	-84.761	99	0.797	-30	1.6	1.101	3.174	0.001	0.095		
1.67E+04	RF	HH	-90.341	82.9	0.03	1.651	5	0.038	5.49	0.001	-6.35		
1.67E+04	RF	VV	-38.159	30.32	0.048	1.913	4.36	0.368	6.263	-0.84	0.064		
2.50E+04	RF	HH	-94.472	99	0.892	30	1.56	-1.918	4.731	-0.007	-3.983		
2.50E+04	RF	HH	-90.341	82.9	0.03	1.651	5	0.038	5.49	0.001	-6.35		
2.50E+04	RF	VV	-59.56	39.284	1.598	30	1.18	-1.178	4.26	-0.002	-4.807		
2.50E+04	RF	VV	-38.159	30.32	0.048	1.913	4.36	0.368	6.263	-0.84	0.064		

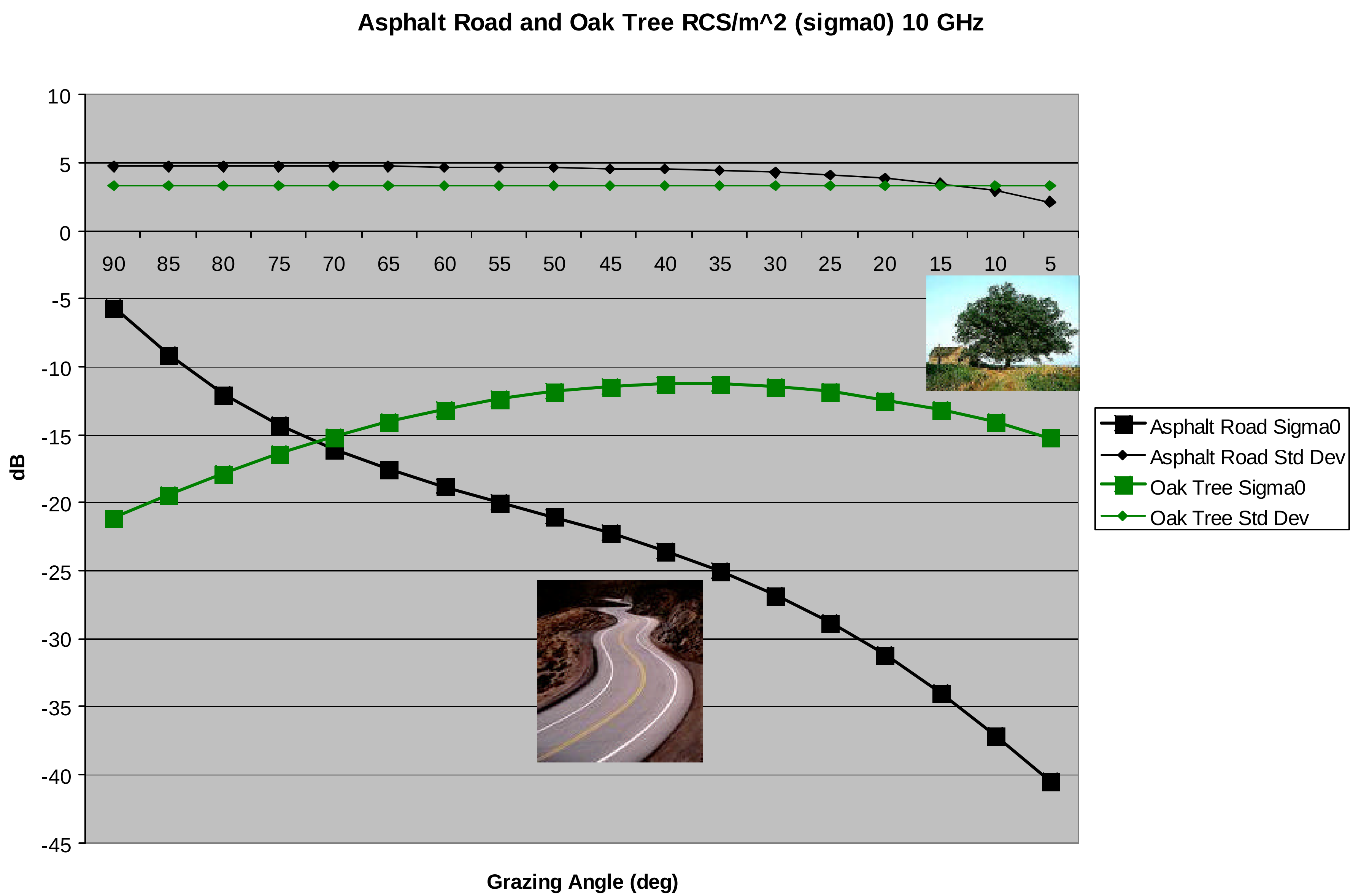


SigSim Material Spectral Surface Optical Modeling

SigSim RT Background Thermal Output



SigSim Natural Environment RF Signature Modeling



Automated Material System Classifier

Signature Predictive Classifier (SPC)

Picks hypothesis material-systems by fitting at-aperture signature predictions from library of material systems to n-channel pixel data

Spatial Correlation Refiner (SCR)

Resolves ambiguities by using nearest neighbor pixels/spatial data to refine material assignments

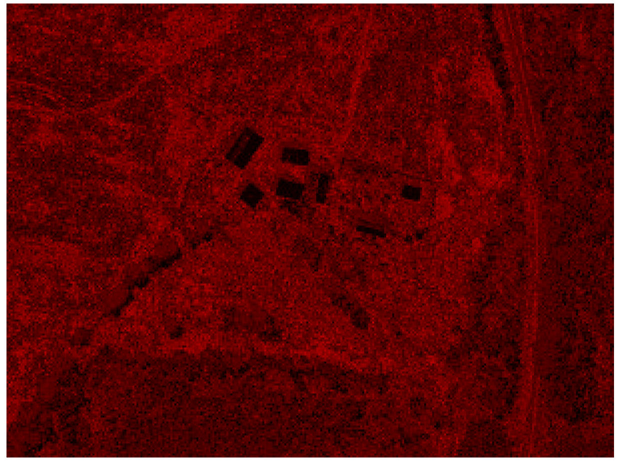
Iterative Context Adjuster (ICA)

Uses geographical and cultural information to further refine material system library/values

Automated Material System Classifier: Sample

Original RGB Image

Material Classifications



Synthesized Visible Image

Signature Predictive Classifier (SigSim in reverse on 200 Material Systems)

→

Material system file (5-channel .mcm above)

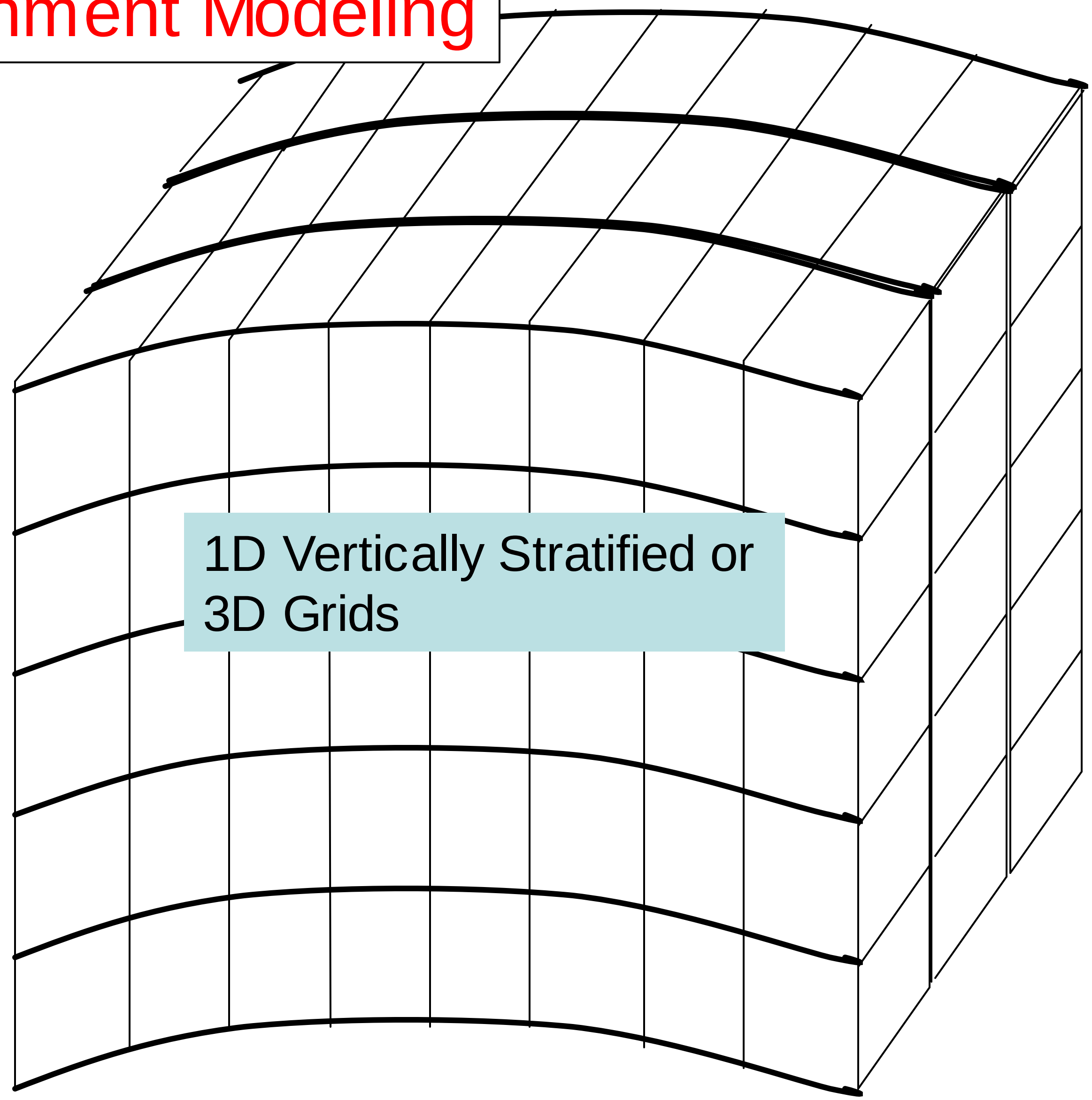
→

Generated RGB image from hypothesized material systems (SigSim)

Atmospheric Environment Modeling

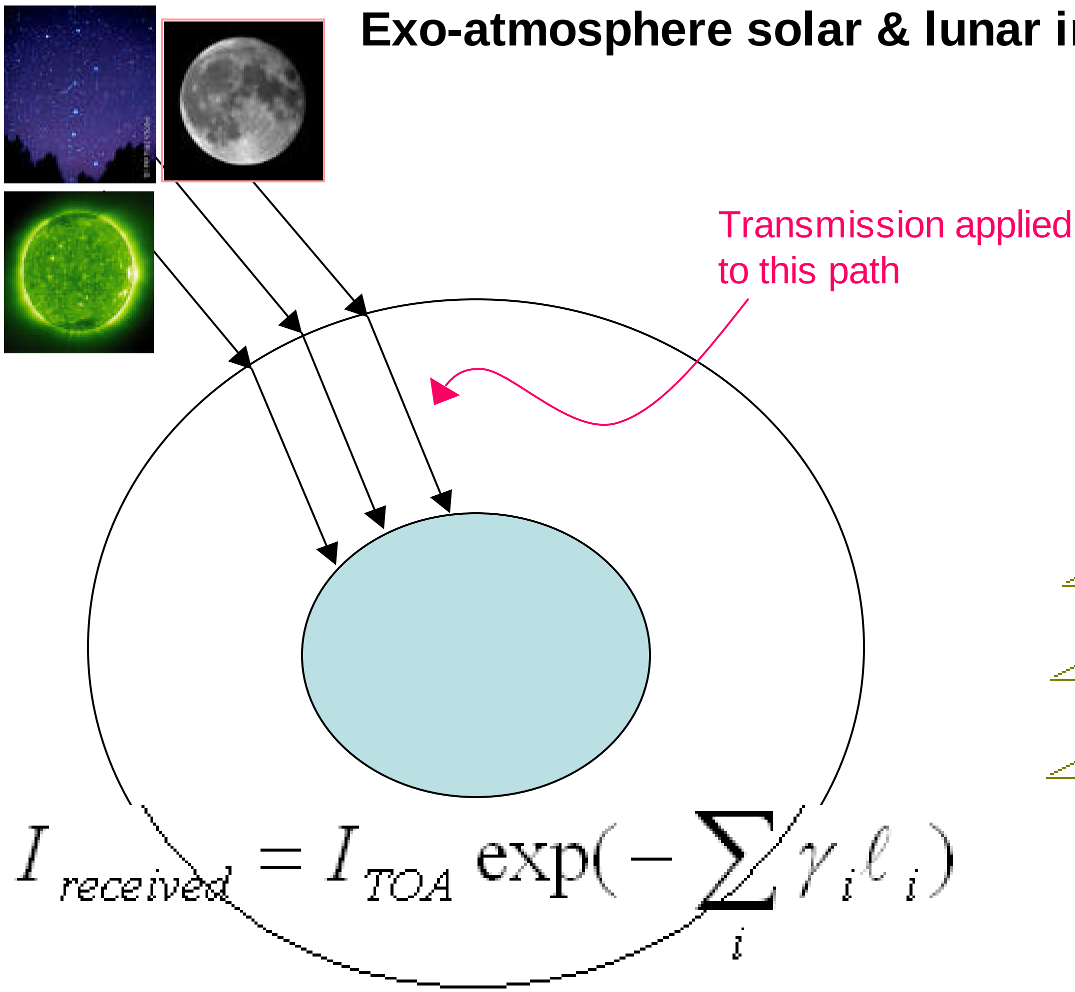
Temperature (x,y,z)
Pressure (x,y,z)
%Relative Humidity (x,y,z)
%H2O (x,y,z)
%O3 (x,y,z)
%CH4 (x,y,z)
%N20 (x,y,z)
%CO (x,y,z)
Cloud Type: (x,y,z)
- ***None,***
- ***Cumulus,***
- ***Alto-stratus,***
- ***Stratus-Strato-Cumulus,***
- ***Nimbo-stratus***

Rain Rate, etc …

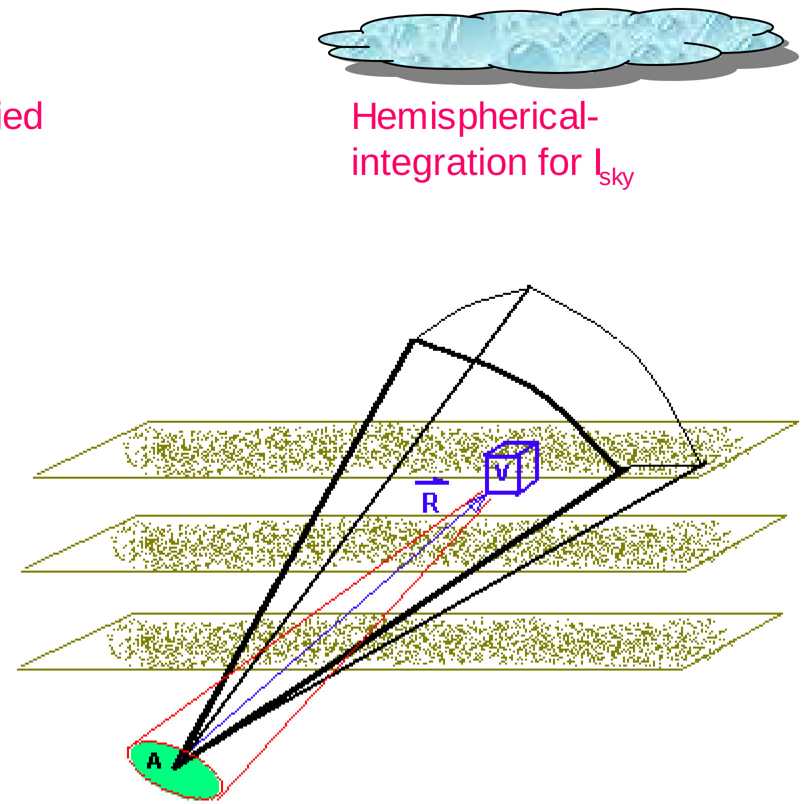


SigSim Spectral Irradiance Modeling

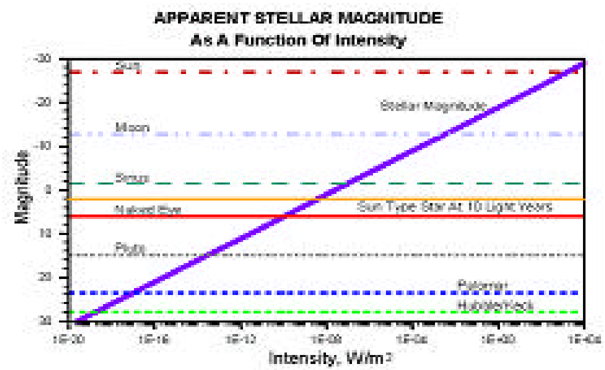
Exo-atmosphere solar & lunar irradiance data from Modtran 4.0

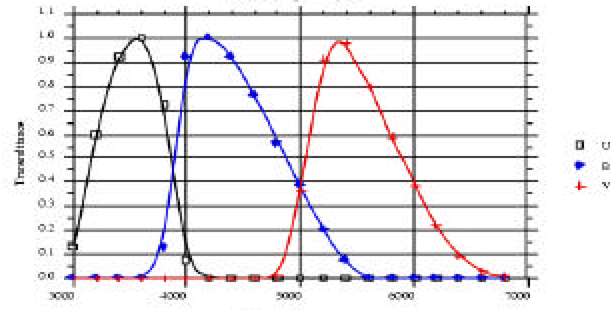


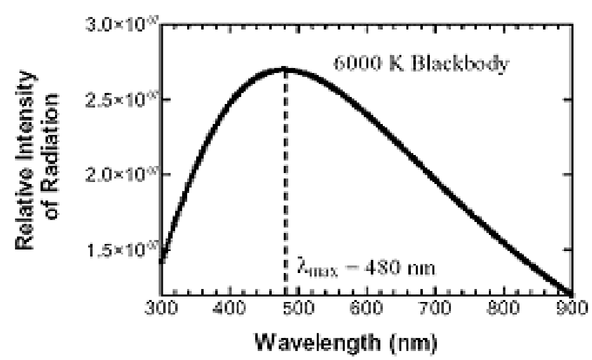
$$I_{received} = I_{TOA} \exp(-\sum_i \gamma_i \ell_i)$$



Star Ephemeris and Irradiance





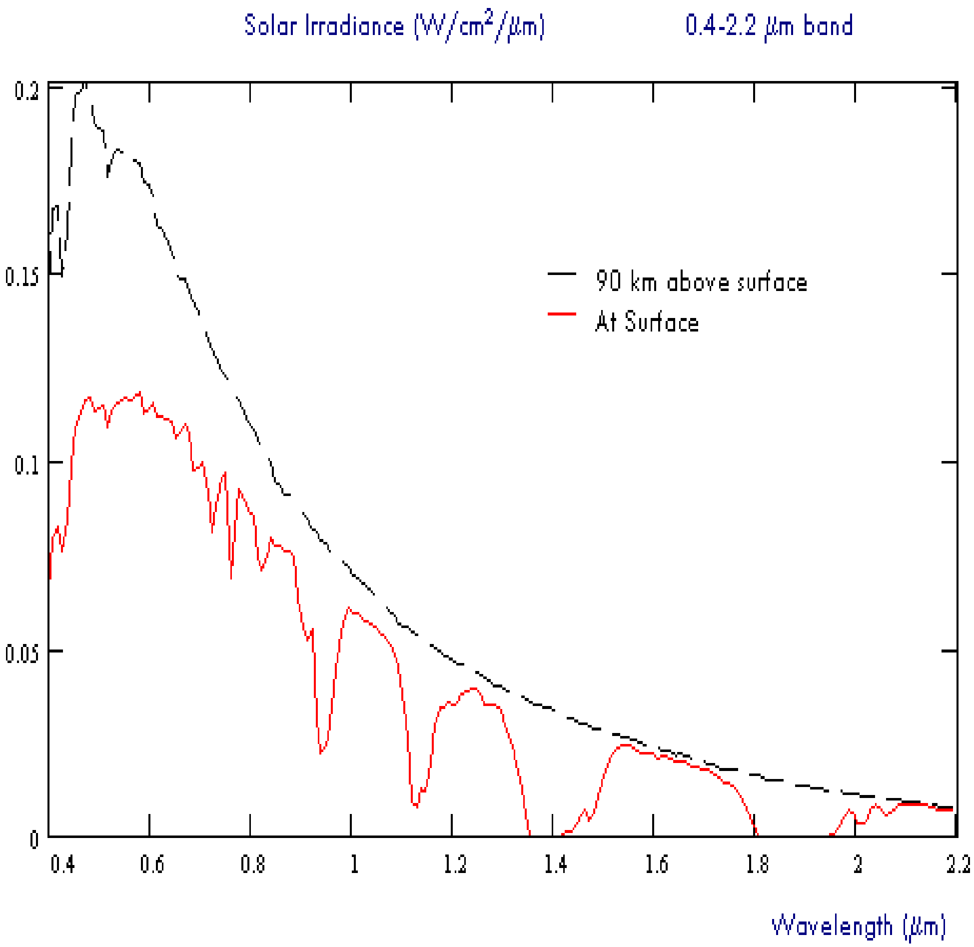


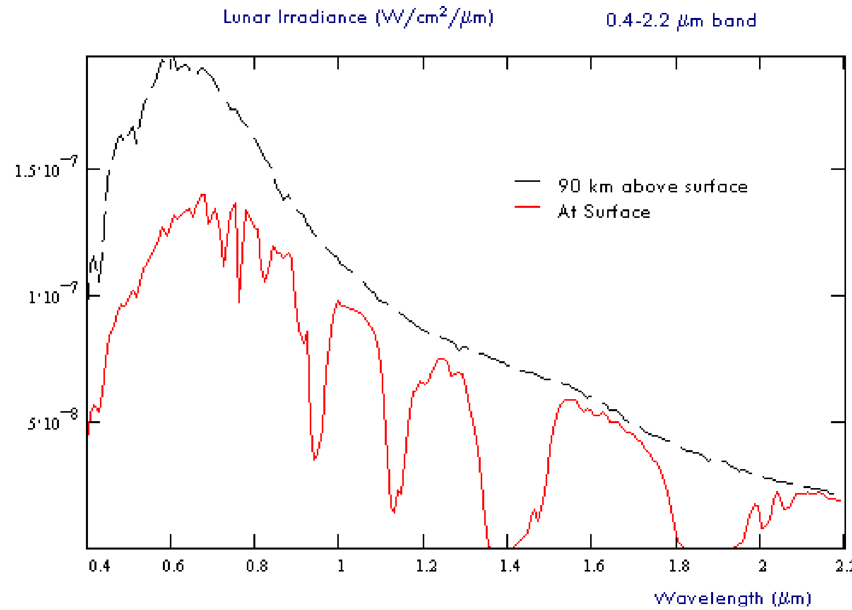
SigSim provides stellar ephemeris and spectral irradiance for over 300,000 stars

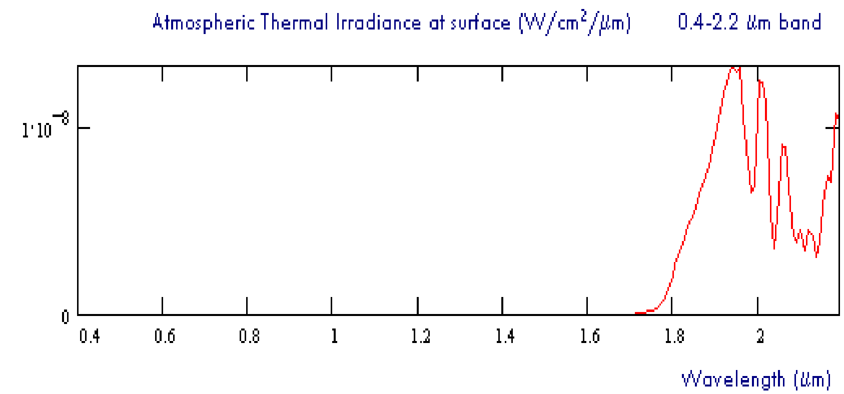
Accurate stellar irradiance for any mission time/location

SigSim Spectral Irradiance Output

Example : 0.4-2.2 micron passband

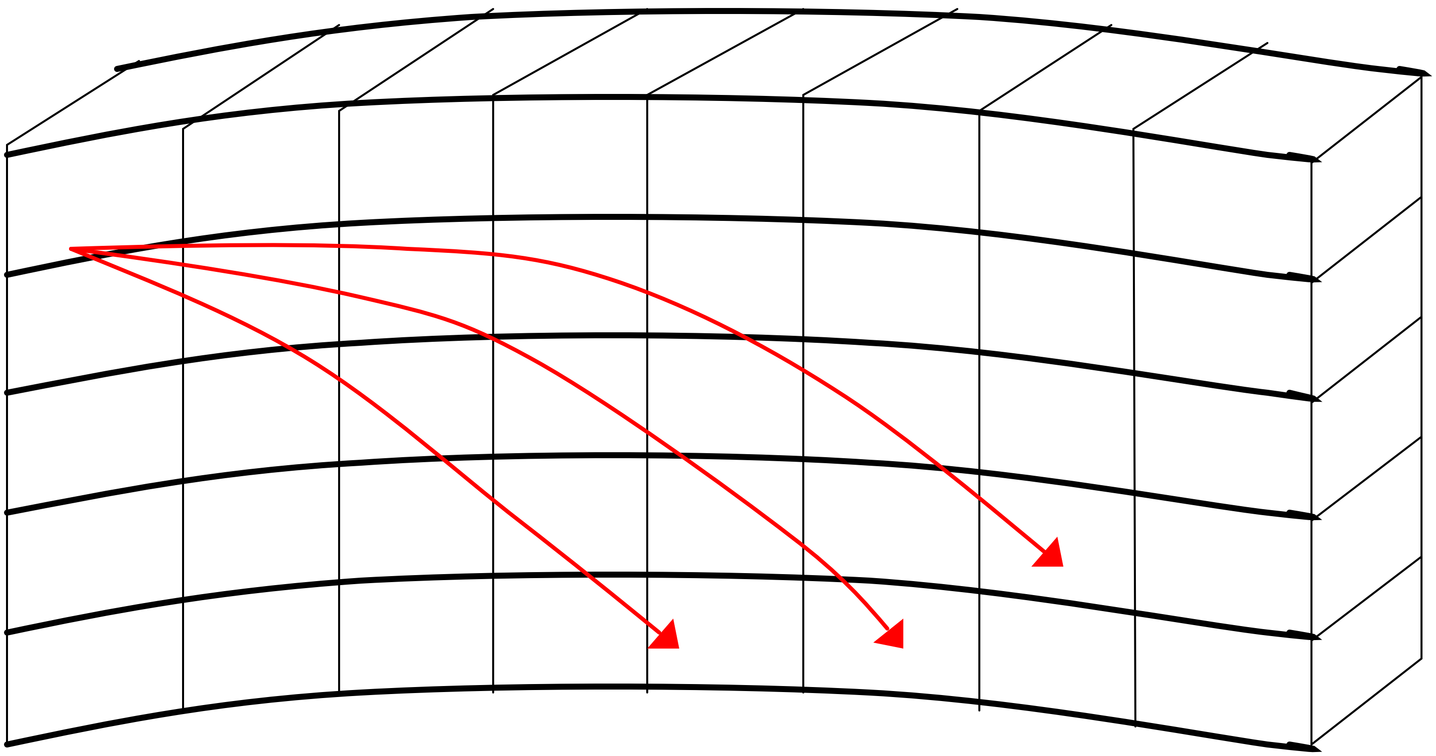






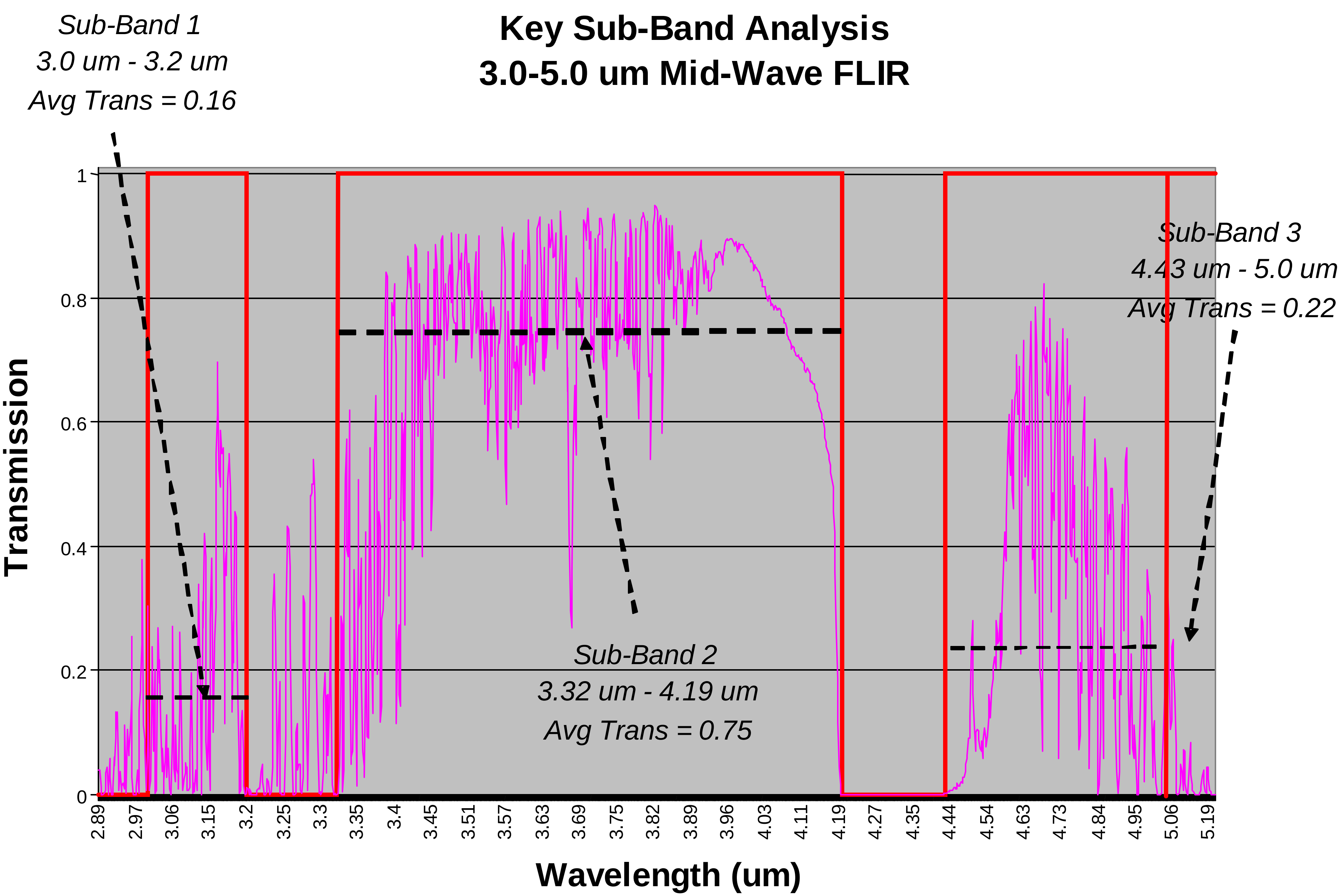
SigSim Real-time 3D Atmospherics

Real-time atmospheric propagation library computes arbitrary LOS EO/IR /RF passband transmission and atmospheric radiance/noise



SigSim Meteorological and Atmospheric Modeling

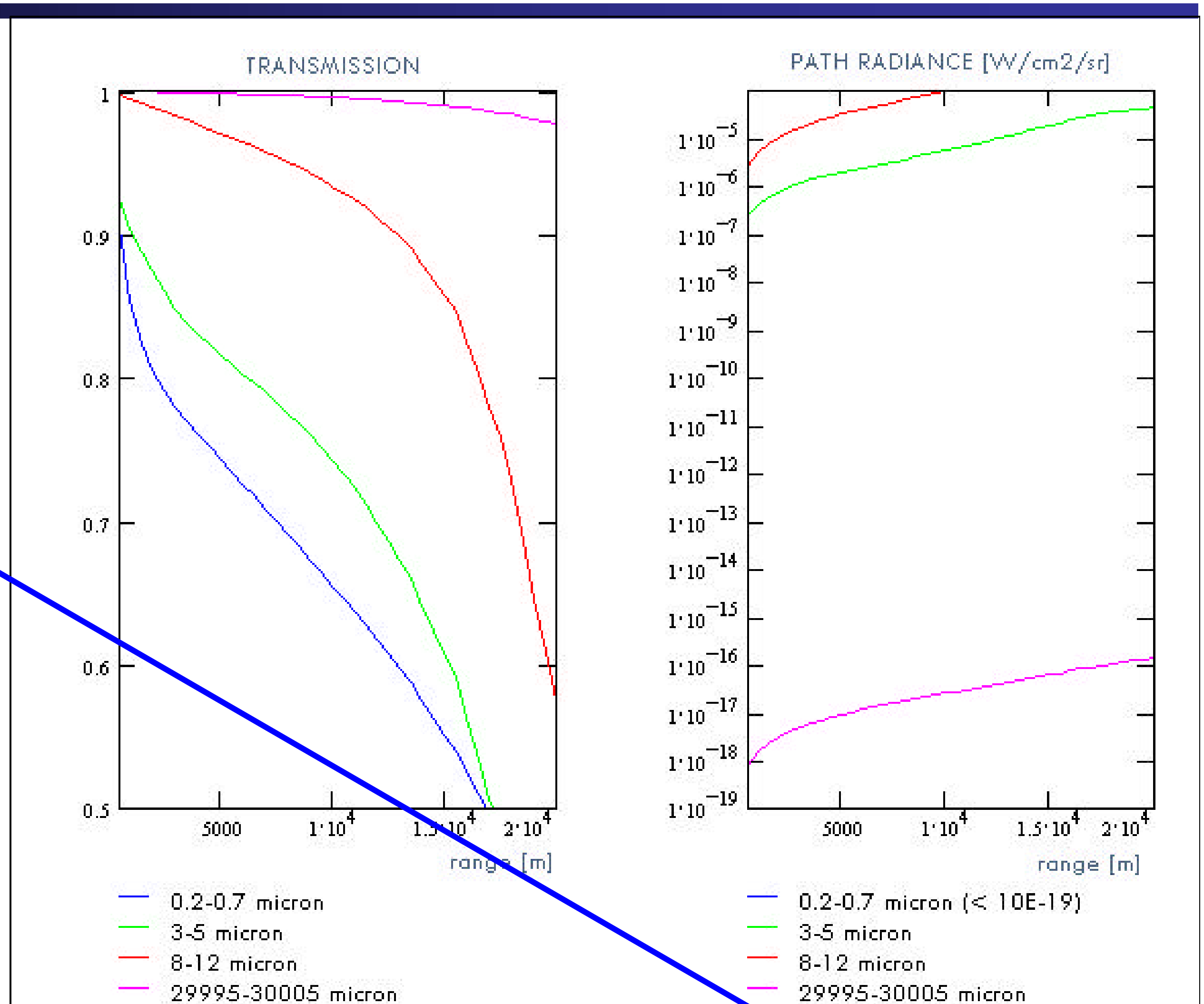
Key Sub-Band Analysis
3.0-5.0 um Mid-Wave FLIR



Emerging Technologies for Sensor Simulation

SigSim EO-IR-RF Atmospherics: Clear Conditions

SigSim Atmospherics



Correlated Multi-Sensor Atmospherics

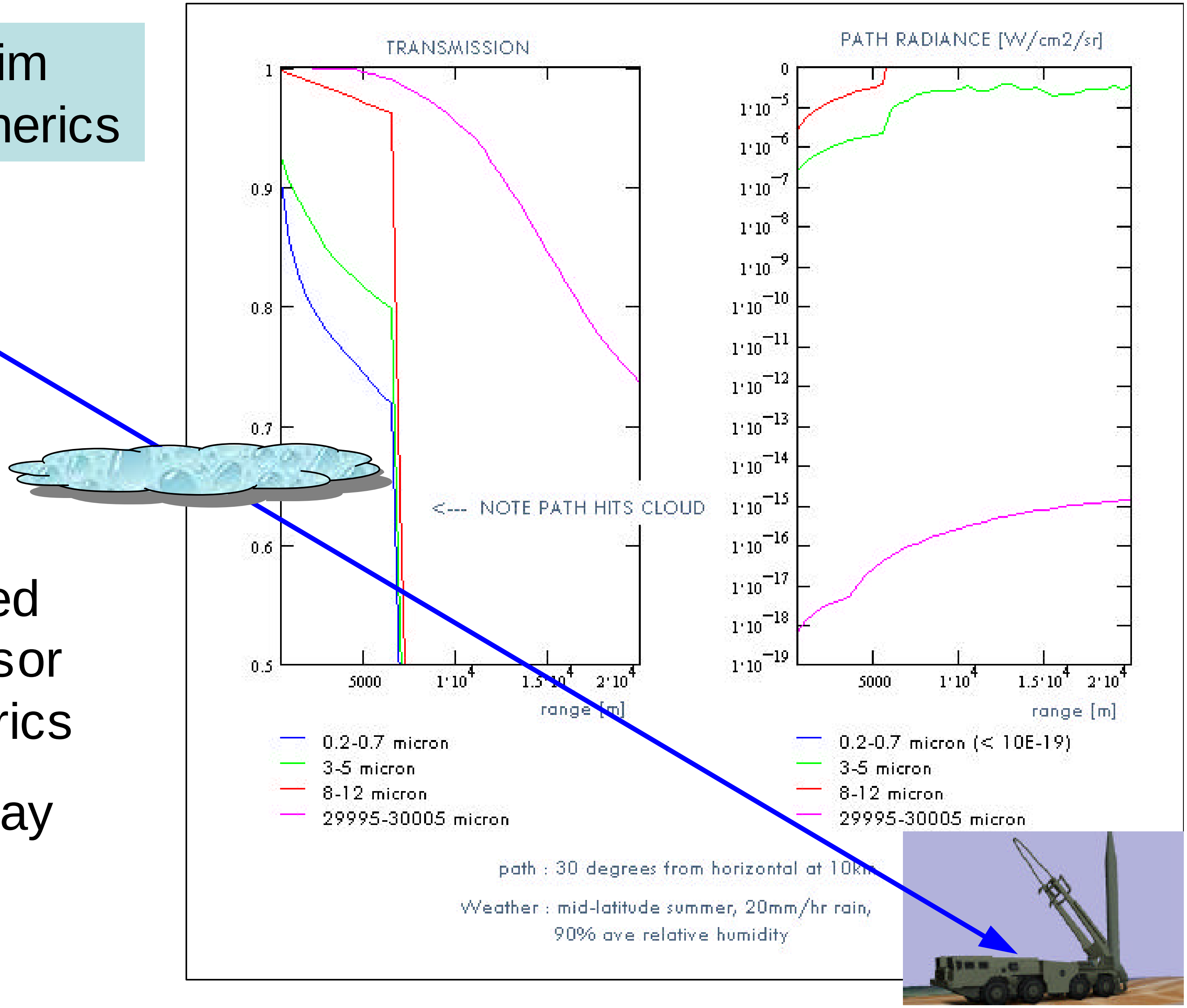
Clear Day

SigSim EO-IR-RF Atmospherics: Cloudy Conditions

SigSim Atmospherics

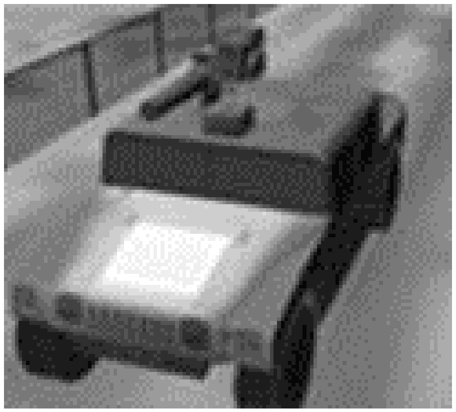
Correlated
Multi-Sensor
Atmospherics

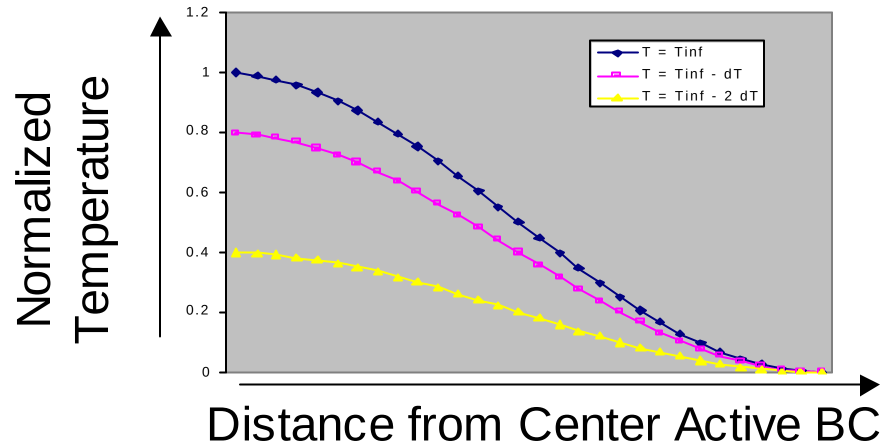
Cloudy Day



Emerging Technologies for Sensor Simulation

SigSim Real Time 3D Thermal Modeling: Methodology





- *Fast $T(x,y,z_{=surface}, t)$ approximator*
- *Dynamically reacts to vehicle and environmental boundary conditions (forcing functions)*

Real Time Thermal Modeling: T72 Example

7 Active Regions:

- Turret, gun-barrel, exhaust, engine compartment, treads, bogey-wheels and drive wheel

- 1D thermal systems and active boundary states ID'd, ie.
  - Exhaust Active thermal systems: Forced gas at 150C&20m/sec behind 5mm sheet metal and ambient air on outside surface
  - Exhaust Ambient Material system: ambient Tair&Vair on both sides of 4 inches of skirt metal

Actual FLIR Image

Synthetic FLIR Image
VixSen

Emerging Technologies for Sensor Simulation

SigSim Real-time 3D Thermal: T72 Cooling

T72 moving T=0 sec.

T72 stopped and engine idling T=1 min.

T72 engine idling T=2 min.

T72 engine idling T=3 min.

T72 engine off T=5 sec. post-idle

T72 engine off T=50 sec. post-idle

T72 engine off T=10 min. post-idle

SigSim Real-time 3D Thermal: T72 Heating

T72 engine off
T=0 sec.

T72 engine idling
T=5 sec.

T72 engine idling
T=10 sec.

T72 engine idling
T=15 min.

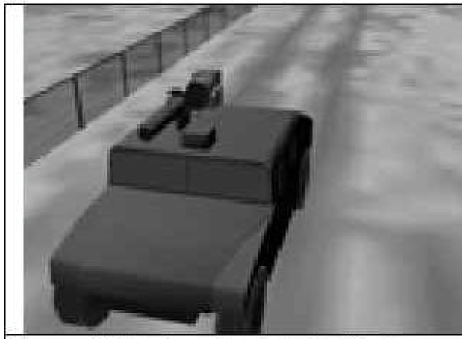
T72 moving
T=5 sec. post-idle

T72 moving
T=10 sec. post-idle

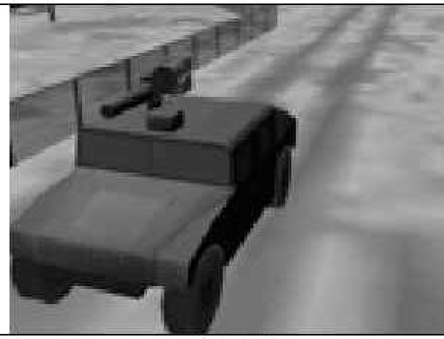
T72 moving
T=15 min. post-idle

Emerging Technologies for Sensor Simulation

SigSim Real-time 3D Thermal: HUMMV Heating

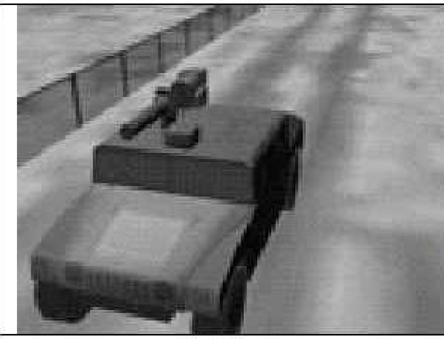


Time 1 -- Engine Ignition

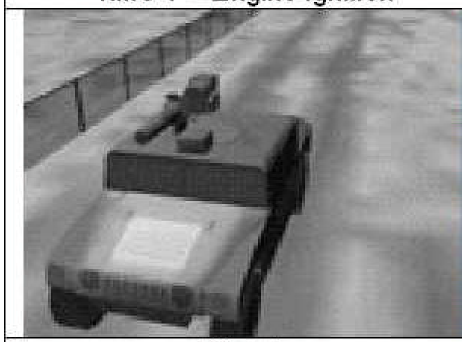


Time 2

Time 3



Time 4



Time 5

Time 6

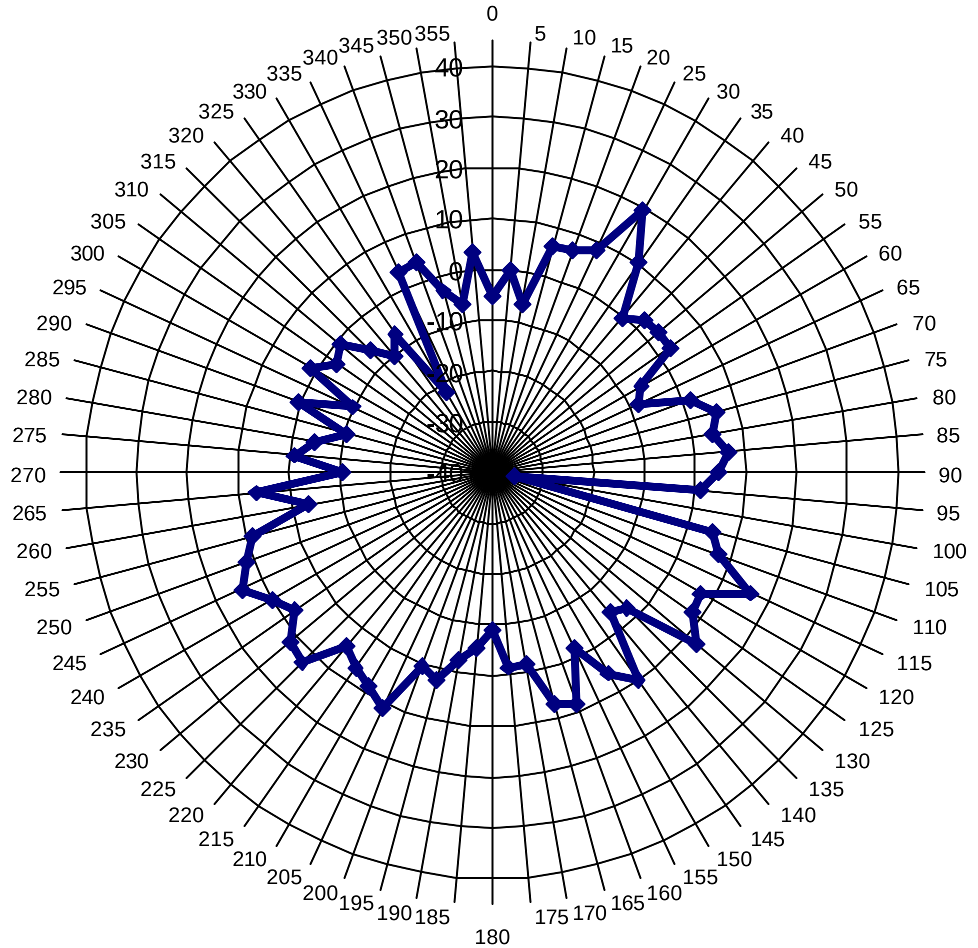
Time 7

Time 8

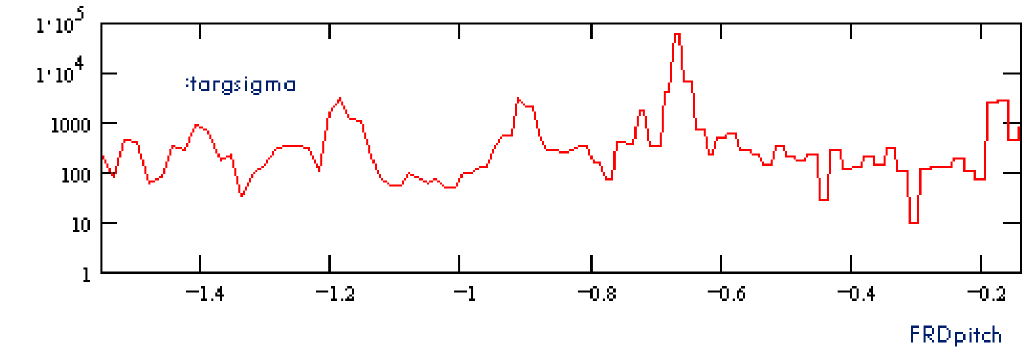
Emerging Technologies for Sensor Simulation

SigSim Target RF Signature Modeling via Radbase

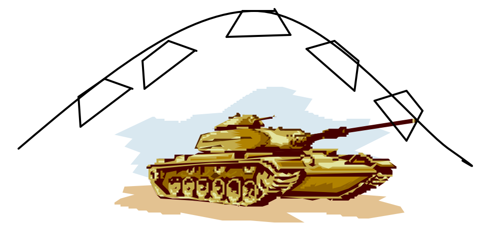
MAZ-543 SCUD RCS 10 GHz
40 Deg Elevation

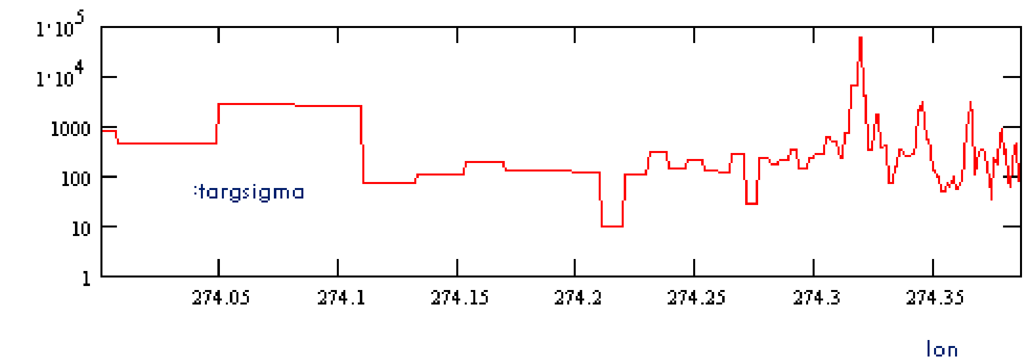


SigSim Target RF Power At Receiver



RCS vs angle at constant range

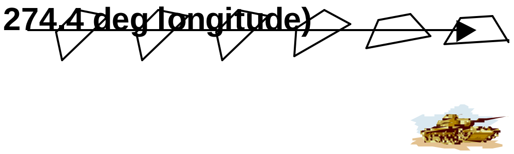


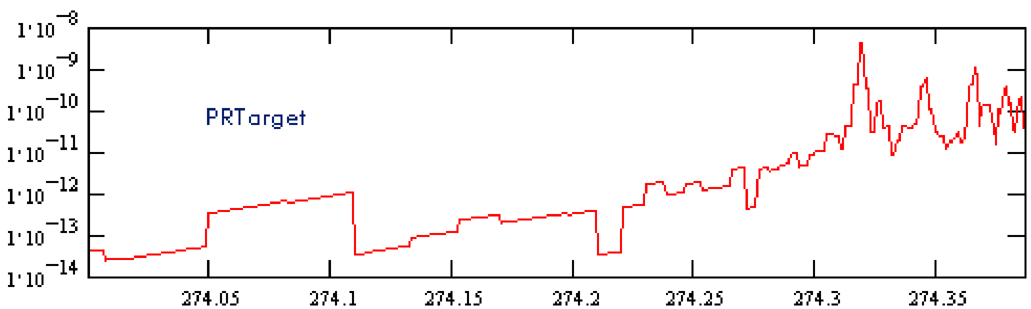


RCS vs sensor longitude

-- without 1/R2 factor or transmission loss

(target at 274.4 deg longitude)





RCS vs sensor longitude

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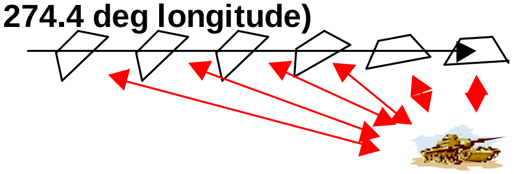
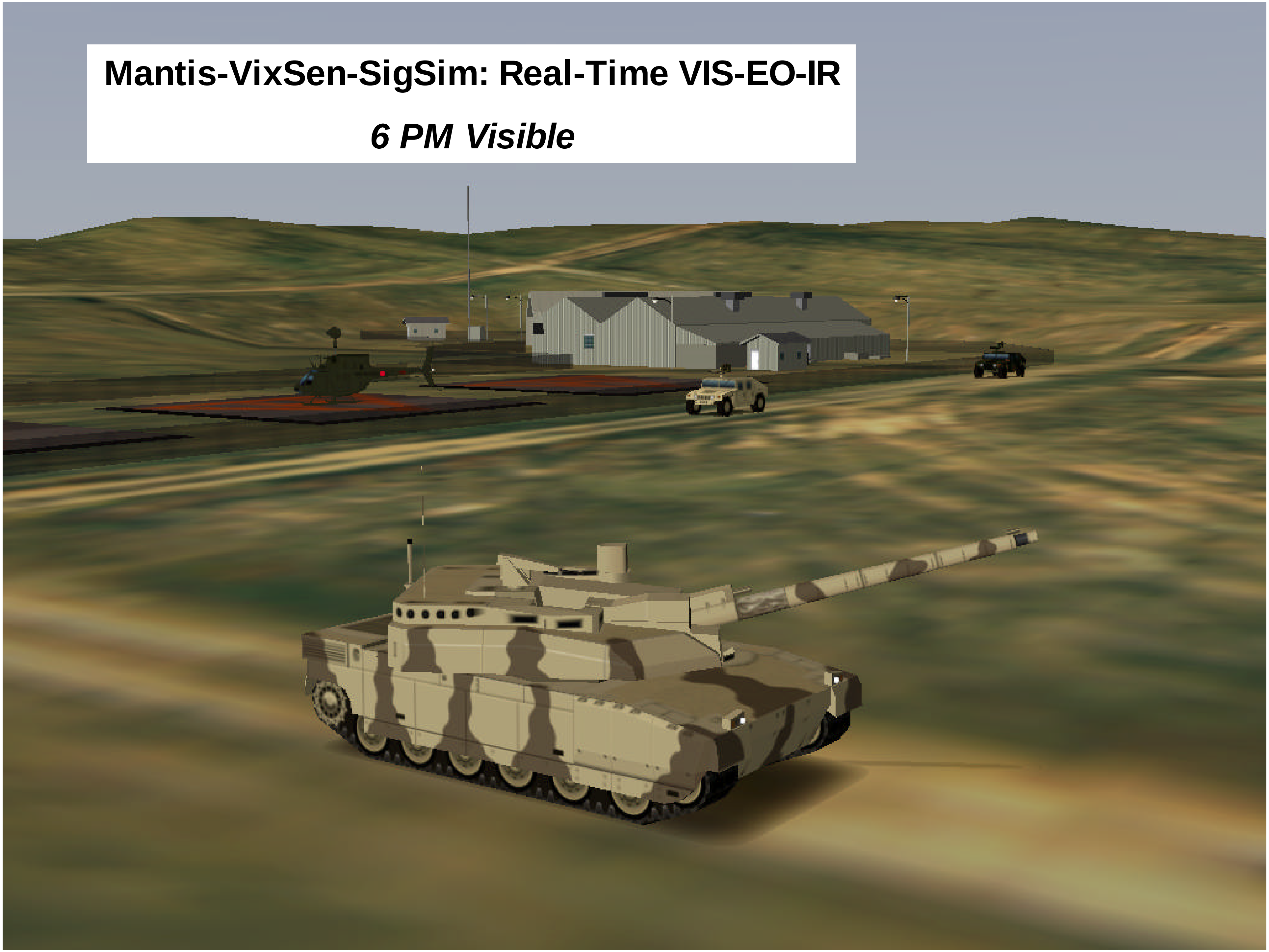


Mantis-VixSen-SigSim: Real-Time VIS-EO-IR

Noon Visible



Mantis-VixSen-SigSim: Real-Time VIS-EO-IR
6 PM Visible


Mantis-VixSen-SigSim: Real-Time VIS-EO-IR
Night-time Visible


Mantis-VixSen-SigSim: Real-Time VIS-EO-IR
Near-IR/NVG

Mantis-VixSen-SigSim: Real-Time VIS-EO-IR

Mid-Wave FLIR


Mantis-VixSen-SigSim: Real-Time VIS-EO-IR
Long-Wave FLIR

SigSim: Run-time Performance

At 189 λ -?Single 2.8 GHz CPU Pentium 4

20.9 sec / 90 cells	*New Atmospheric Builds*
14.1 secs	*72-hour thermal spin-up 10 material systems*
918 Hz	*Re-run transient thermal solver single time-step*
3500 Hz	*Compute 189 λ EO,IR,RF atmospherics single LOS path*
2.1 Hz	*Re-compute 189 λ ?direct& diffuse solar, lunar, stellar, sky/cloud&earthshine irradiances*

POST-APERTURE: SenSim = Sensor Simulation

- Advanced design modeling for passive EO/IR Sensors
- Windows-based GUI for advanced modeling of components

  Optics, diffraction and geometric

  Detectors, sampling and 1/f noise

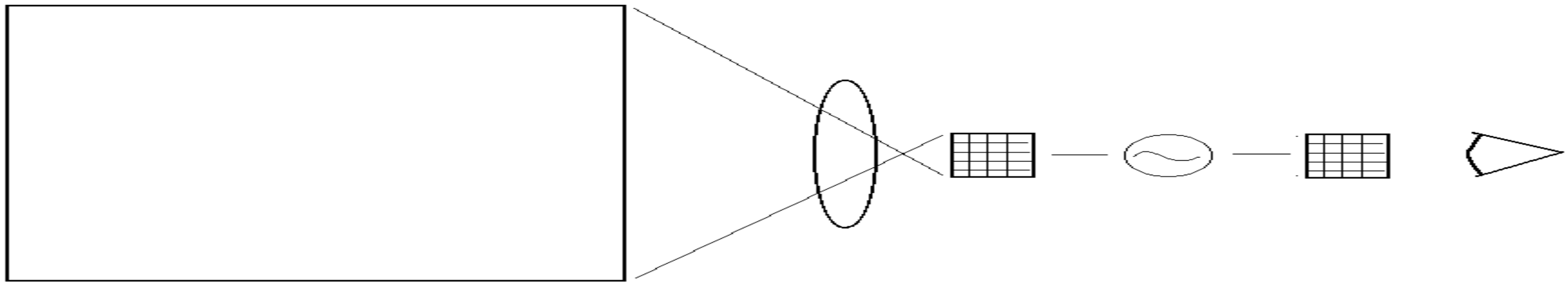
  Signal processing, boost and filtering

  Display, various types, sampling resolutions

- Instant Sensor Design Visualization Feed-back

  See the real-time display effect of advanced sensor designs before proto-typing

SenSim Modeling



Input Pre-processing

- acquisition atmospherics effects restoration
- acquisition sensor effects restoration
- simulated atmospherics degradation

Sensor Pre-Filtering

- nyquist upsampling and edge treatment
- motion MTF *
- diffraction optics
- design optics blur
- detector MTF & sampling

Detector Noise Injection

- spectral temporal noise synthesis/application:
- $(1/f)^n$ noise
- white noise
- back-end filtering
- non-uniformity *
- frame to frame noise *

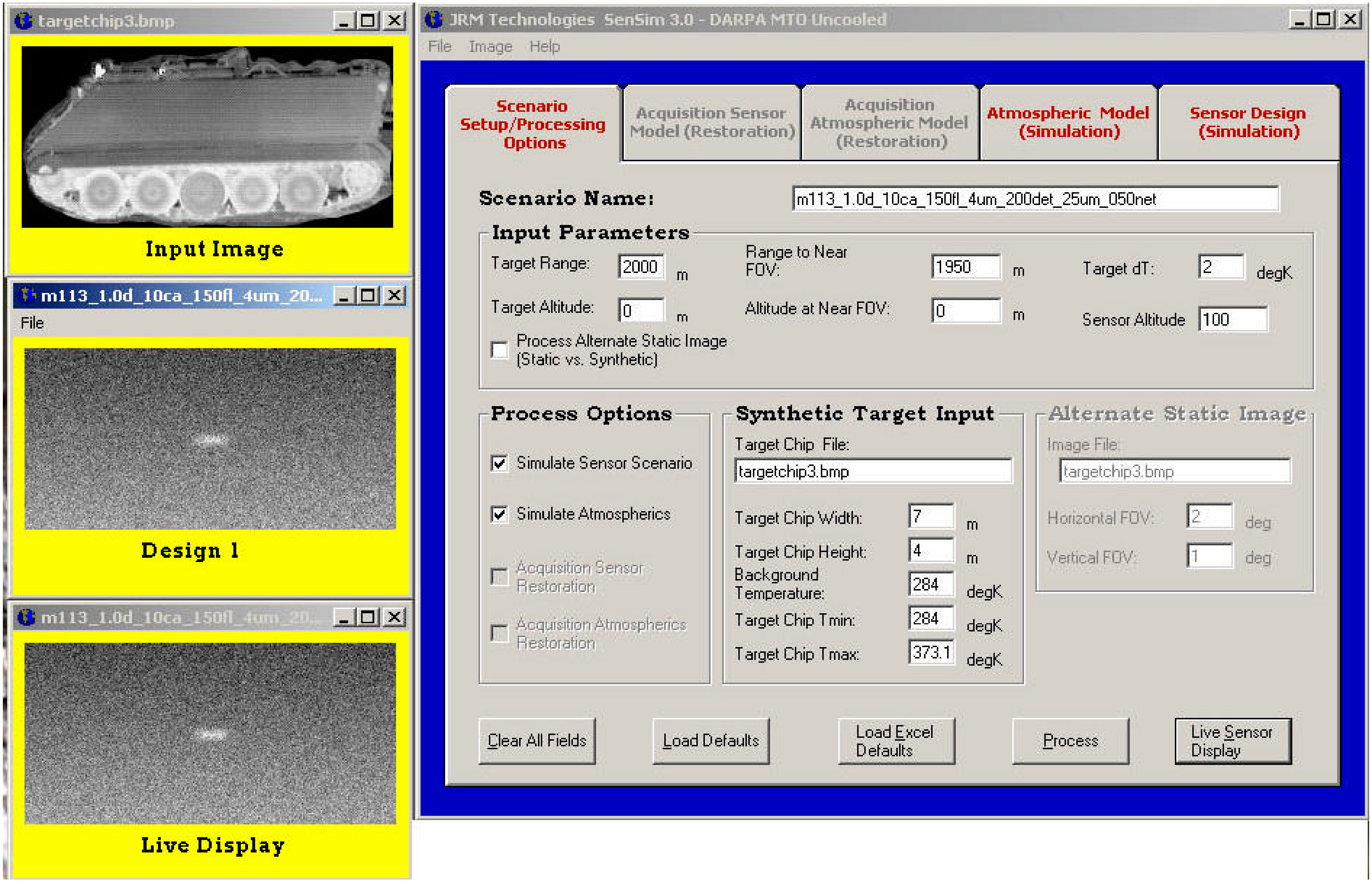
Post Filtering

- read-out
- pre-amplifier
- boost elex OTF *
- display MTF *
- continuous frame output *
- dynamic, real-time display **

* in development ** future capability

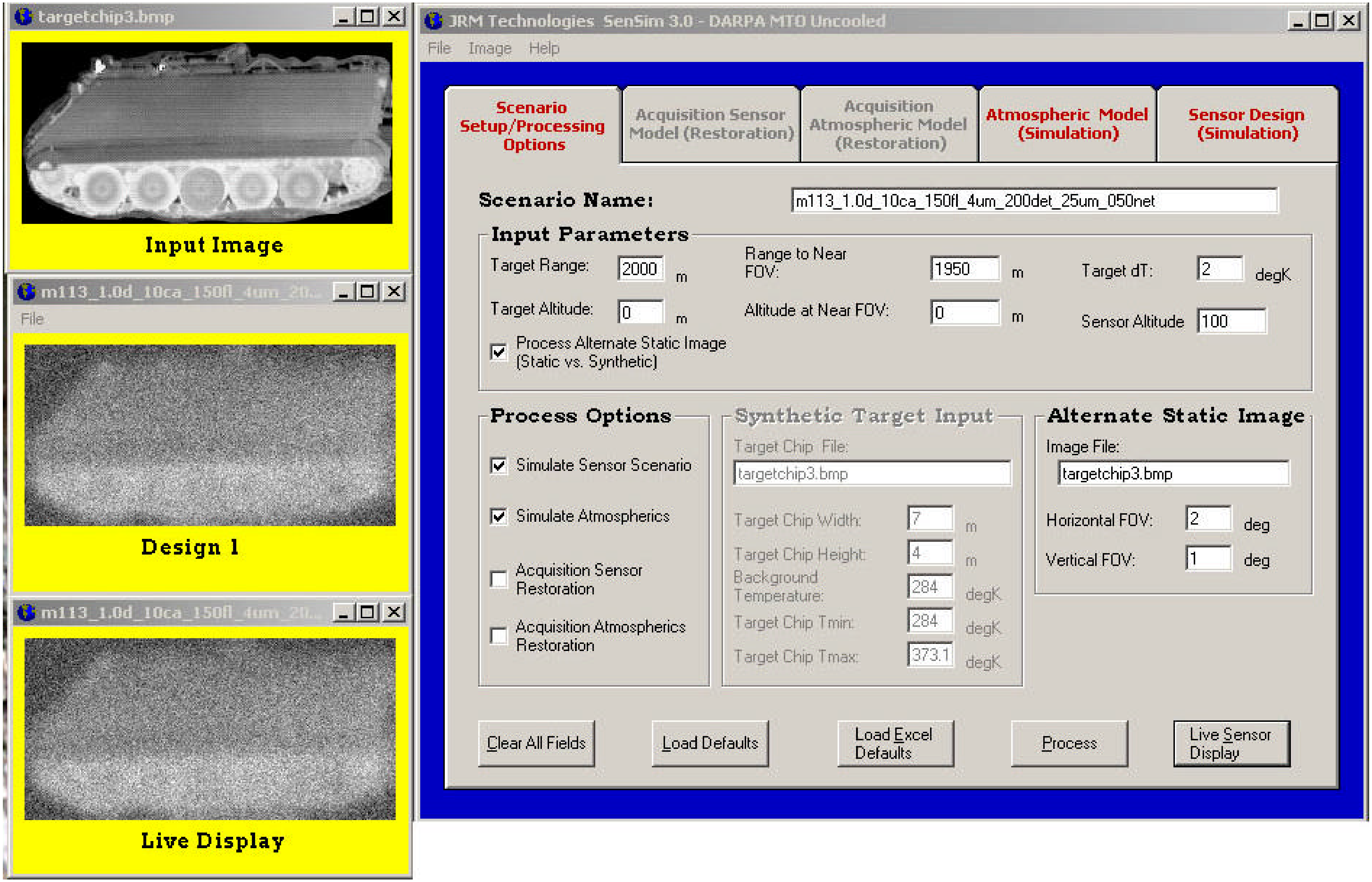
Emerging Technologies for Sensor Simulation

SenSim: Tactical Scenario Sensor Performance



Emerging Technologies for Sensor Simulation

SenSim: Static Image Sensor Design Analysis

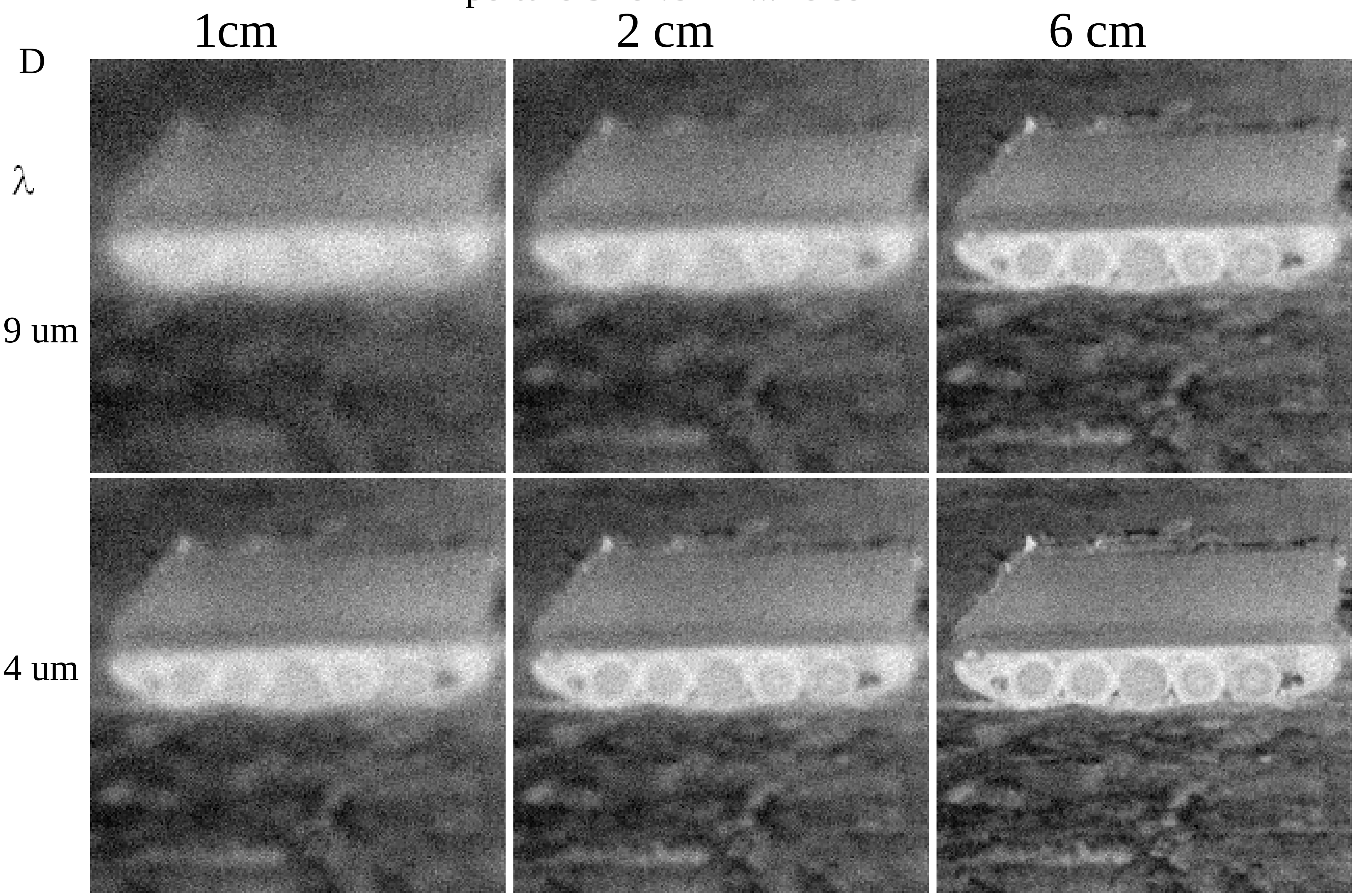


JRM

Emerging Technologies for Sensor Simulation

SenSim: Waveband Diffraction Analysis

Aperture Size vs λ w/noise



SenSim: Noise-Equivalent Temperature Visualization

4um 10 cm circular / Scene dT=1K

degK

0.01

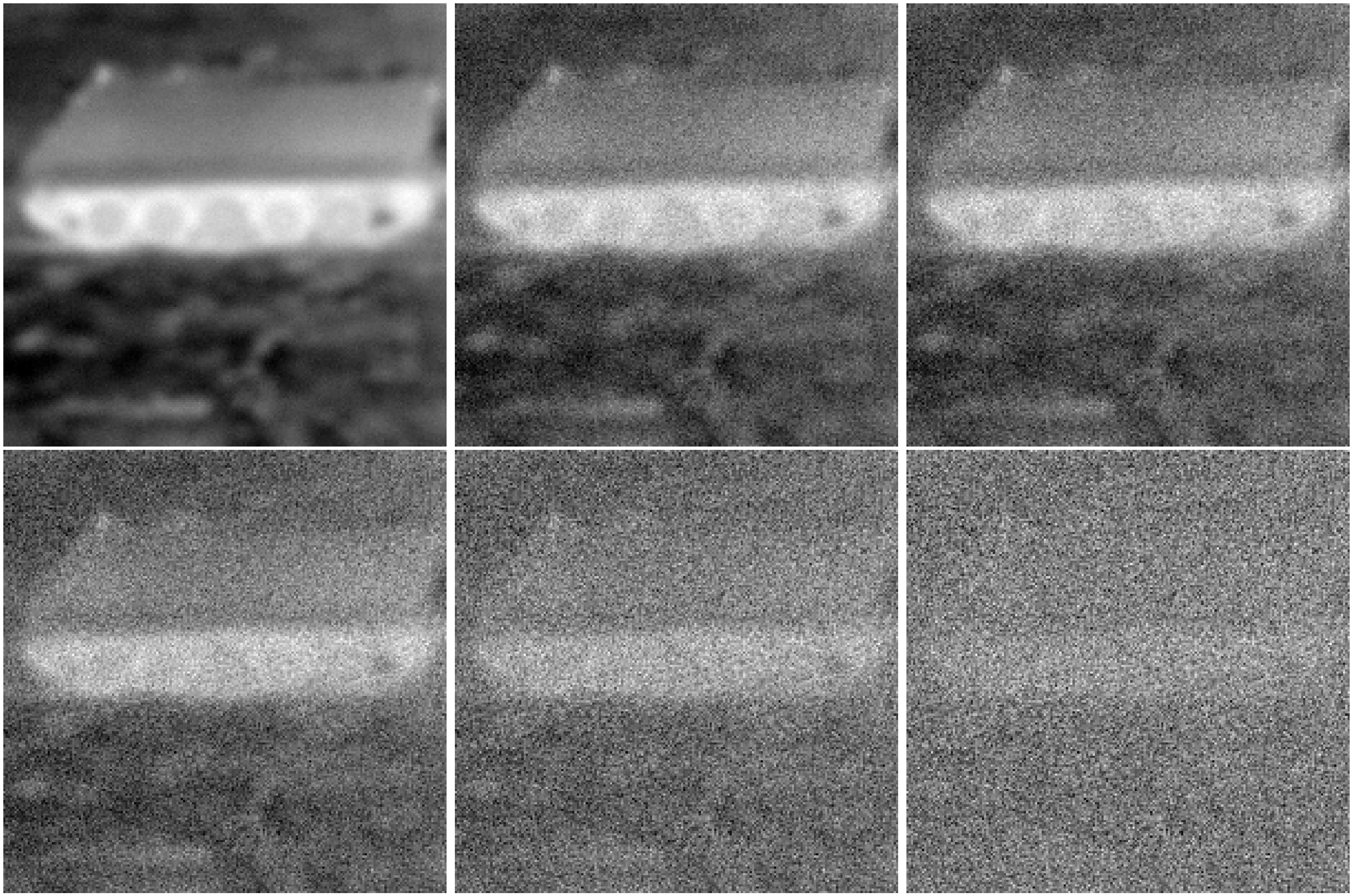
0.050

0.075

0.100

0.200

0.500



TAA: Target Acquisition Agent for Improved CGF Sensors

PROBLEM: Current SAF sensor modeling (ACQUIRE/Johnson Criteria) doesn't address dynamic target signatures, camouflage, scene clutter, and false alarms

SOLUTION: TAA – a SAF search and target acquisition library for CGFs to process SAME virtual sensor signals as Man-In-The-Loop

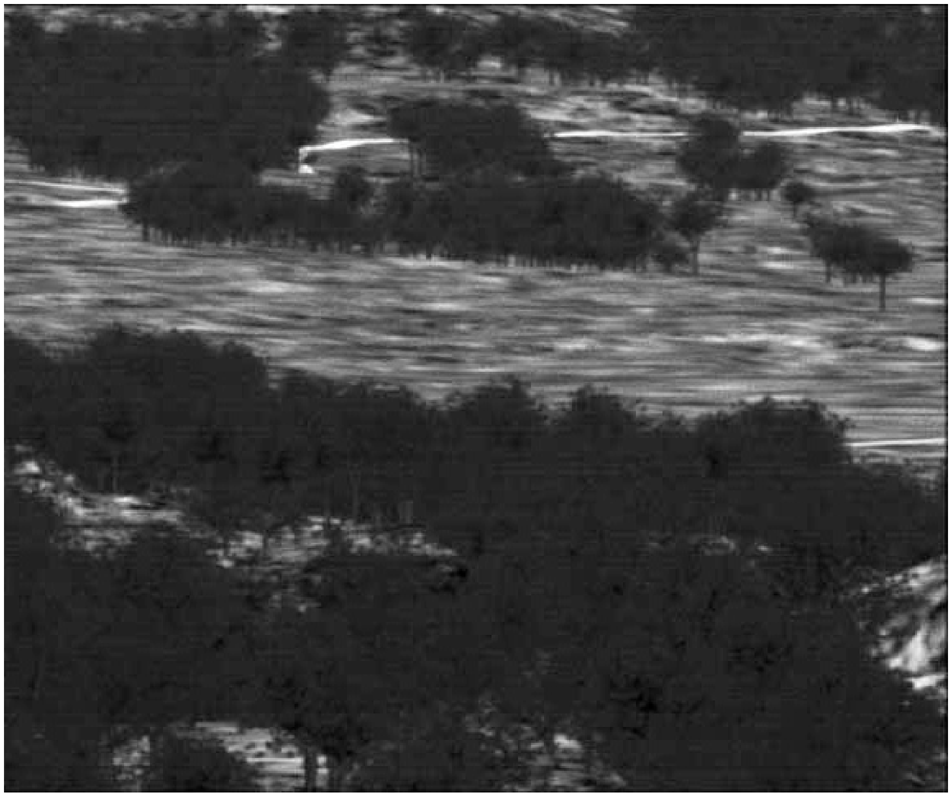
FEATURES:

- Image Analysis-Based Realistic Modeling of Human Search and Target Acquisition

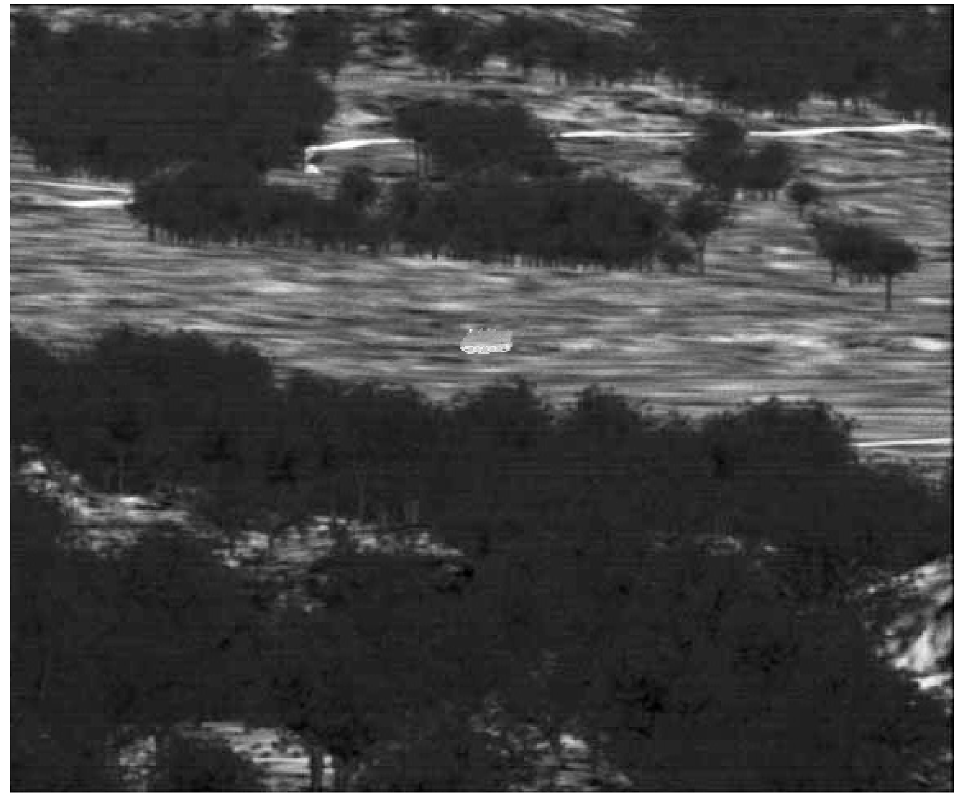
  Able to ingest synthetic or real battlefield sensor imagery
- Full Scene Clutter Modeling (Wilson Clutter Metric)
- False Alarm Detection and Rejection
- Probability of Detection and Time-to-Detect
- Run-time Scalable for High-Entity Count scenarios

TAA: Target Acquisition Agent for Improved CGF Sensors

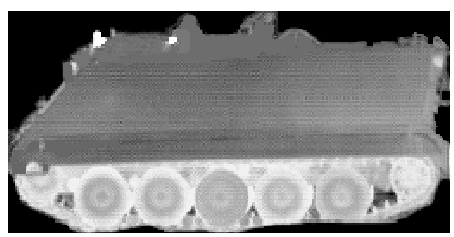
Virtual FLIR w/o Target



Virtual FLIR with Target



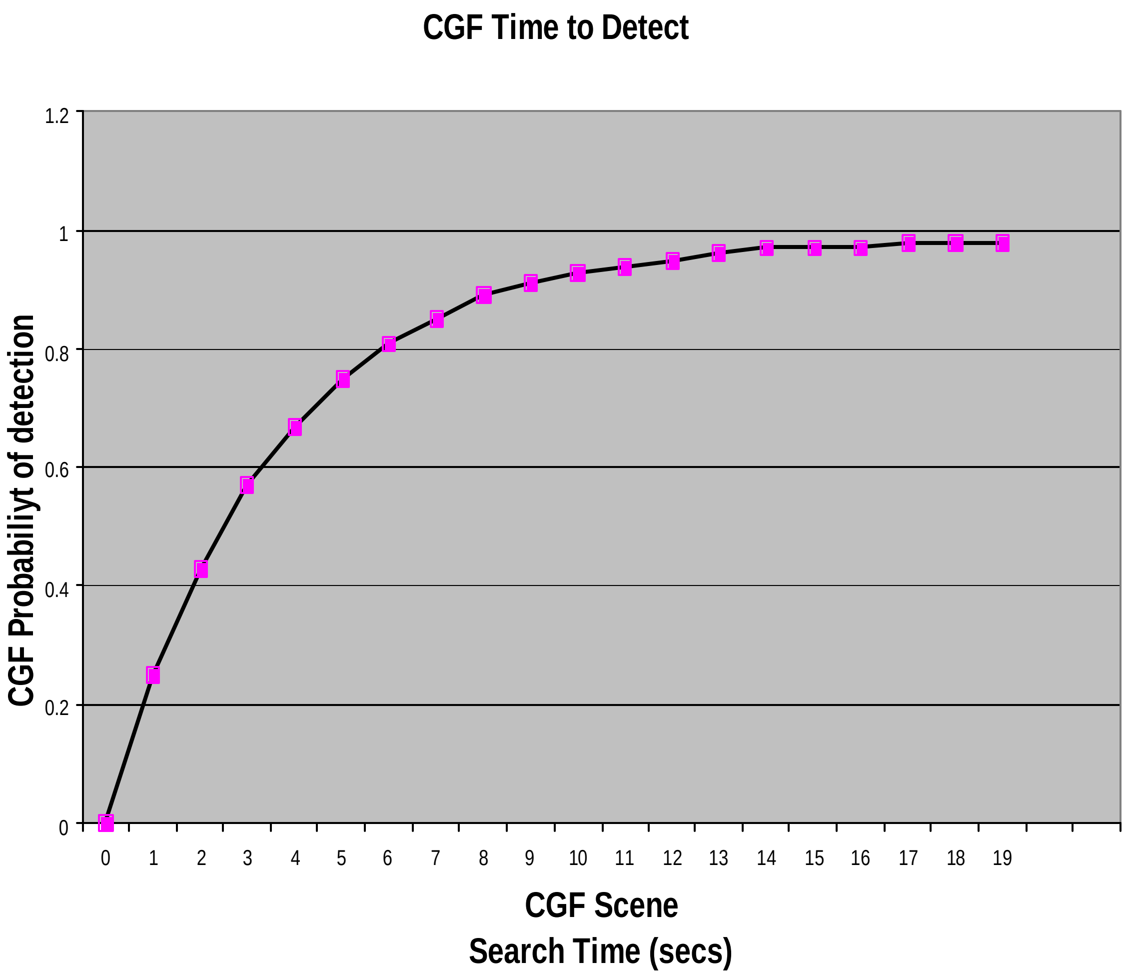
Target-only Pixels



TAA: Target Acquisition Agent

White Boxes: False Alarms

Red Box: Target Detection



CGF Sensor Perception via TAA

- Common JSB-MATREX FOM
  - *Common design accommodates both JSB-oriented sensor-target acquisition and MATREX-oriented network-centric warfare*
- Common Data Distribution Manager (DDM)
  - *Common design approach for accommodating very large entity count sensor-target and SIGINT-target LOS problems*
- Common Signature & Propagation Federates
  - *Common, correlated signature synthesis and atmospheric propagation approach in support of EO, IR, RF, COMM, & SIGINT domains on common environment DB and entity models*