MCSCENE LIMB-VIEWING HYPERSPECTRAL IMAGE SIMULATION BASED ON A POLYGONAL EARTH CROSS-SECTION (PEX) MODEL

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Summary

MCScene is a hyperspectral scene simulation model applicable to both the solar and thermal spectral regimes, from 0.2 to >500 µm. High fidelity line-of-sight (LOS) radiances for each sensor pixel and spectral channel are computed by Direct Simulation Monte-Carlo (DSMC) sampling of reverse path trajectories (from sensor), as illustrated in Slide **1**. Importance sampling accelerates convergence by preferentially selecting and weighting trajectories that contribute most significantly to radiance integrals. MCScene avoids explicit sampling of the individual spectral points within each sensor channel by spectrally convolving MODTRAN® optical and molecular transmittance data and computing path length transmittance derivatives to determine thermal radiances.

The 3D scenes can include cloud fields, embedded objects such as buildings and vehicles, and a topographical ground surface. Surface reflectance maps retrieved from FLAASH® atmospherically corrected radiance data are combined with digital elevation map (DEM) data to provide a highly accurate surface characterization.

MCScene was designed for simulating Earth viewing sensors and the atmosphere was confined to a cube with 50-km long sides (Slide **2** left). Here we illustrate a generalization of MCScene for limb (Slide **3**) and upward viewing sensor simulations. The spherical Earth is defined via a newly introduced Polygonal Earth Cross-Section (PEX) model with reflective side boundary conditions (Slide **2** right). This construct retains the efficiencies of a rectilinear world for Monte-Carlo sampling.

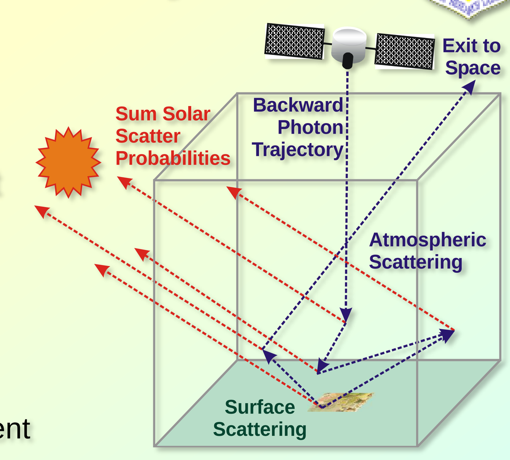
MCScene was validated against MODTRAN spectra with the 3D world defined using a uniform, flat, ground surface and 1D vertical atmospheric profiles. Validation results for limb views are shown in Slides **4-6**.

In Slide **3**, MCScene models twilight conditions, with the sun just below or just above the horizon. To our knowledge, MCScene is the only first-principles radiative transfer (RT) algorithm capable of modeling low light multiple scatter from the below-the-horizon sun.

Slide **7** defines a cloud field and surface used to validate the CameoSim model against MCScene. A panorama of MCScene RGB images are displayed as a function of relative solar azimuth angle.

MCScene radiative transfer

- Photon tracked along reverse paths from sensor
- Distance traveled to scattering event based on randomly selected optical depth, $\tau = -\ln(\beta)$, with $0 < \beta < 1$
  - Distance traveled truncated if facet or ground reflection occurs before τ
  - Solar and thermal radiance contributions summed at each scattering, reflection event
- Scattering optical depths are sampled to determine type of scatter
  - Rayleigh, aerosol, or cloud
- New direction determined by sampling
  - Atmospheric (particulate/molecular) scattering phase functions or,
  - Surface bidirectional reflection distribution function (BRDF)
- Biasing and trajectory weighting (importance sampling) selects the most pertinent directions preferentially



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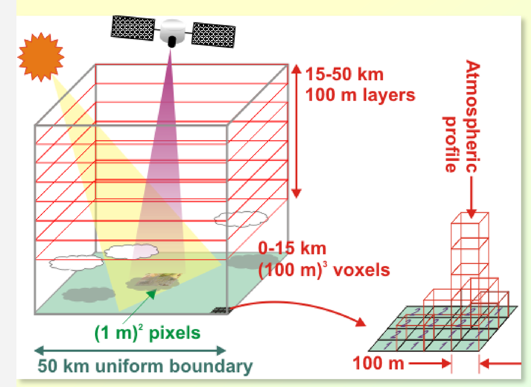
MCScene Versions

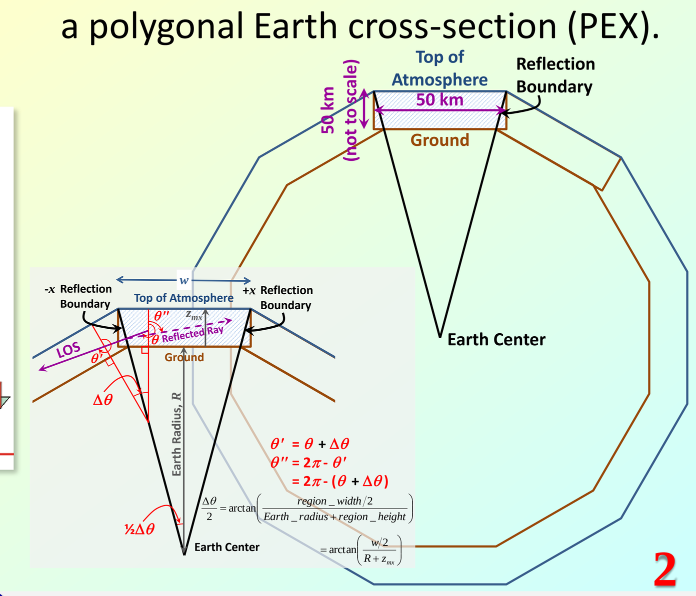
Flat Earth MCScene

Photons exit if side boundary is hit.



PEX MCScene

Photons reflect if side boundary is hit. Path / solar angles updated based on a polygonal Earth cross-section (PEX).



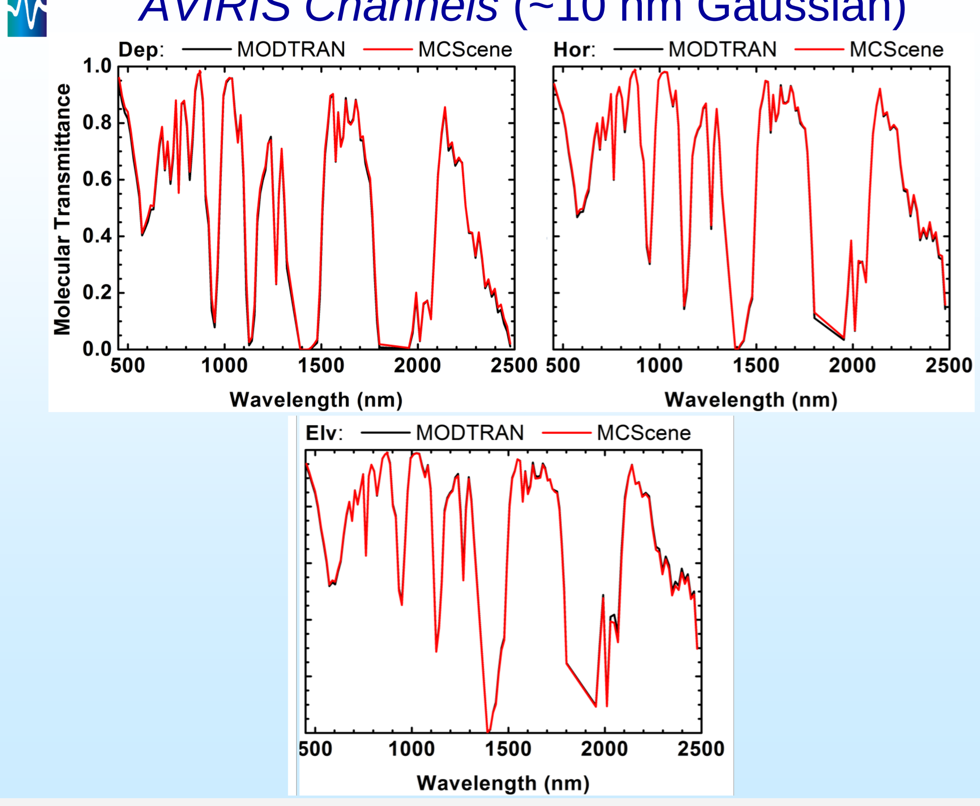
2

Low sun, limb view tests

3

Molecular Transmittance Validation

AVIRIS Channels (~10 nm Gaussian)



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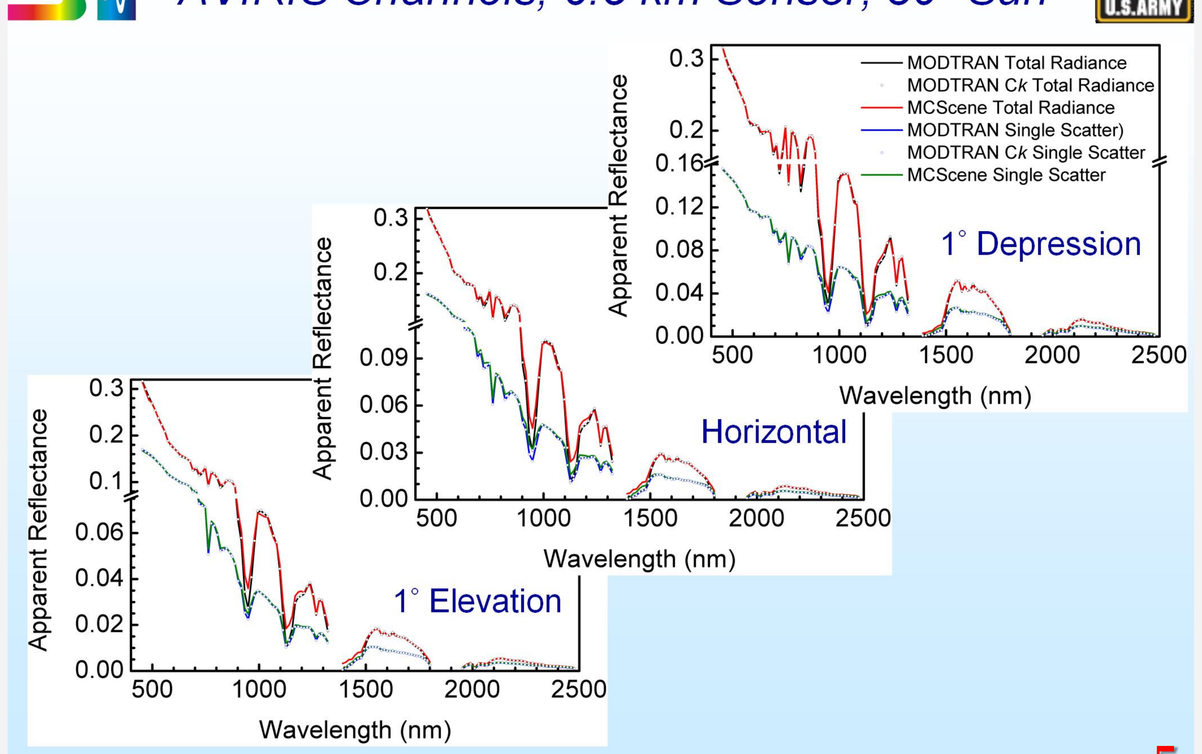
Solar Radiance Validation

AVIRIS Channels, 6.5 km Sensor, 30° Sun



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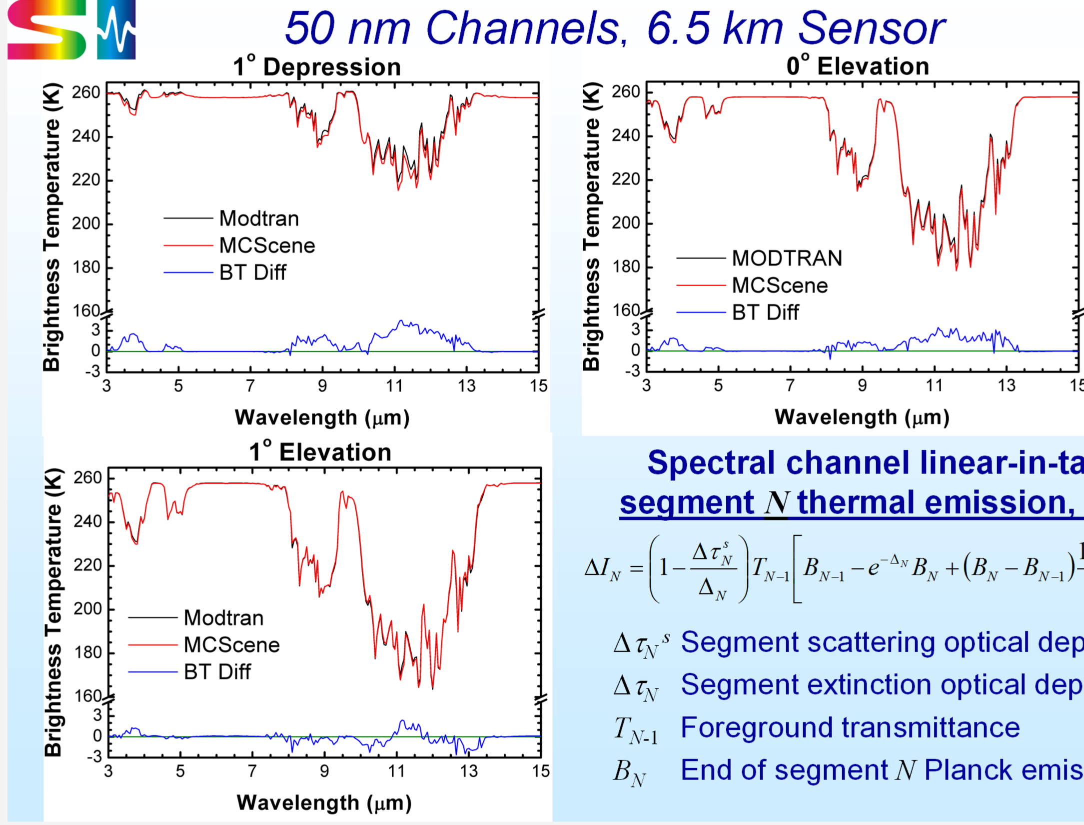
Thermal Emission Validation

50 nm Channels, 6.5 km Sensor



Spectral channel linear-in-tau segment N thermal emission, ΔI_N

$$\Delta I_N = \left(1 - \frac{\Delta\tau_N^s}{\Delta_N}\right) T_{N-1} \left[B_{N-1} - e^{-\Delta_N} B_N + \left(B_N - B_{N-1}\right) \frac{1 - e^{-\Delta_N}}{\Delta_N} \right]$$

$\Delta\tau_N{}^s$ Segment scattering optical depth

$\Delta\tau_N$ Segment extinction optical depth

T_{N-1} Foreground transmittance

B_N End of segment N Planck emission

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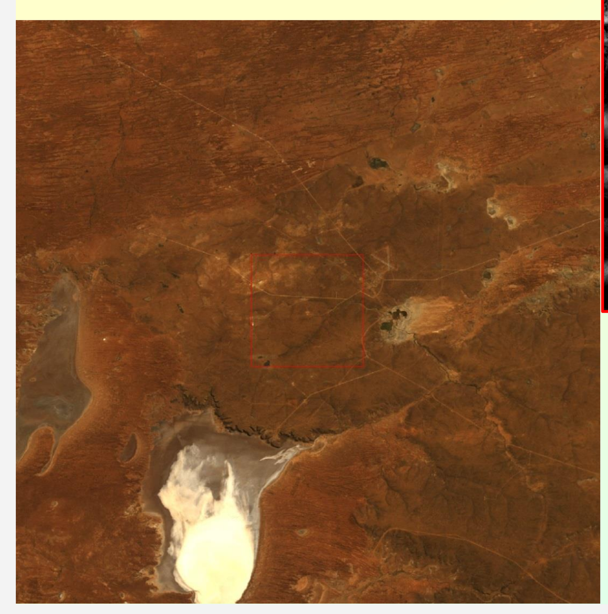
Panorama

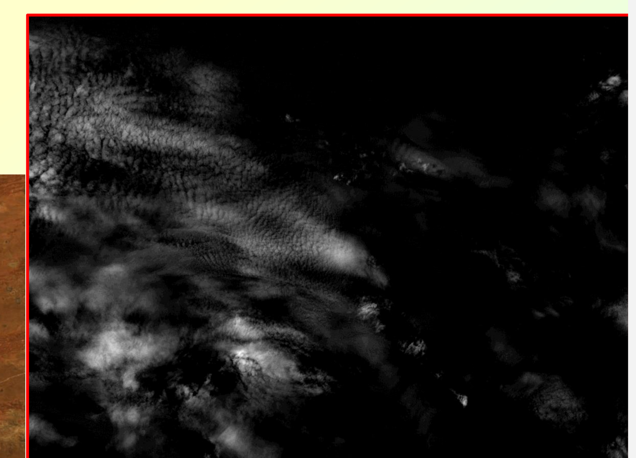
6.5 km Sensor, 30° Sun, 40 km Visibility, ±50° FOV

Each RGB image generated in 5½ hr using 11 cores of a dual Intel Core i7-3960X system (3.30 GHz)

Input Surface and Cloud Field

- South Australia, 50 x 50 km²
- Landsat NBAR (Nadir BRDF Adjusted Reflectance) product





- 8 km base altitude cirrus cloud field, 18 x 39 km²
- 3D cloud field extracted from Landsat imagery

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