Atmospheric Radiative Transfer Modeling
Common Sun-Target-Sensor Configuration

Sun

IFOV

Nadir
Radiative Transfer Models

• 5/6S
• MODTRAN
Radiative Transfer Models

- *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

Facts:

1. In the solar spectrum, satellite sensors measure the radiance reflected by the atmosphere-Earth surface system illuminated by the sun.

2. The signal is perturbed by the atmosphere. Only a fraction of the photons coming from the target reaches the satellite sensor, typically 80% at 850nm and 50% at 450nm, so that the target seems less reflecting.

3. The missing photons have been lost through two processes: absorption and scattering.
Radiative Transfer Models

- *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

Facts:

4. Absorption by aerosols or atmospheric gases, principally O$_2$, H$_2$O, O$_3$, and CO$_2$. However most satellite sensors avoid these absorption bands. Nevertheless, this needs to be taken into account in the modeling.

5. Scattering by molecules or aerosols changes the direction of radiation, which result in photons leaving the original path.
Radiative Transfer Models

- *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

**Modeling**

**Step 1:** Sun-surface path-scattered component
a. sun-surface path scattering to the sensor
b. sun-surface path attenuation and paths illumination counter-balance

**Step 2:** surface-sensor path
photons scattered by surface and end up being in the path to sensor

**Step 3:** surface-backscattered toward the target
Radiative Transfer Models

- *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

**Modeling**

1. Absorbing effects:
   - Oxygen (O$_2$)
   - Ozone (O$_3$)
   - Water vapor (H$_2$O)
   - Carbon dioxide (CO$_2$)

2. Three lumped together

   Water vapor (H$_2$O)
   - Oxygen (O$_2$)
   - Ozone (O$_3$)
   - Carbon dioxide (CO$_2$) \[\rightarrow\] one model

Fall 2015
Radiative Transfer Models

• Simulation of the Satellite Signal in the Solar Spectrum (5S)

Modeling

Absorption equations for H_2O and other three gases:

\[ \tau_{\Delta \nu}^G = e^\left[ -\frac{N_o km}{\Delta \nu} \left( 1 + \frac{km}{\pi \alpha_o} \right)^{-1/2} \right] \]

\[ \tau_{\Delta \nu}^M = e^\left[ -\frac{2\pi \alpha_o N_o}{\Delta \nu} \left( \left( 1 + \frac{km}{\pi \alpha_o} \right)^{1/2} - 1 \right) \right] \]
Radiative Transfer Models

• *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

**Modeling**

Absorption equations for H2O and other three gases:

where $m$ is the absorber amount, $N_o$ the total line number in the frequency interval $\Delta \nu$, $k$ the average intensity and $\alpha_o$ the average Lorentz half width, obtained from intensity $S_j$ and half width $\alpha_j$ of the $j^{th}$ spectral line by:

$$k = \frac{\sum_{j=1}^{N_o} S_j}{N_o},$$

$$\frac{k}{\pi \alpha} = \frac{1}{4} \left[ \frac{\sum_{j=1}^{N_o} S_j}{\sum_{j=1}^{N_o} (S_j \alpha_j)^{1/2}} \right]^2.$$
Radiative Transfer Models

• *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

**Modeling**

Scattering effects: Take three processes into account.

- Direct solar flux attenuated by atmosphere
  \[ e^{-\tau / u_s} \]
  \[ \mu_s = \cos (\theta_s) \text{ and } \tau \text{ is atmosphere thickness} \]

- Scattered flux on the first sun-surface path:
  \[ \tau_d (\theta_s) = \frac{[e_{sol}^{\text{diff}} (\theta_s)]}{\mu_s E_s} \]

- Second scattered flux due to the trapping mechanism:
  \[ e^{-\tau / \mu_s} + \tau_d (\theta_s) [\rho S + \rho^2 S^2 + ...] \]
Radiative Transfer Models

• *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

**Modeling**

Total normalized transmittance at the surface level is

\[
T(\theta_s) = e^{-\tau/\mu_s} + \tau_d(\theta_s)
\]

\[
T(\theta_s) / [1 - \rho S]
\]
Radiative Transfer Models

- *Simulation of the Satellite Signal in the Solar Spectrum (5S)*

- At satellite level, the radiance results from:
  - Contribution of the total (direct and diffuse) solar radiation reflected by the surface and directly transmitted from the surface to the sensor expressed by $e^{-\tau/\mu_s}$ with $u_v = \cos(\theta_v)$
  - Intrinsic atmospheric radiance expressed in terms of reflectances by a function of $\rho_a(\theta_s, \theta_v, \phi_v)$
  - The contribution of the environment which reflects the total flux, the photons reaching the sensor by scattering, we note this new atmospheric diffuse transmittance $\tau_d(\theta_v)$
Radiative Transfer Models

• *Simulation of the Satellite Signal in the Solar Spectrum (5S)*
  
  – At satellite level, the apparent reflectance at the satellite:

\[
\rho^*(\theta_s, \theta_v, \phi_v) = \rho_a(\theta_s, \theta_v, \phi_v) + \frac{T(\theta_s)}{1 - \rho S} \left( \rho e^{-\tau/\mu_v} + \rho \tau'_d(\theta_v) \right)
\]

  – In fact, the function should be reciprocal, and therefore it can be rewritten as:

\[
\rho^*(\theta_s, \theta_v, \phi_v) = \rho_a(\theta_s, \theta_v, \phi_v) + \frac{\rho}{1 - \rho S} T(\theta_s)T(\theta_v)
\]

\[
T(\theta_v) = e^{-\tau/\mu_v} + \tau_d(\theta_v)
\]
Radiative Transfer Models

• *Simulation of the Satellite Signal in the Solar Spectrum (5S)*
  
  – When taking into account the non-homogeneous surrounding surfaces, the equation becomes:

\[
\rho^*(\theta_s, \theta_v, \phi_v) = \rho_a(\theta_s, \theta_v, \phi_v) + \frac{T(\theta_s)}{1 - \rho_e S} \left( \rho_c(M) e^{-\tau/\mu_v} + \rho_e \tau_d(\theta_v) \right)
\]
5S Flowchart

Geometric Conditions

Atmospheric Conditions

Aerosol Model

Aerosol Concentration

Spectral Bands

Ground Reflectance

Computation of the Atmospheric Functions at Discrete Wavelength Values

Integration over the Spectral Bands

Computation of the gaseous Absorption Functions

Solar Spectral Irradiance

Interpolation of the Scattering Atmospheric Functions

Environmental Reflectance

Computation of the Apparent Reflectance
5S Radiative Transfer Model Demonstration

Required inputs:
- Site Elevation
- Sun-Earth-Sensor geometry
- Model selection
- Either surface reflectance or TOA reflectance.
- If a patchy target chosen, reflectance properties of surrounding targets need to be provided
Geometric Conditions

0 - Enter solar zenith angle (degrees)
   Solar azimuth angle
   Satellite zenith angle
   Satellite azimuth angle

1 - Meteosat Observation
   Mon. Day, Decimal hour (UT), N. of C. & N.of L.

2 - GOES East Observation
   Mon. Day, Decimal hour (UT), N. of C. & N.of L.

3 - GOES West Observation
   Mon. Day, Decimal hour (UT), N. of C. & N.of L.

4 - AVHRR (NOAA8)
   Mon. Day, Decimal hour (UT), N. of C.XLONAN (Long), HNA (Overpass time)

5 - AVHRR (NOAA9)
   Mon. Day, Decimal hour (UT), N. of C.XLONAN (Long), HNA (Overpass time)

6 - HRV (SPOT)

7 - TM (Landsat)
Atmospheric Model

0 - No Gaseous Absorption
1 - Tropical
2 - Midlatitude Summer
3 - Midlatitude Winter
4 - Subarctic Summer
5 - Subarctic Winter
6 - US Standard 62
7 - User Profile (Radiosonde data on 34 levels)
   – Altitude (km)
   – Pressure (MB)
   – Temperature (K)
   – H2O Density (G/m^3)
   – O3 Density (g/ m^3)
8 - User Profile
   – UW (g/m^2)
   – UO3 (cm-ATM)
Aerosol Model

0. - No Aerosols

1. - Continental Model

2. - Maritime Model

3. - Urban Model

4. - User Defined
   – Volumetric % of dust-like
   – Volumetric % of water-soluble
   – Volumetric % of oceanic
   – Volumetric % of soot
   – (between 0 and 1)

• Aerosol Concentration
  – Visibility (at 550nm)
  – Optical Depth (550nm)
Use of RTM models to correct atmospheric effect

1. Obtain the visibility parameter of atmosphere
2. Run 5/6S or Modtran model at various surface reflectance values
3. Establish a regression line for each spectral band
4. Use the regression coefficient in an image processing software environment to make correct for atmospheric effect