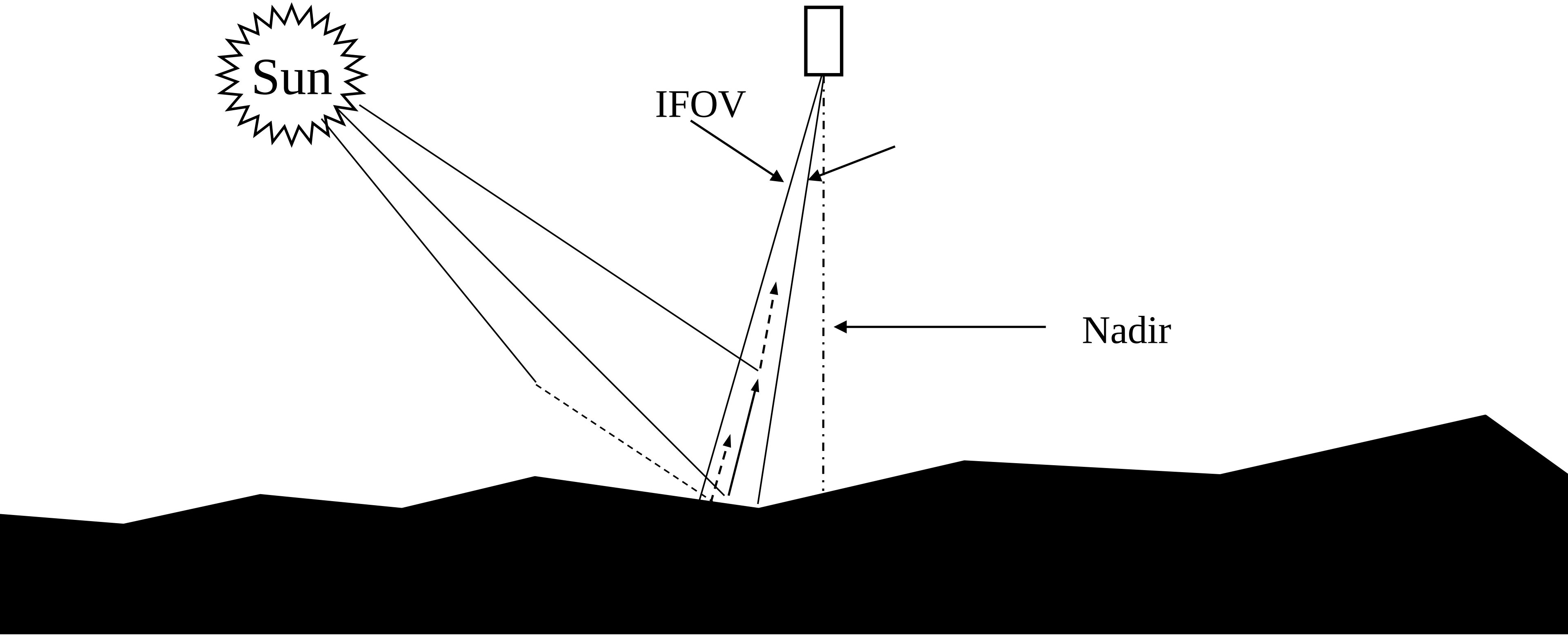
Atmospheric Radiative Transfer Modeling

9/22/2015

Common Sun-Target-Sensor Configuration

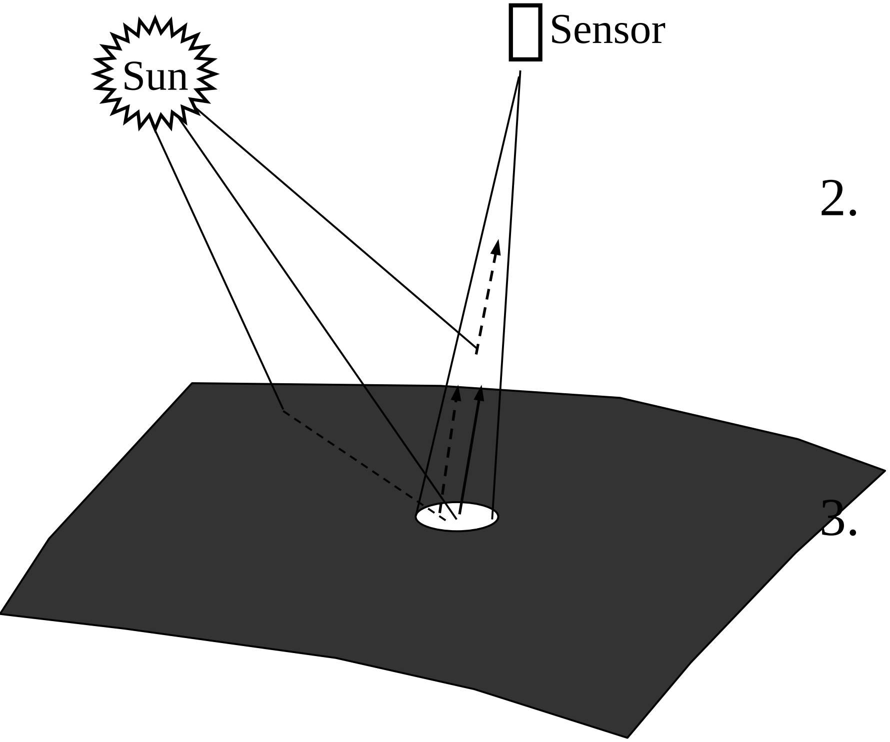


Radiative Transfer Models

- 5/6S
- MODTRAN

Radiative Transfer Models

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

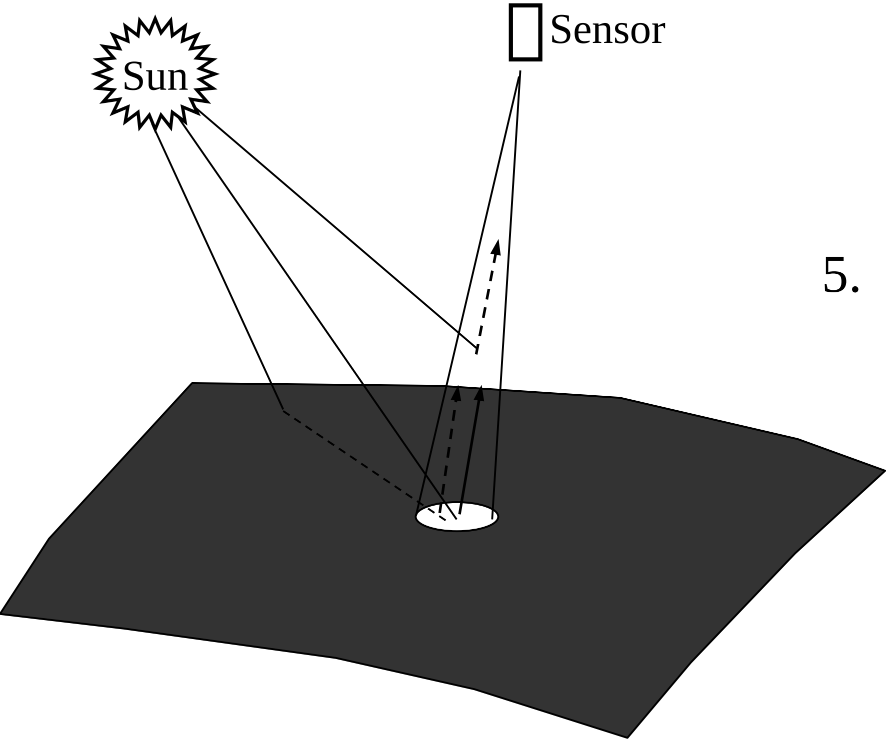


Facts:

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)***

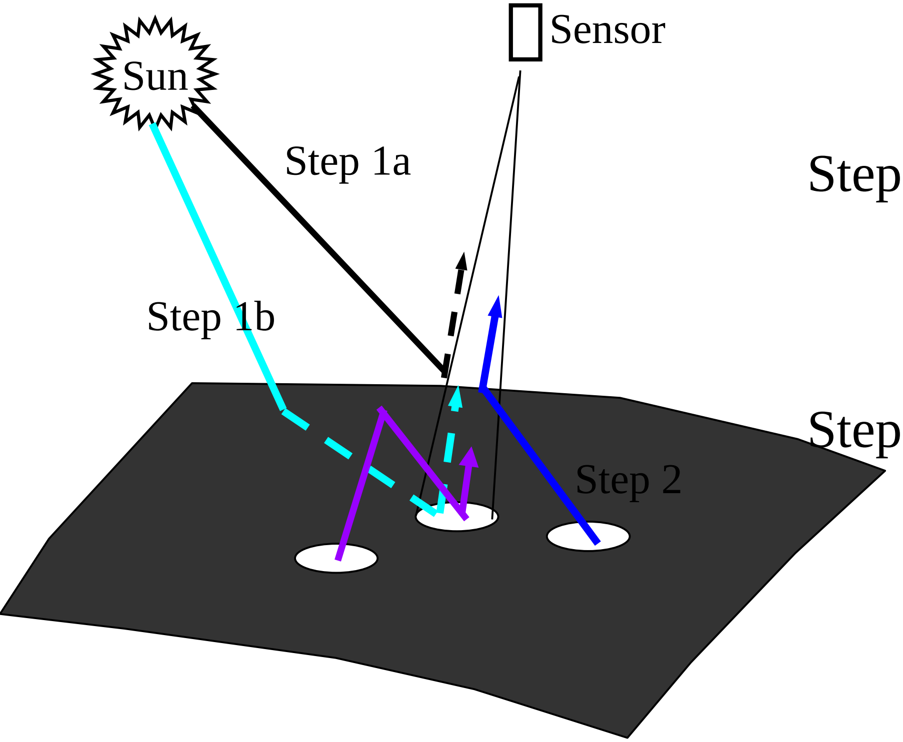


Facts:

4. Absorption by aerosols or atmospheric gases, principally O_2, H_2O, 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

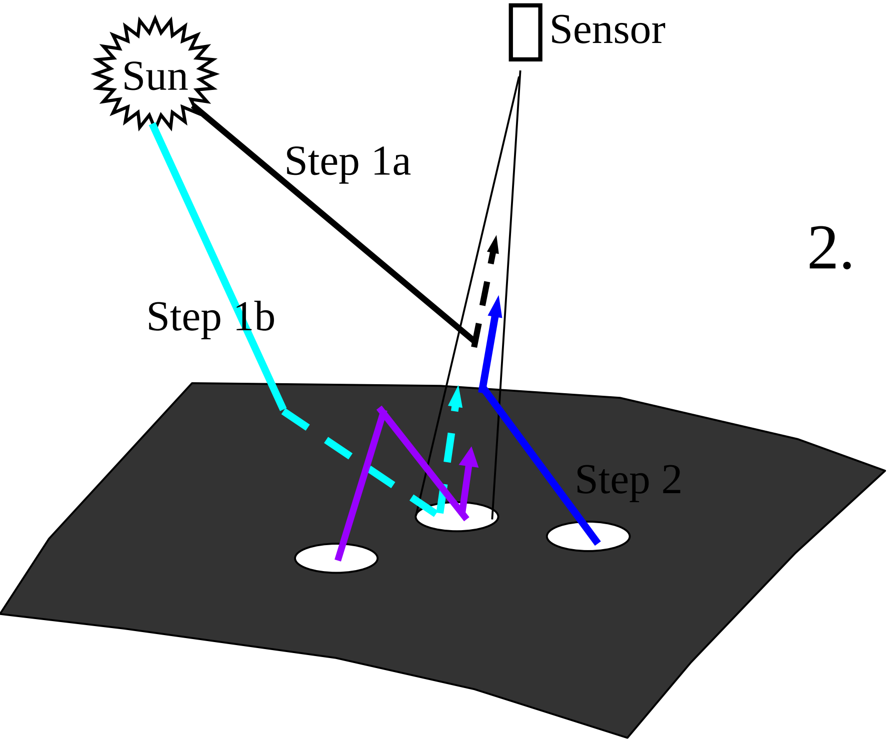
Step 2: surface-sensor path

  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_2O)
   Carbon dioxide (CO_2)
2. Three lumped together

Water vapor (H_2O)

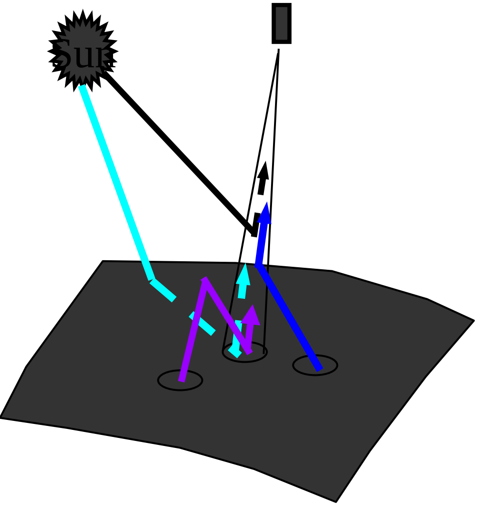
Oxygen (O_2)
Ozone (O_3)
Carbon dioxide (CO_2)
} →one model

Radiative Transfer Models

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

Modeling

Absorption equations for H_2O and other three gases:



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

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

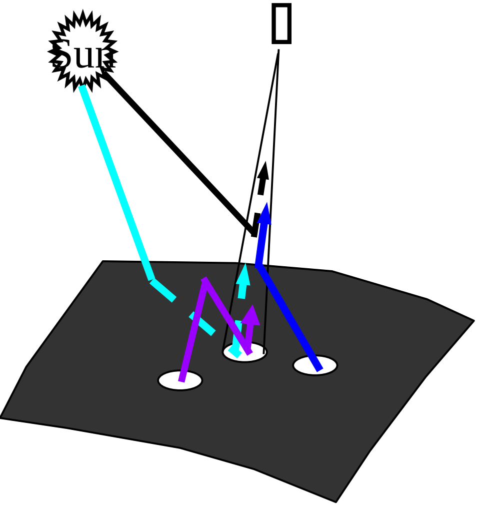
Radiative Transfer Models

- ***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 α_o the average Lorentz half width, obtained from intensity S_j and half width α_j of the j^{th} spectral line by:



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

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

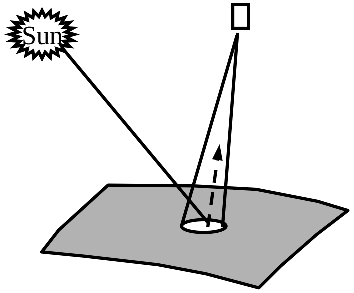
Radiative Transfer Models

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

Modeling

Scattering effects:Take three processes into account.

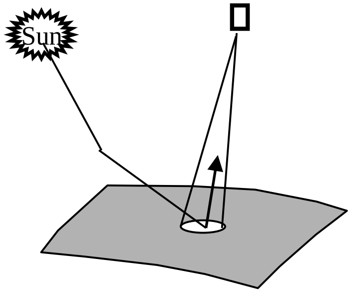
- Direct solar flux attenuated by atmosphere



$$e^{-\tau/u_s}$$

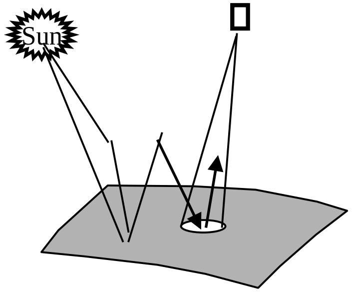
$\mu_s = \cos(\theta s)$ and is atmosphere thickness

- Scattered flux on the first sun-surface path:



$$\tau_d(\theta_s) = \left[e_{sol}^{diff}(\theta_s)\right] / \mu_s E_s$$

- Second scattered flux due to the trapping mechanism:



$$e^{-\tau/\mu_s} + \tau_d(\theta_s)\left[\rho S + \rho^2 S^2 + \ldots\right]$$

Radiative Transfer Models

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

Modeling

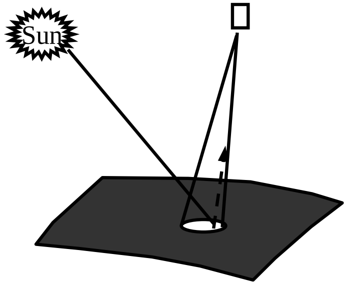
Total normalized transmittance at the surface level is

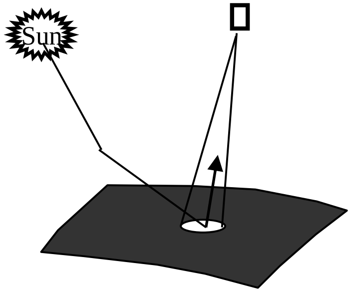
$$T(\theta_s)/[1-\rho S]$$

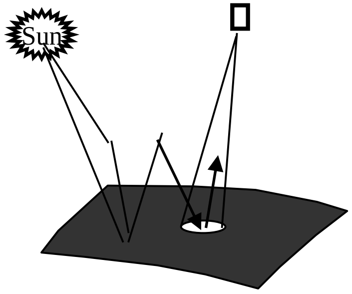
$$T(\theta_s)=e^{-\tau/\mu_s}+\tau_d(\theta_s)$$

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:

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

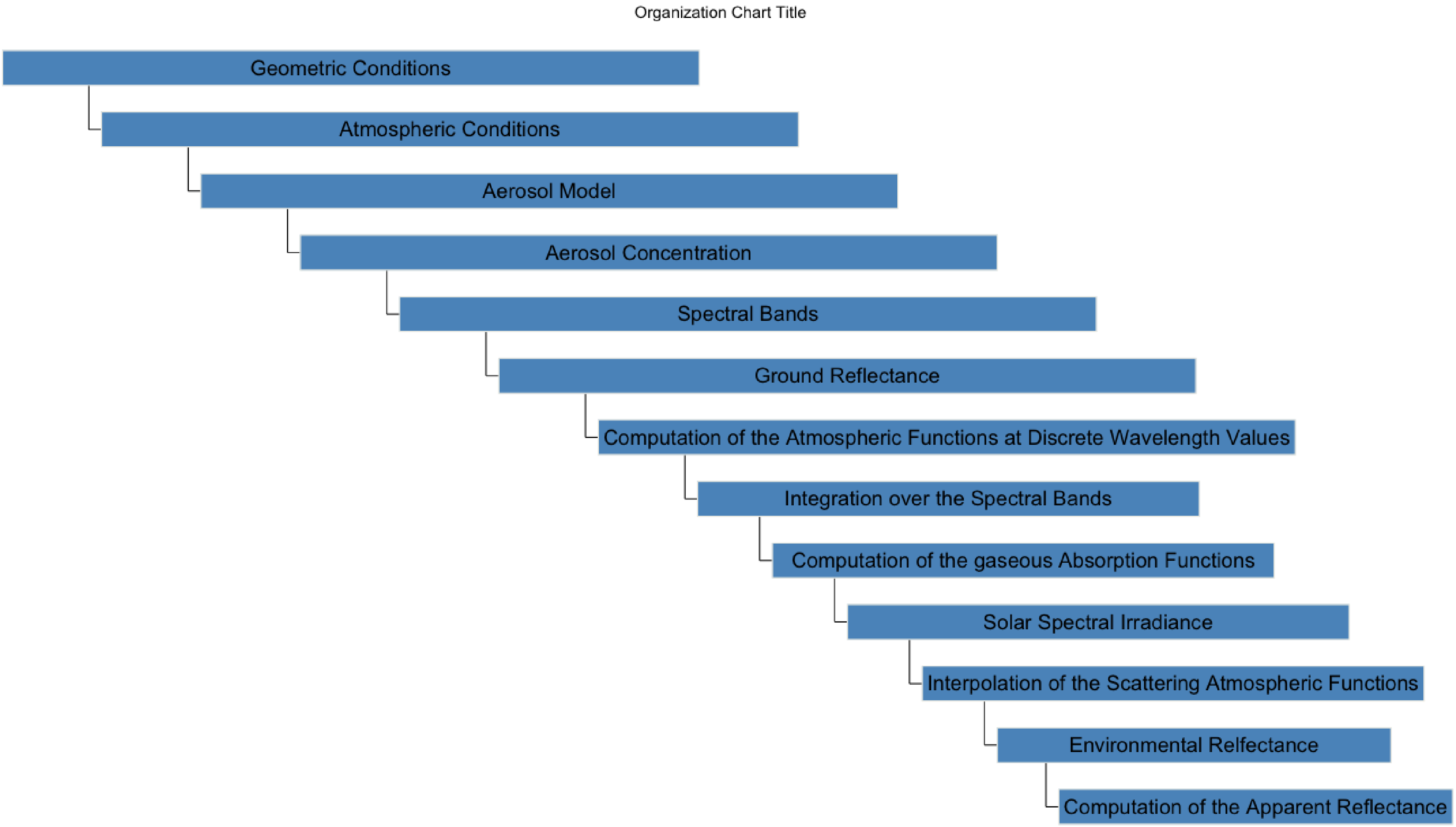
$$T(\theta_v)=e^{-\tau/\mu_v}+\tau_d(\theta_v)$$

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



Organization Chart Title

- 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 Relfectance
                        - Computation of the Apparent Reflectance

Model Demonstration

- 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)

Mon. Day, HH.DD, Long. Lat.

7 - TM (Landsat)

Mon. Day, HH.DD, Long. Lat.

Atmospheric Model

0 - No Gaseous Absorption
1 - Tropical
2 - Midlatitude Summer
3 - Midlatitude Winter
4 - Subarctic Summer
5 - Subartic Winter
6 - US Standard 62
7 User Profile (Radiosonde data on 34 levels)
  - Altitude (km)
  - Pressure (MB)
  - Temperature (K)
  - H_20 Density (G/m^3)
  - O_3 Density (g/ m^3)
8 - User Profile
  - UW (g/m^2)
  - UO_3 (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