1. Radiometric Correction

1.2. Atmospheric Correction

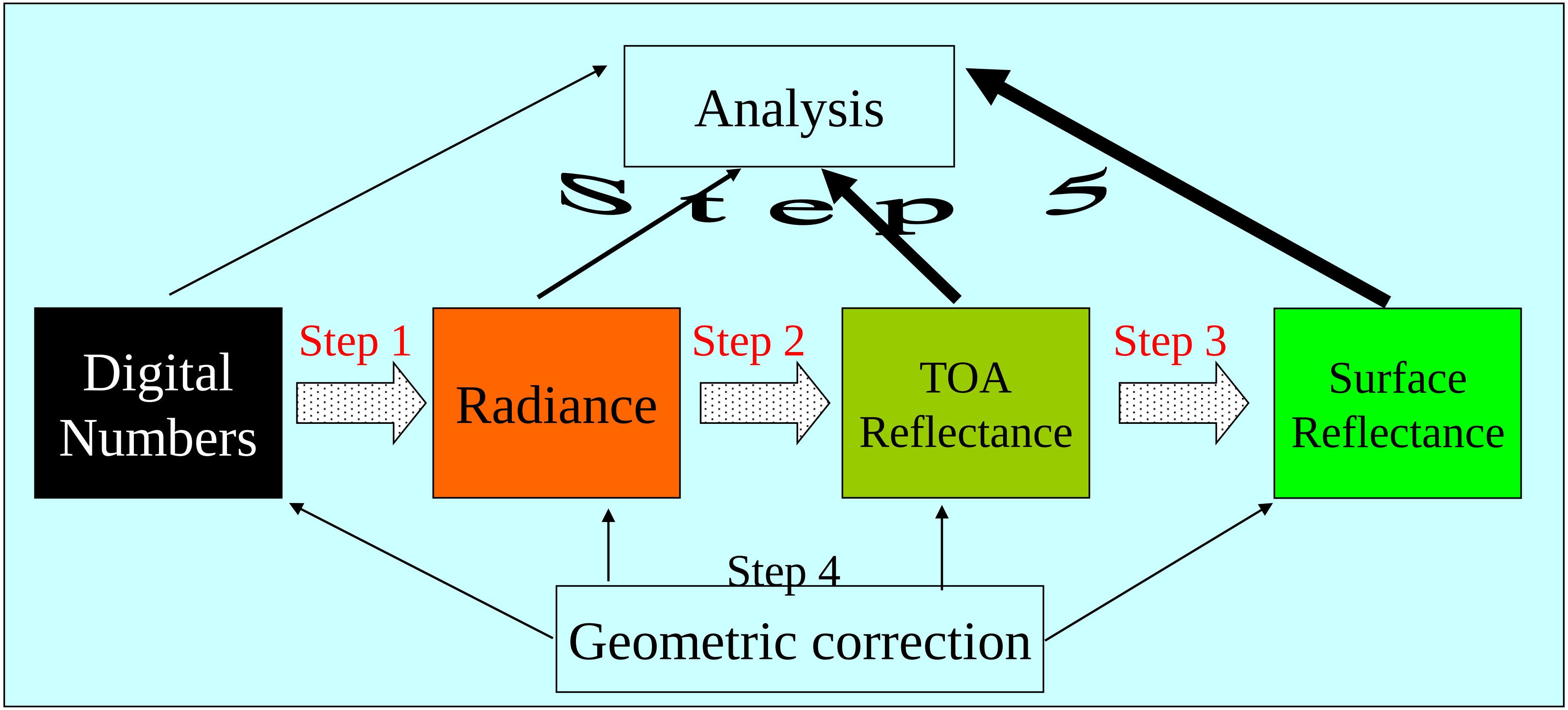
1.2.1 Atmospheric properties

Reading Assignment

Chapter 2 and part of Chapter 7 of Schowengerdt (1997)

DIPA Flowchart

0. **Overview of Remote Sensing**
1. **Radiometric correction (Step 1,2,3)**
   - **System radiometric correction**
   - **Atmospheric correction**
   - **Bidirectional correction**
2. **Geometric registration (Step 4)**
3. **Analysis (Step 5 or information extraction)**



Analysis

Step 5

Digital Numbers

Step 1

Radiance

Step 2

TOA Reflectance

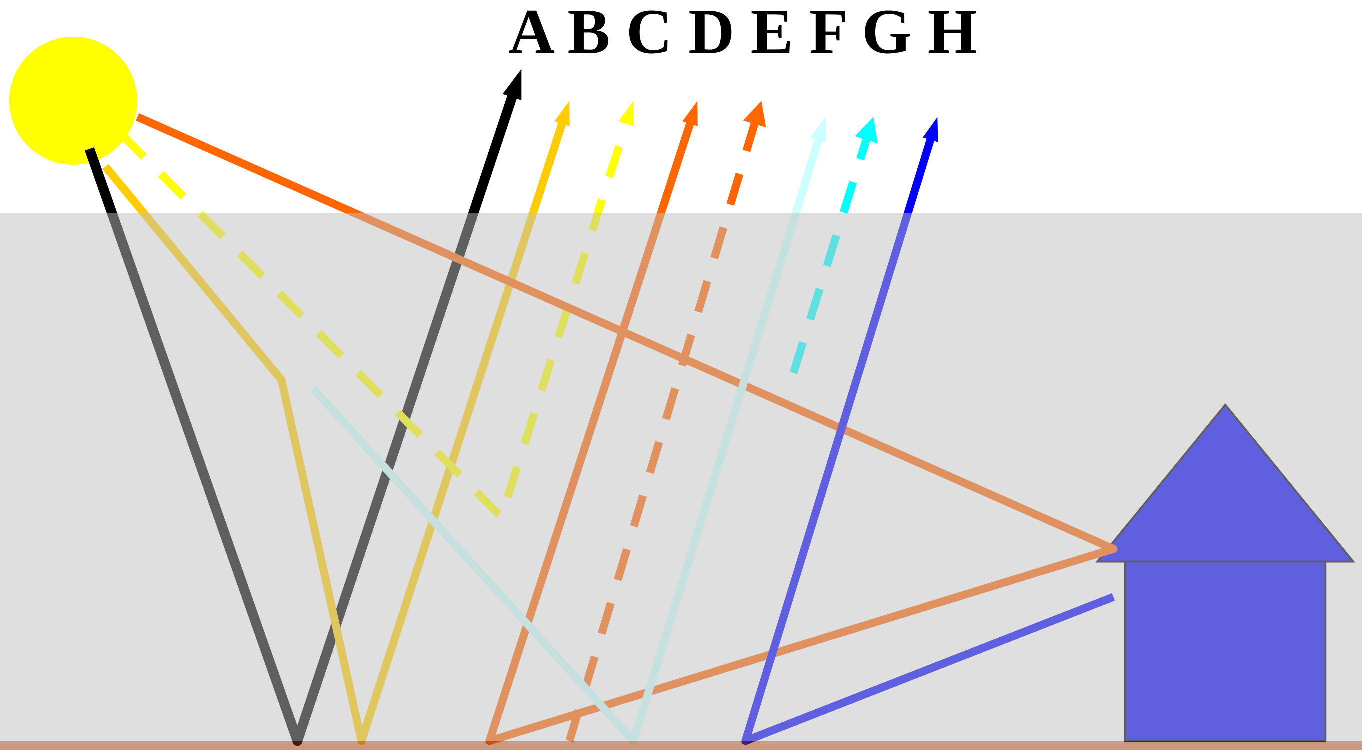
Step 3

Surface Reflectance

Step 4

Geometric correction

Ways of light interacting with atmosphere



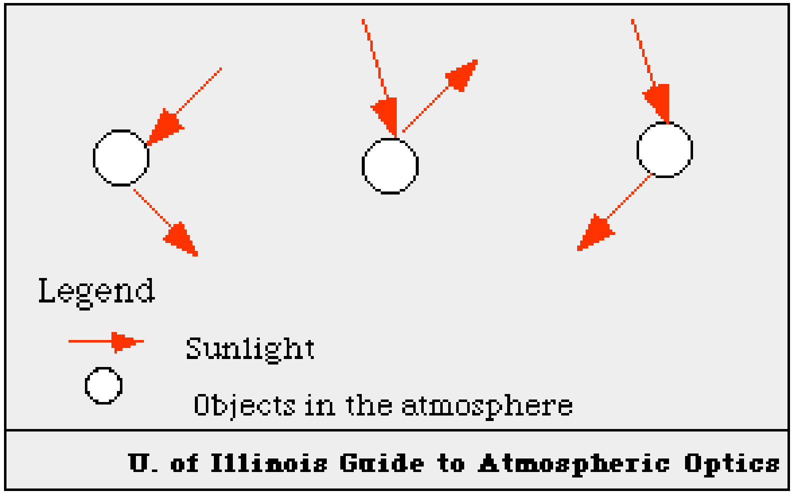
Question: What are these components and what environmental factors would affect their contributions to sensed radiance?

Atmospheric Constituents

- Atmospheric gases
  - Nitrogen, N_2 (78%), oxygen, O_2(21%), small amount of water vapor, H_2O, carbon dioxide CO_2 and ozone O_3
- Atmospheric Aerosols
  - Refers to liquid and solid matter suspended in air. Liquid particles of size larger than 1 μm are usually called "cloud drops". Their effects on remotely sensed images depend on
    - Size distribution
    - Refractive index
    - Shape of the particles
    - Spatial distributions

Atmospheric Scattering

- Scattering is the process by which "small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions." With scattering, there is no energy transformation, but a change in the spatial distribution of the energy. Scattering, along with absorption, causes attenuation problems with radar and other measuring devices.



Atmospheric Scattering

- Three types of scattering:
  - 1. Rayleigh scattering -Rayleigh scattering mainly consists of scattering from atmospheric gases. This occurs when the particles causing the scattering are smaller in size than the wavelengths of radiation in contact with them. This type of scattering is therefore wavelength dependent. As the wavelength decreases, the amount of scattering increases.

Atmospheric Scattering

- 2. Mie Scattering - Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of the atmosphere. It occurs when the particles causing the scattering are larger than the wavelengths of radiation in contact with them.

Atmospheric Scattering

- 3. Non-Selective Scattering -It occurs in the lower portion of the atmosphere when the particles are much larger than the incident radiation. This type of scattering is not wavelength dependent and is the primary cause of haze.

Atmospheric Absorption

- Absorption is the process by which "incident radiant energy is retained by a substance." In this case, the substance is the atmosphere.When the atmosphere absorbs energy, the result is an irreversible transformation of radiation into another form of energy. This energy is transformed according to the nature of the medium doing the absorbing.
- Absorption is mainly caused by three different atmospheric gases. Contrary to popular belief, water vapor causes the most absorption, followed by carbon dioxide and then ozone.

Atmospheric Absorption

- Ozone - absorbs UV
- Carbon Dioxide - Lower atmosphere absorbs energy in the 13 - 17.5 micrometer region.
- Water Vapor -Lower atmosphere. Mostly important in humid areas, very effective at absorbing in portions of the spectrum between 5.5 and 7 micrometer and above 27 micrometer.

Atmospheric Transmission

- Transmission is the process by which, "radiation is propagated through a medium. Measured as transmittance (*Tr*), it is the ratio of the transmitted radiation to the total radiation incident upon the medium."

Atmospheric Transmission

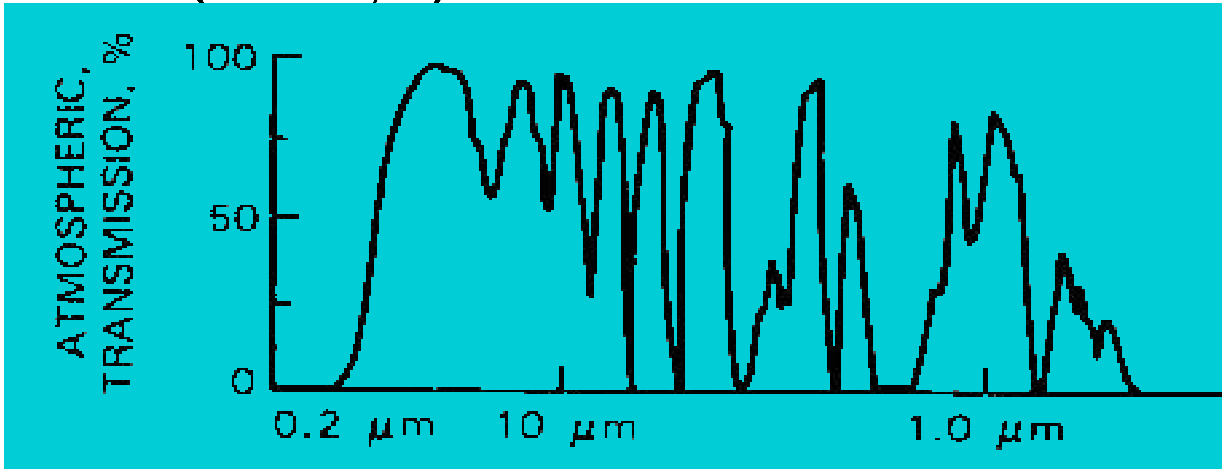
- Absorbing molecules in the atmosphere strongly modify the incoming solar irradiance.
- By far, water vapor is the strongest modifier of the incoming solar spectrum.
- All absorption features increase in intensity as the atmospheric path length of the incoming solar radiation increases (i.e. with changing solar elevation angle).

Atmospheric Transmission

- Optical Thickness, τ, is defined as
  - $\tau_r = - \ln Tr$
  - Rayleigh optical thickness decreases as a function of the wavelength (λ) roughly as λ^{-4} and can be approximated with
  - $\tau_r = 0.008569\lambda^{-4}(1 + 0.0113\,\lambda^{-2} + 0.00013\,\lambda^{-4})$
  - where λ is in μm

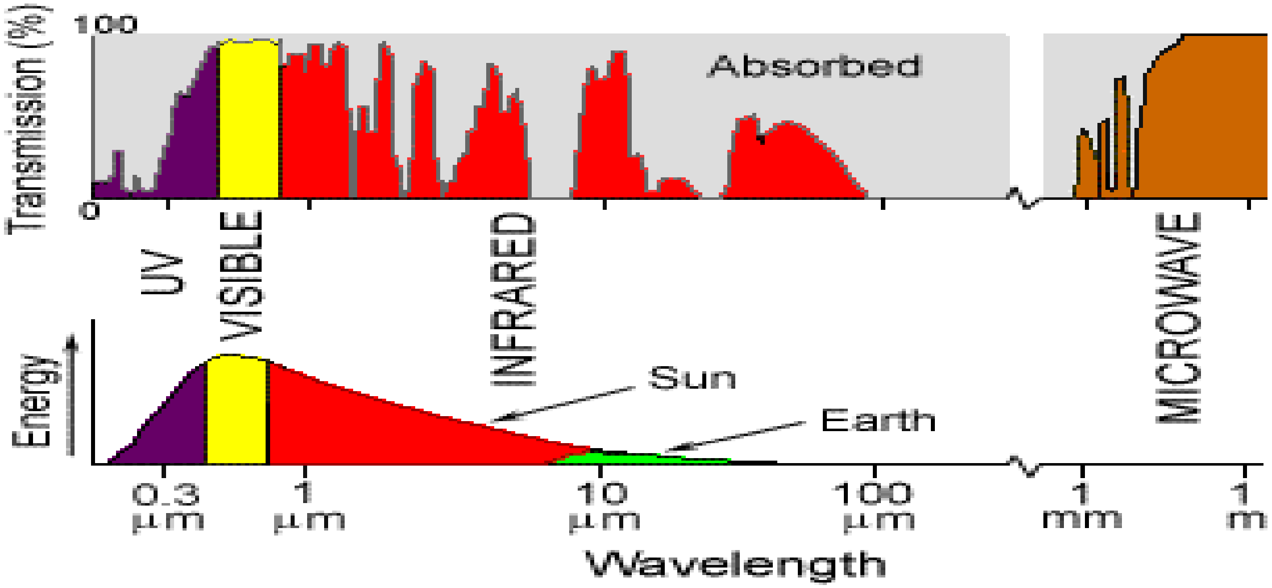
Atmospheric Windows

- Portions of the electromagnetic (EM) spectrum that can pass through the atmosphere with little or no attenuation. The figure below shows areas of the spectrum that can pass through the atmosphere without attenuation (peaks) and areas that are attenuated (valleys)



Atmospheric Windows

- The range of wavelengths at which water vapor, carbon dioxide, or other atmospheric gases only slightly absorb radiation. Atmospheric windows allow the Earth's radiation to escape into space unless clouds absorb the radiation.



Atmospheric Characteristics

- Wind can be a source of error if the material being measured moves during the time the spectrum is acquired.
- If a spectrum is slowly scanned, changes in the amount of shadow in the instrument field-of-view will result in erroneous "features" in the spectrum.
  - Vegetation canopies, with their large proportion of shadow, are especially susceptible to wind-induced errors. Instruments using an array detector or that scan the spectrum rapidly are not significantly affected by wind.

Radiative Transfer

- Visible,Near IR and Shortwave IR (VIS,NIR,SWIR)
  - Solar radiation
  - Propagates unchanged from Sun to Earth Top-Of-the-Atmosphere (TOA)
  - Modified by propagation downward through atmosphere to Earth ’s surface
  - Modified by reflection from objects on Earth ’s surface
  - Modified by propagation upward through atmosphere to airborne or satellite sensor
  - Solar radiation scattered by atmosphere also seen by sensor

Radiative Transfer

- Midwave IR (MWIR)
  - Solar and thermal radiation
- Longwave (Thermal)IR (LWIR,TIR)
  - Thermal radiation
  - Emitted by objects on Earth ’s surface as a function of their temperature and emissivity
  - Modified by propagation upward through atmosphere
  - Additional thermal radiation emitted downward by atmosphere and reflected by objects on Earth ’s surface
  - Thermal radiation emitted upward by atmosphere also seen by sensor

Visible to Shortwave Infrared Region

- 0.4 to 2.4 µm (400 to 2400nm)
- Solar radiation
- Three *at-sensor* (Top-Of-the-Atmosphere,TOA) components
  - unscattered, surface-reflected (direct)
  - down-scattered,surface-reflected (skylight)
  - path-scattered (atmospheric radiance)
- Measured geophysical variable
  - spectral reflectance

Solar Radiation

- Spectral radiant exitance,M_λ ,modeled by Planck ’s blackbody equation,

$$M_\lambda = \frac{C_1}{\lambda^5[e^{C_2/(\lambda T)} - 1]} \, (w/m^2/\mu m)$$

T is the blackbody ’s temperature in Kelvin (K),

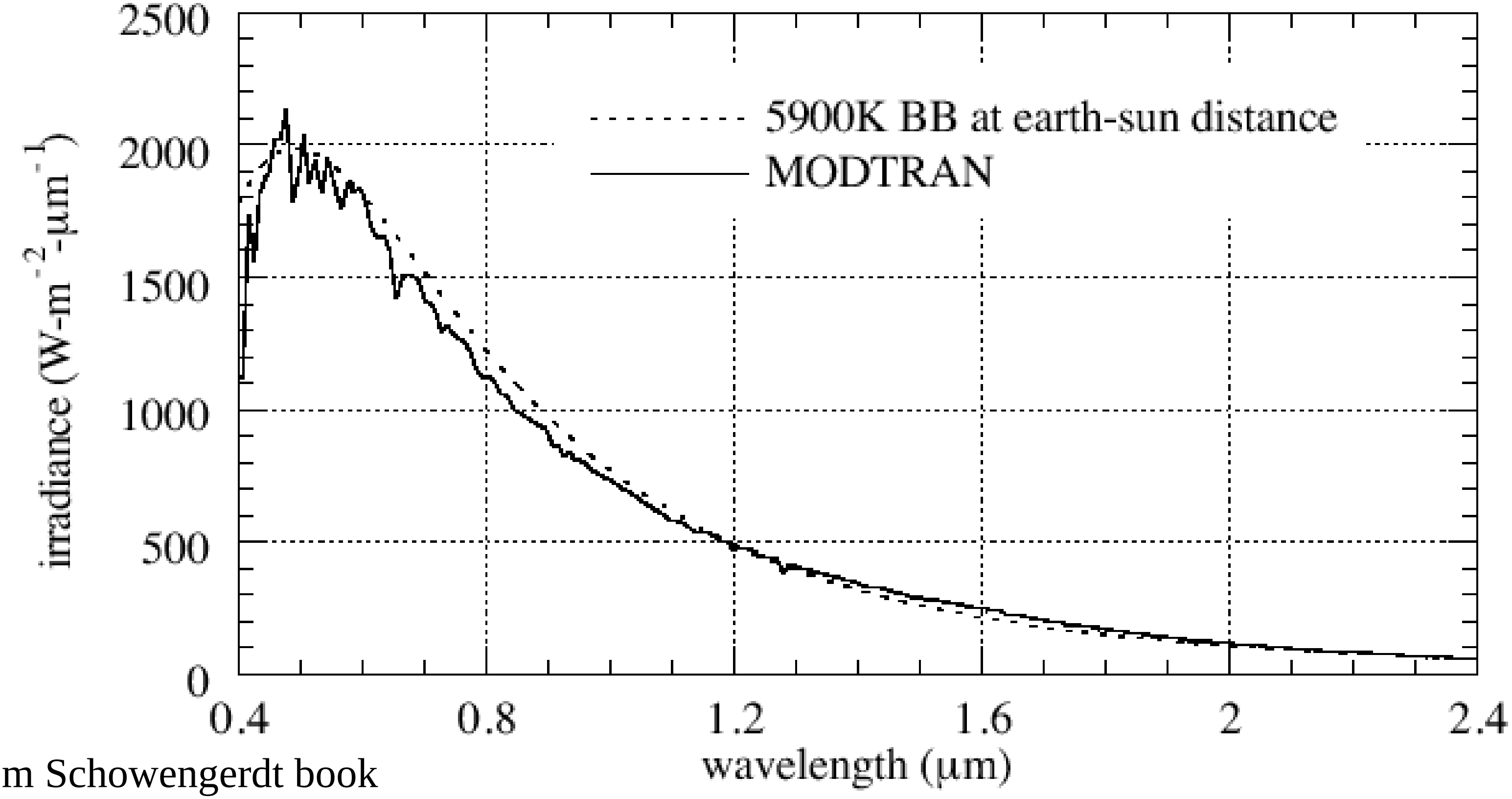
C 1 =3.74151 x 10^8 W/m^{-2} •μm^4 ,and

C 2 =1.43879 x 10^4 µm•K.

- M_λ is a function of both wavelength of radiation and temperature of the source
  - usually plotted as a function of wavelength,for given temperature

Solar radiation spectral distribution accurately approximated by 5900K blackbody

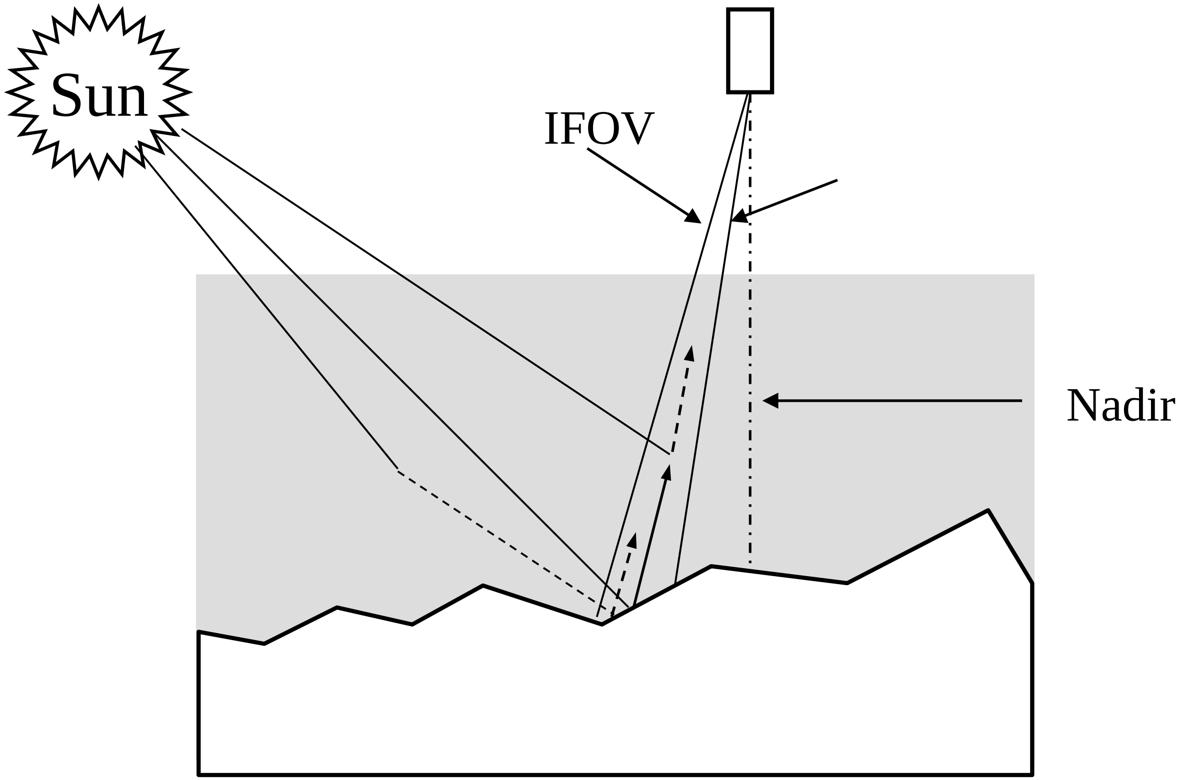
Solar spectrum and blackbody approximation



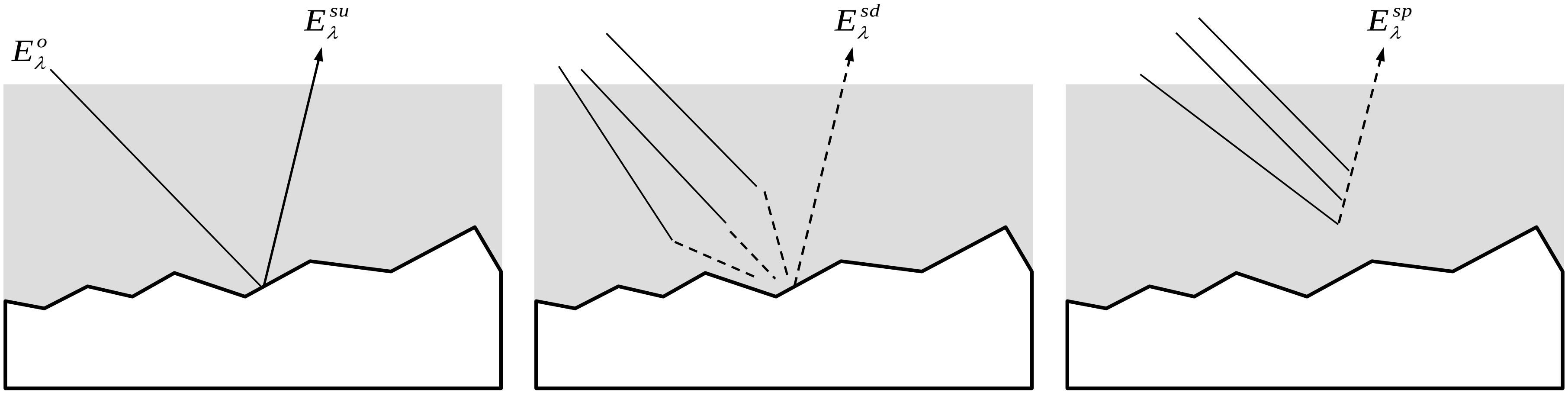
From Schowengerdt book

Major Radiation Components

- Three major radiation components in the VIS-SWIR interacting with atmosphere.



Three radiation Components



Surface-reflected

unscattered down-unscattered path-unscattered

Unscattered, surface-reflected Component

- Primary signal component
- TOA radiation modified by atmospheric transmittance along solar path
- Radiation density at earth's surface (E_λ, *irradiance*) depends on the angle of incidence, which in-turn depends on solar angle and topography

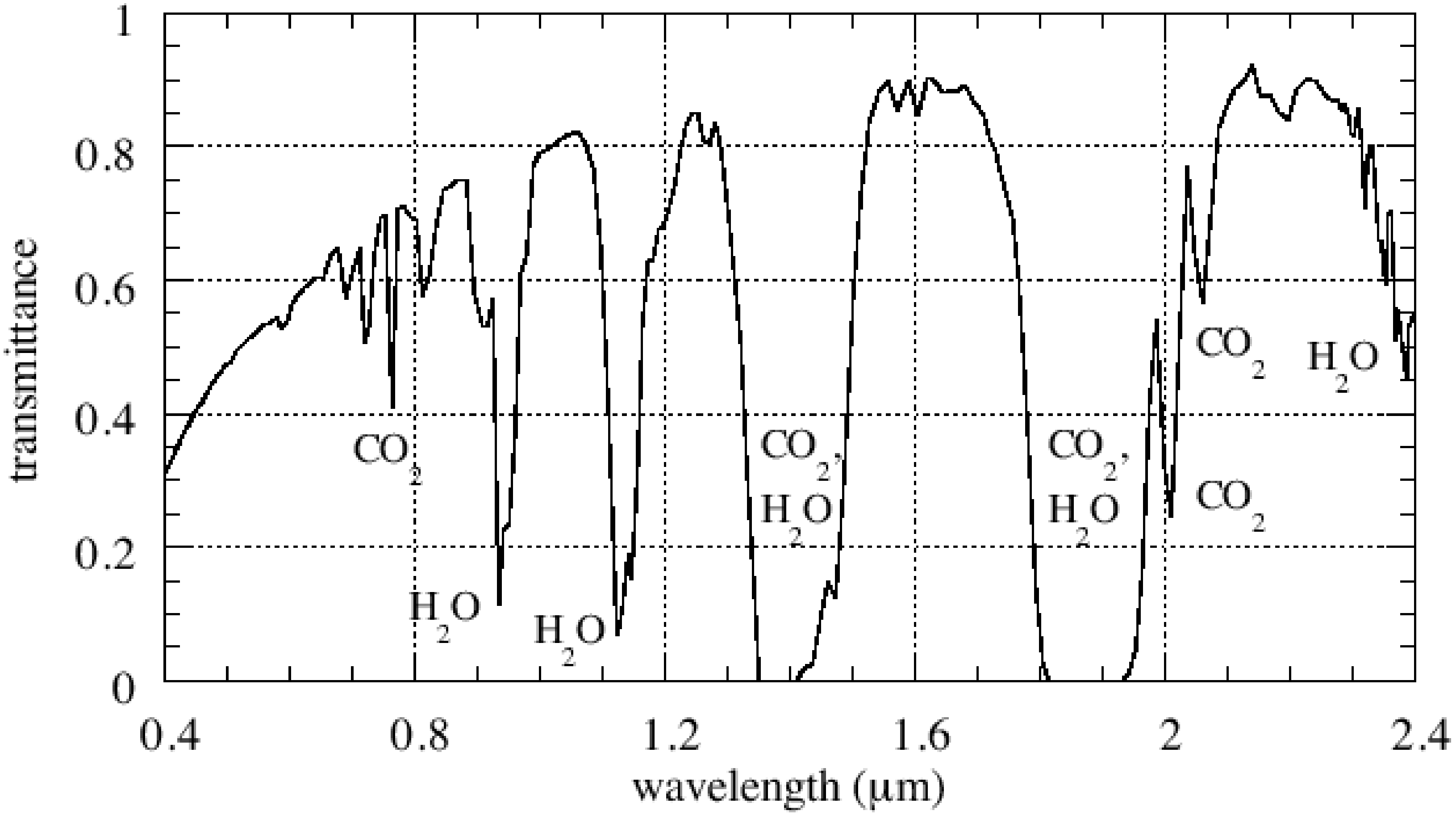
Earth's surface (normal to solar path) $E_\lambda = \tau_s(\lambda) E_\lambda^o (w/m^2/\mu m)$

Earth's surface

$$E_\lambda = \tau_s(\lambda) E_\lambda^o \cos\theta(x,y) \quad (w/m^2/\mu m)$$

$$E_\lambda = \tau_s(\lambda) E_\lambda^o \vec{n}(x,y) \bullet \vec{s}$$

Typical atmospheric transmittance in VIS-SWIR



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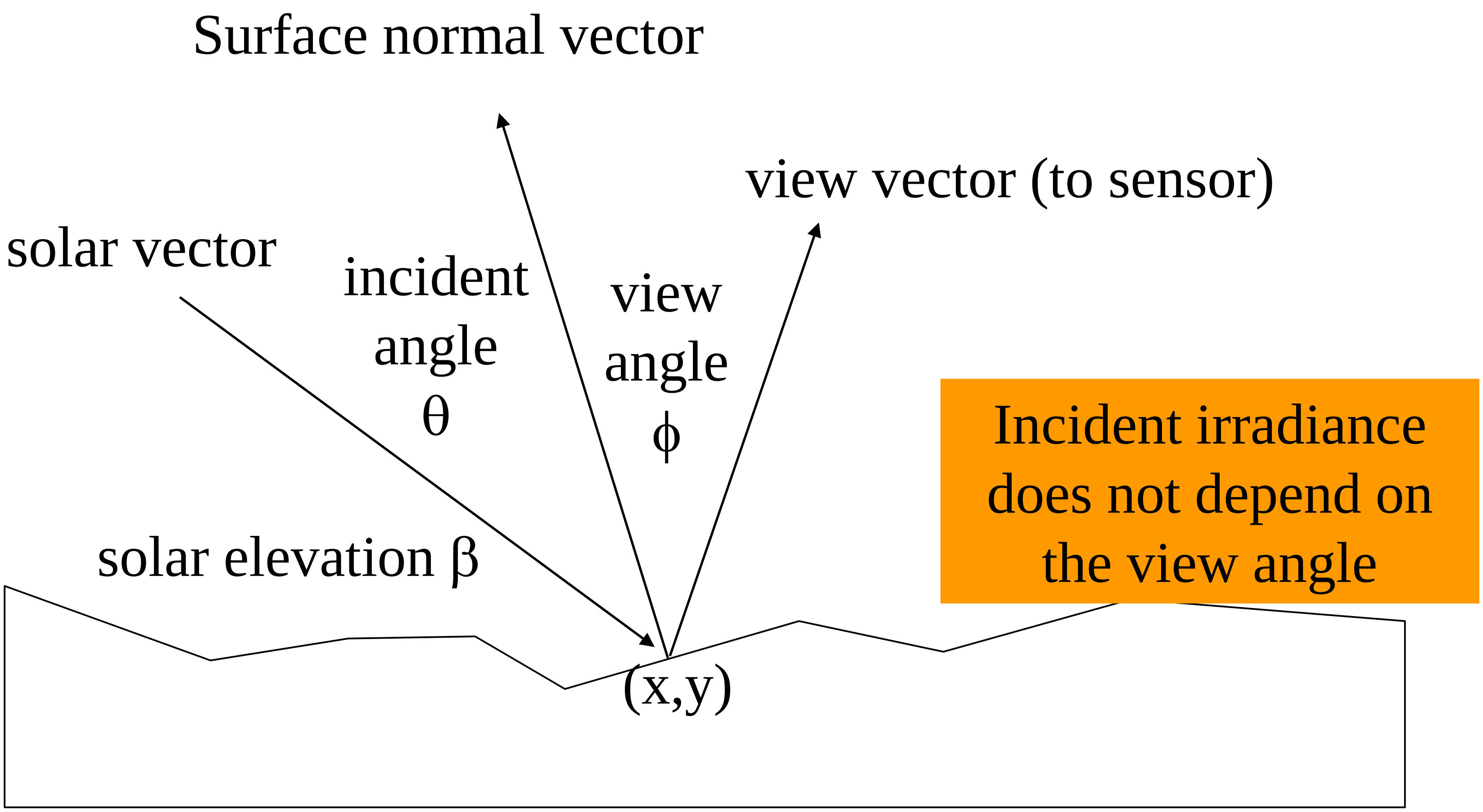
Angle of incidence is a function of solar direction and local topography (slope,aspect)



Surface normal vector

view vector (to sensor)

solar vector

incident
angle
θ

view
angle
ϕ

solar elevation β

(x,y)

Incident irradiance does not depend on the view angle

- *Incident irradiance* transformed by reflection at Earth surface to *surface radiance*

$$L_\lambda(x,y) = \rho(x,y,\lambda)\frac{E_\lambda}{\pi}(w/m^2/\mu m/sr)$$

$$= \rho(x,y,\lambda)\frac{\tau_s(\lambda)E_\lambda^o}{\pi}\cos\theta(x,y) \ (w/m^2/\mu m/sr)$$

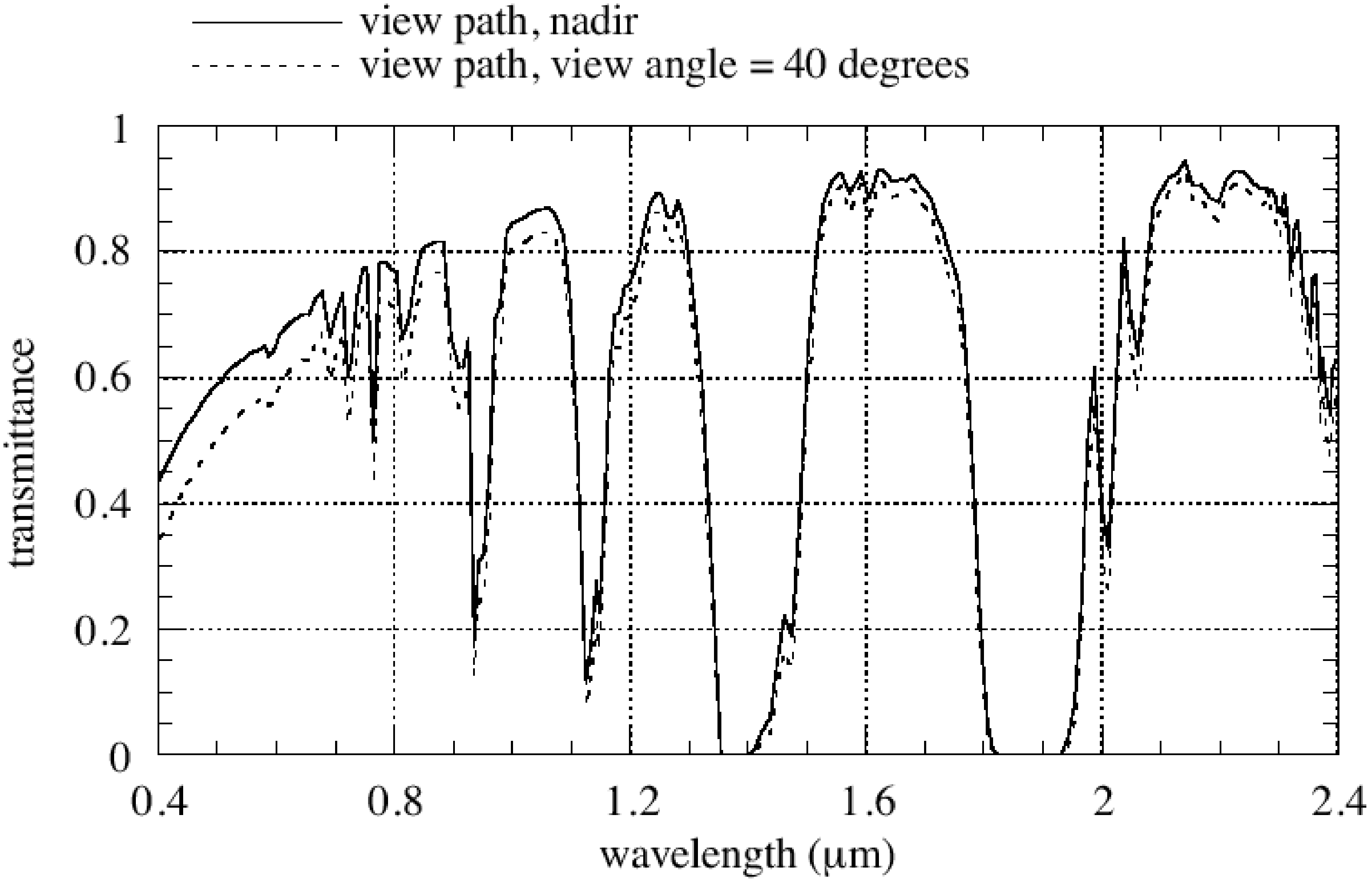
- *Surface radiance* modified by atmospheric transmittance along sensor view path to *at-sensor-radiance*

$$L_\lambda^{su} = \tau_v L_\lambda$$

$$L_\lambda^{su}(x,y) = \rho(x,y,\lambda)\frac{\tau_v(\lambda)\tau_s(\lambda)E_\lambda^o}{\pi}\cos\theta(x,y)$$

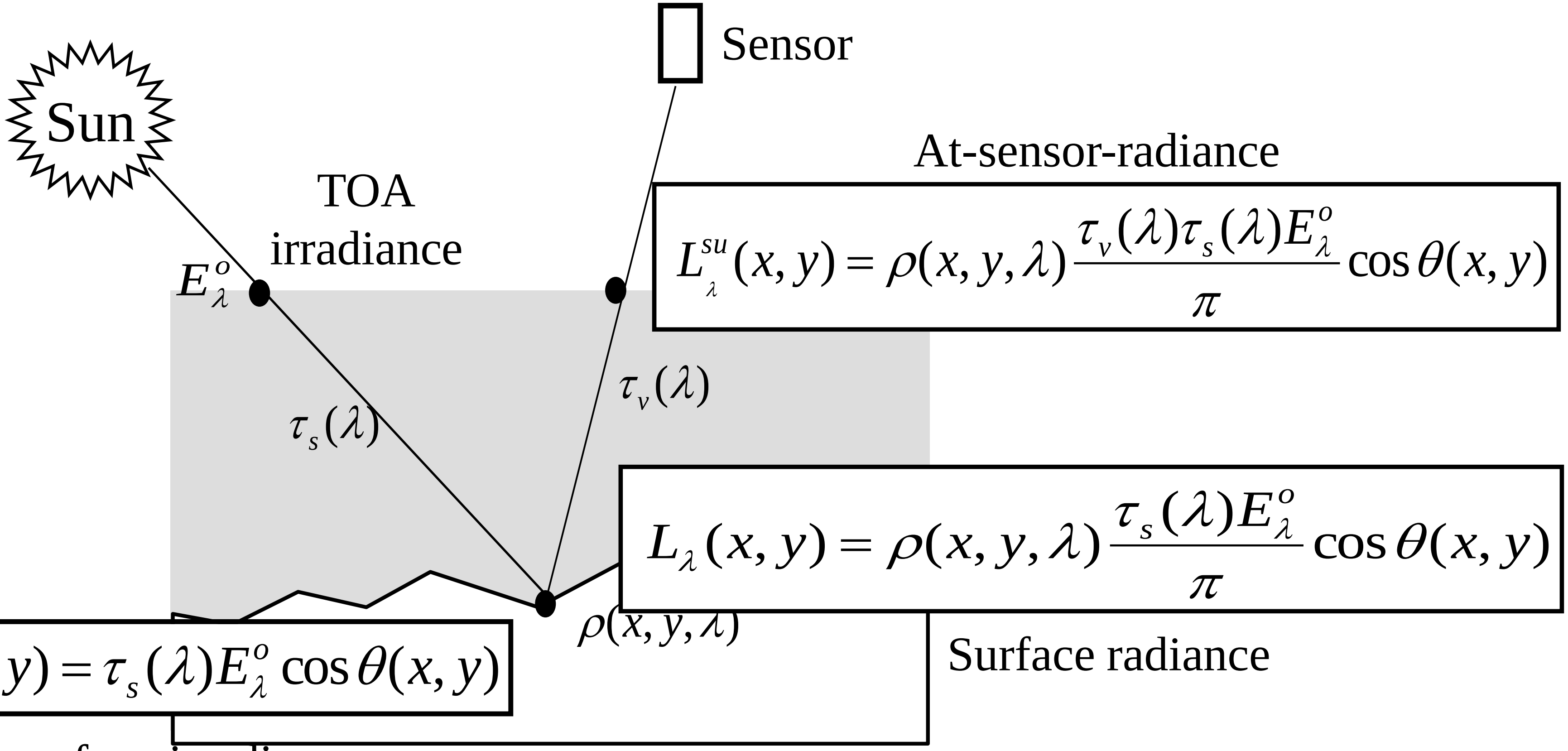
Atmospheric transmittance varies with both view and solar angles

Atmospheric transmittance at nadir and 40°



From Schowengerdt book

Summary for direct unscattered, surface-reflected component



At-sensor-radiance

$$L_\lambda^{su}(x, y) = \rho(x, y, \lambda)\frac{\tau_v(\lambda)\tau_s(\lambda)E_\lambda^o}{\pi}\cos\theta(x, y)$$

$$L_\lambda(x, y) = \rho(x, y, \lambda)\frac{\tau_s(\lambda)E_\lambda^o}{\pi}\cos\theta(x, y)$$

Surface radiance

$$E_\lambda(x, y) = \tau_s(\lambda)E_\lambda^o\cos\theta(x, y)$$

At-surface-irradiance

From Schowengerdt book

Down-scattered, surface-reflected skylight component

- Secondary signal component

At-sensor: $$L_{\lambda}^{sd}(x,y) = F(x,y)\rho(x,y,\lambda)\frac{\tau_v(\lambda)E_{\lambda}^{d}}{\pi}$$

where *F* is the fraction of sky visible at a given earth surface point

- Path-scattered radiance
  - Almost no signal content
  - *Rayleigh scattering* for a clear atmosphere (molecules only)
  - *Mie scattering* for an atmosphere with aerosols (water vapor) or particulates (dust, smoke)
  - Real atmospheres exhibit both *Rayleigh and Mie* scattering

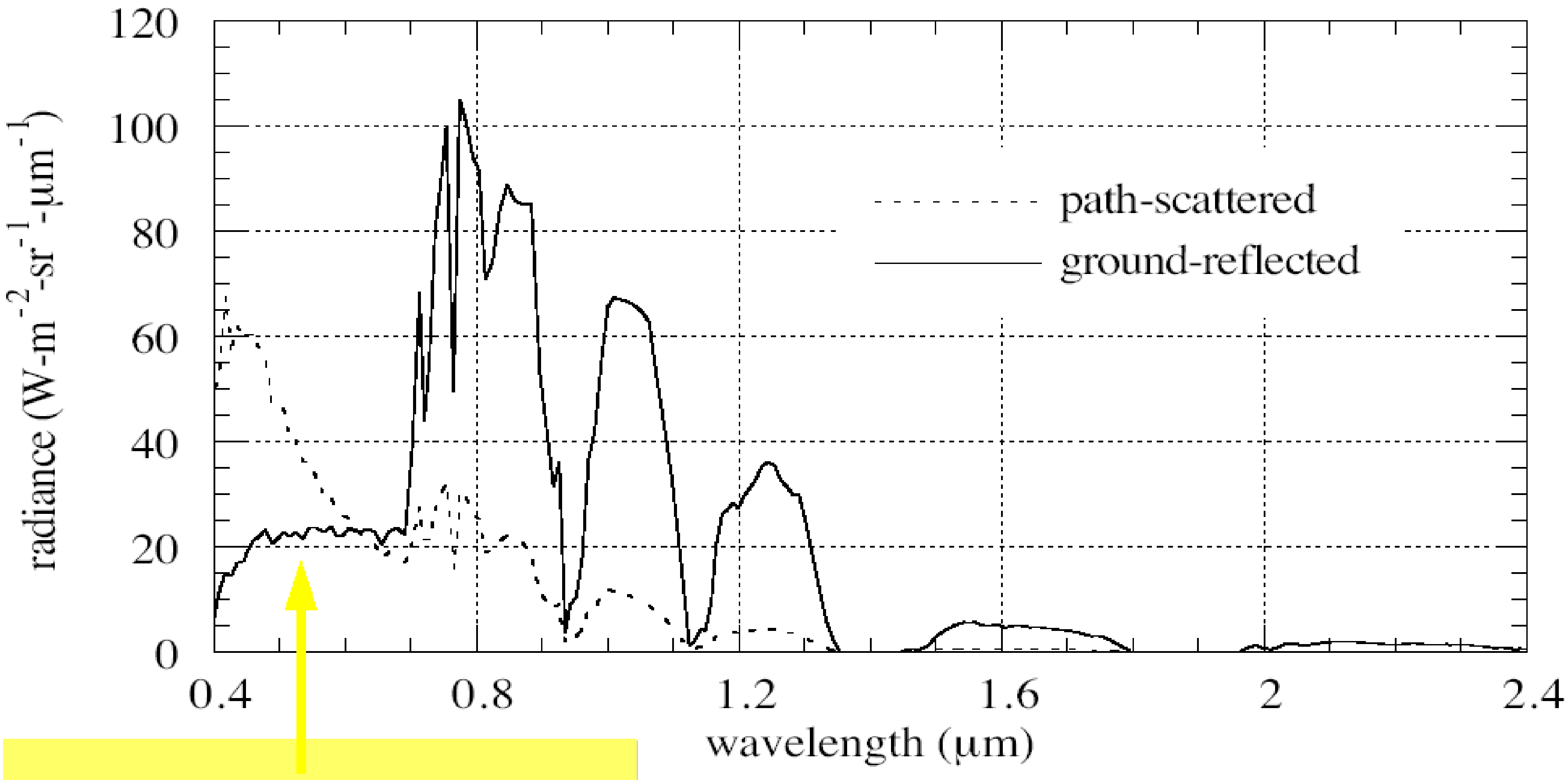
Total at-sensor radiance (solar)

$$L_\lambda^s(x,y) = L_\lambda^{su}(x,y) + L_\lambda^{sd}(x,y) + L_\lambda^{sp}$$

$$= \rho(x,y,\lambda)\frac{\tau_v(\lambda)\tau_s(\lambda)E_\lambda^o}{\pi}\cos\theta(x,y)$$

$$+ F(x,y)\rho(x,y,\lambda)\frac{\tau_v(\lambda)E_\lambda^d}{\pi} + L_\lambda^{sp}$$

$$= \rho(x,y,\lambda)\frac{\tau_v(\lambda)}{\pi}\left\{\tau_s(\lambda)E_\lambda^o\cos\theta(x,y) + F(x,y)E_\lambda^d\right\} + L_\lambda^{sp}$$



path-scattered component dominates below 600nm

Total at-sensor radiance (solar) (cont)

- $\rho(x,y,\lambda)$: surface diffuse reflectance (unitless)
- $\tau_v(\lambda)$: view path atmospheric transmittance (unitless)
- $\tau_s(\lambda)$: solar path atmospheric transmittance (unitless)
- E_λ^o: incident, exo-atmospheric spectral irradiance (w-$\text{m}^{-2}um^{-1}$)
- $\cos\theta(x,y)$: cosine of angle between solar vector and surface normal
- F (x,y): fraction of sky hemisphere visible from surface point
- E_λ^d : downwelling atmospheric spectral irradiance (w $\text{m}^{-2}um^{-1}$)
- L_λ^{sp} :upwelling atmospheric path spectral radiance (w $\text{m}^{-2}um^{-1}\text{sr}^{-1}$)

Atmospheric Correction

- Questions: How would you correct atmospheric effect on remotely sensed images?
- DOS = Dark object subtraction
- Empirical or in-situ field techniques
- Radiative transfer modeling
  - 5S / 6S
  - MODTRAN / Herman Browning Code

Atmospheric Correction

- Dark-Object-Subtraction (DOS)
    - Definition of “dark object” on remotely sensed images
    - Assumption: DOs have uniformly zero radiance for all bands and that non-zero measured radiance must be due to atmospheric scattering into the object’s pixels.
    - If any data are available for those objects, they should be used, instead
    - How to perform DOS

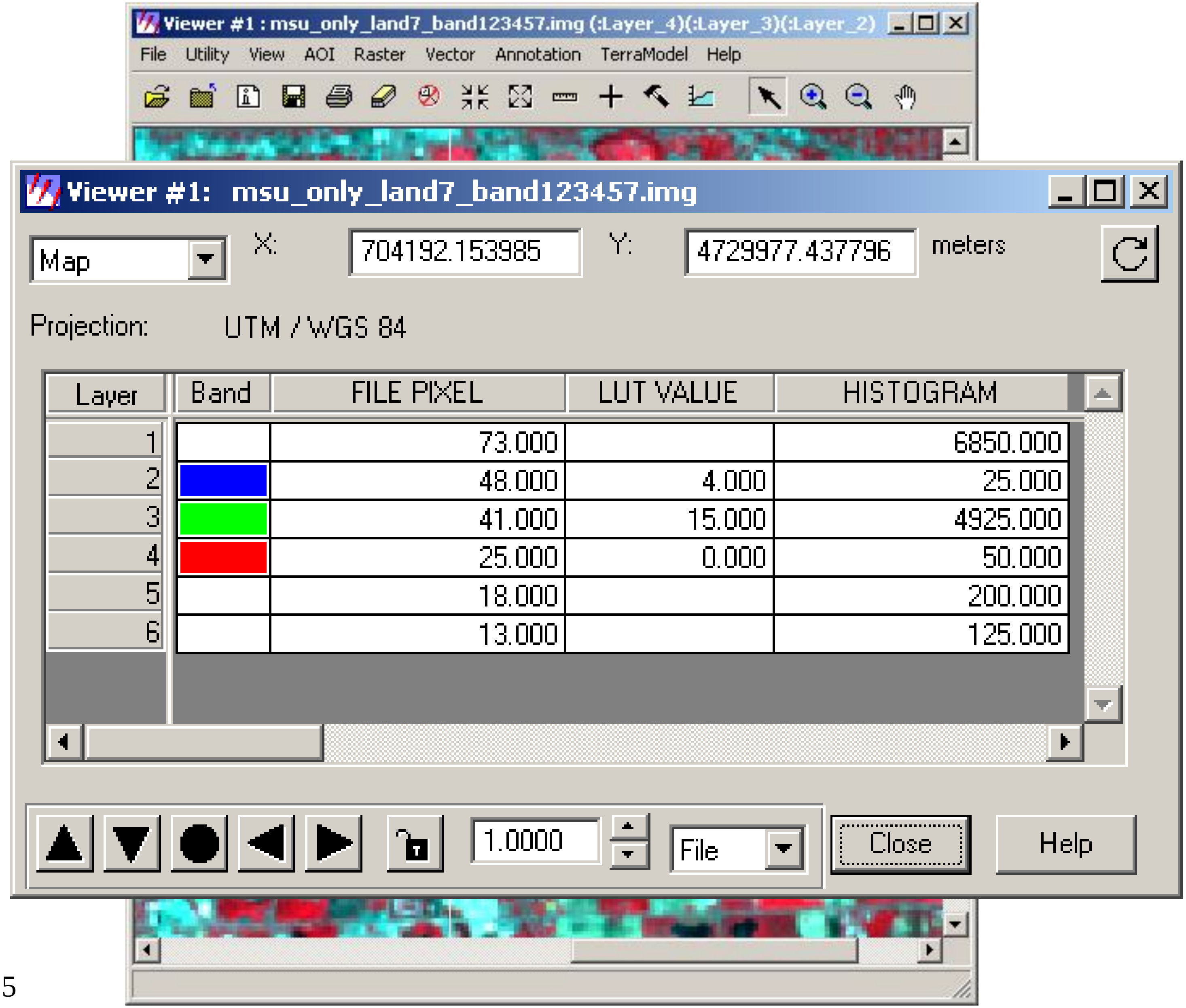
Atmospheric Correction

- DOS
  - Locate “DOs” on your image, and compute the mean radiance values of these pixels for each spectral bands
  - Subtract these values from the image
  - One can also look at the histograms for each band
  - Locate the minimum values and subtract them from the image

Atmospheric Correction

- DOS - NOTES:
  - There might be different DOs for different spectral bands
  - Deep shadows of mountains work quite well
  - Deep water bodies will also serve the purpose
  - Clouds shadows are often used too
  - Make sure that you use all pixels when computing histograms. In Erdas Imagine, there is an option to skip some pixels. The default skipping factor is image dependent.
  - Can you use some pseudo invariant objects instead of dark objects?

DOS example

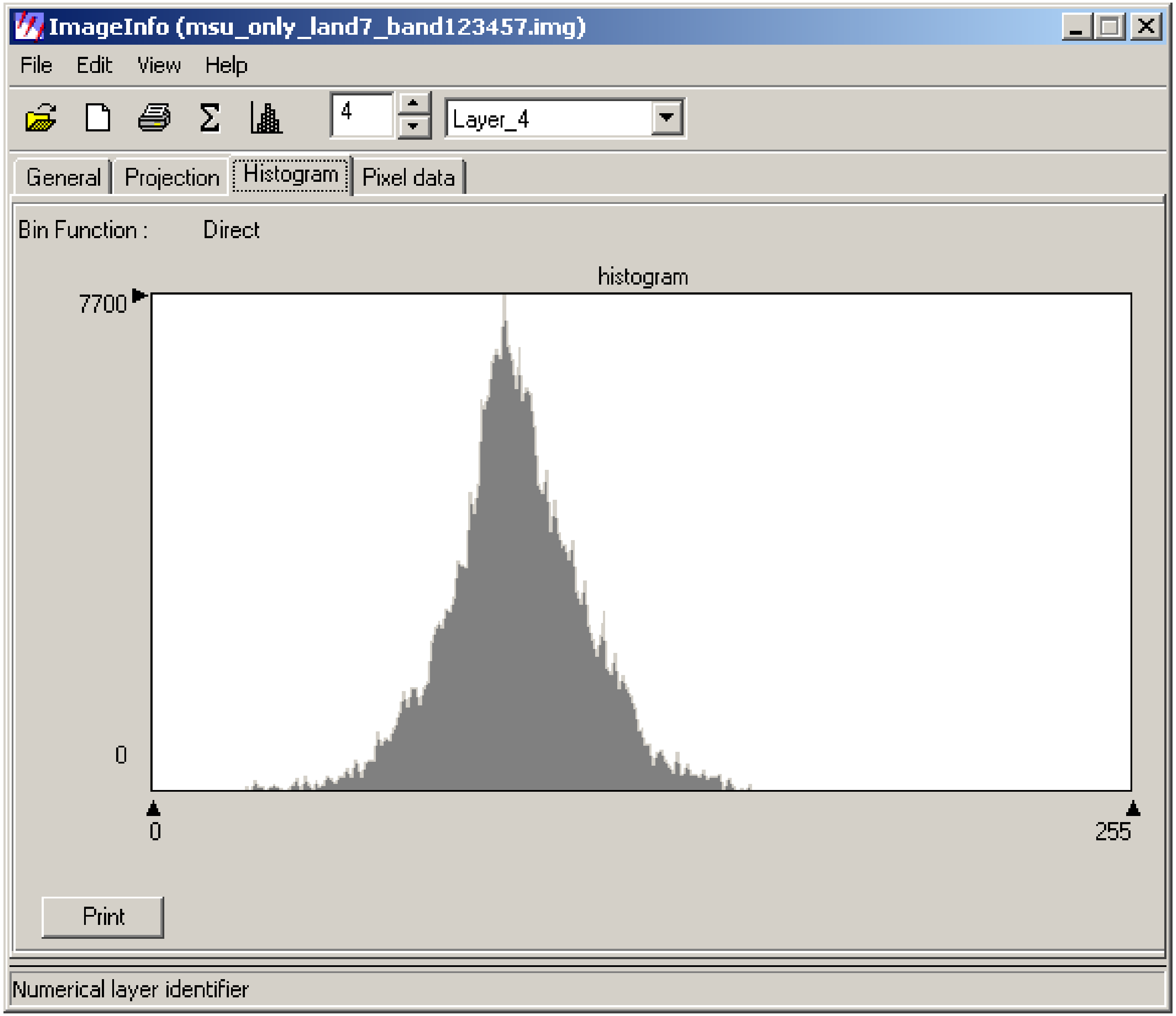


X: 704192.153985 Y: 4729977.437796 meters

Projection: UTM / WGS 84

Layer	Band	FILE PIXEL	LUT VALUE	HISTOGRAM
1		73.000		6850.000
2	🟦	48.000	4.000	25.000
3	🟩	41.000	15.000	4925.000
4	🟥	25.000	0.000	50.000
5		18.000		200.000
6		13.000		125.000

DOS example



Bin Function : Direct

Numerical layer identifier

Atmospheric Correction

- Pseudo invariant object techniques
- Similar to DOS
- Requires known surface reflectance properties
- Assumptions: they do not vary from time to time or with external conditions
- Large enough to be seen on satellite images
- Uniform

Atmospheric Correction

- Given two targets of known surface reflectance that can be used as a pseudo invariant objects.
- Establish atmospheric correction equations using the following images:
    - DNs
    - Radiance
    - TOA reflectance

Atmospheric Correction

- Example

  A soil target : $\rho_{s\lambda}$

  A vegetation target : $\rho_{v\lambda}$

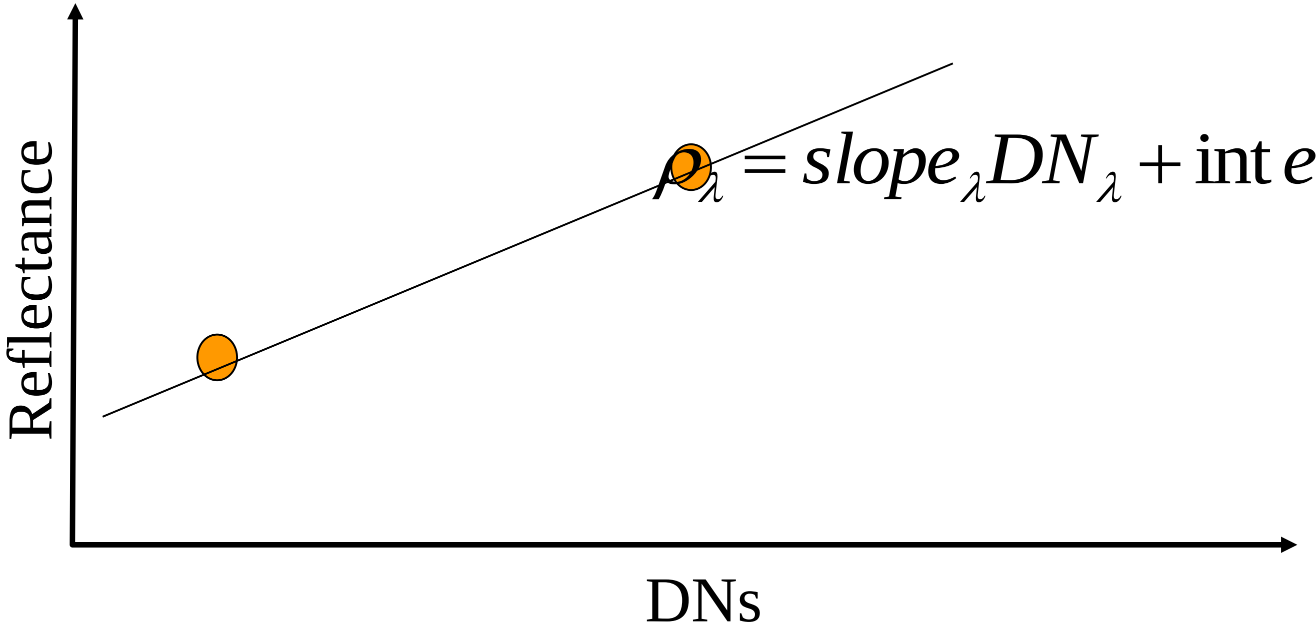
- The corresponding DN values on the image you are to correct are $DN_{s\lambda}$ and $DN_{v\lambda}$

$$\rho_\lambda = \tau_\lambda DN_\lambda + p_\lambda$$

$$\rho_{s\lambda} = \tau_\lambda DN_{s\lambda} + p_\lambda$$

$$\rho_{v\lambda} = \tau_\lambda DN_{v\lambda} + p_\lambda$$

ATM Correction using PIO



$$\rho_\lambda = slope_\lambda DN_\lambda + \mathrm{int}\,ercept_\lambda$$

ATM Correction with PIO

$$slope_{\lambda} = \frac{\rho_{v\lambda} - \rho_{s\lambda}}{DN_{v\lambda} - DN_{s\lambda}}$$

$$\mathrm{int}\,ercept_{\lambda} = \rho_{s\lambda} - \frac{\rho_{v\lambda} - \rho_{s\lambda}}{DN_{v\lambda} - DN_{s\lambda}} DN_{s\lambda}$$

- NOTE: You have to develop these coefficients for each spectral band. Choose very different targets as your PIOs.

ATM Correction-Radiative Transfer Modeling

- 5S/6S
- MODTRAN
- Herman Browning Code
- Demonstration of 5S model

Reading assignment

Read the following article at

http://www.tucson.ars.ag.gov/unit/Publications/PDFfiles/1320.pdf