Remote Sensing 1: GEOG 4/585

Lecture 5.1.

Atmospheric correction

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Required reading:
Principles of Remote Sensing pp 185-188, pp 411-415, pp 424-436

Recap from Lab #3

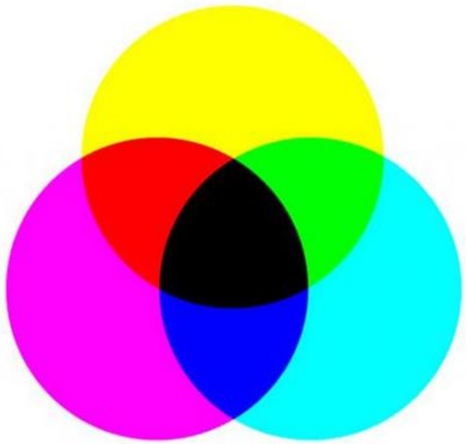
- We find healthier vegetation in the Central Oregon Irrigation District because of “prior appropriation”which allocates water according to which landowner diverts water first

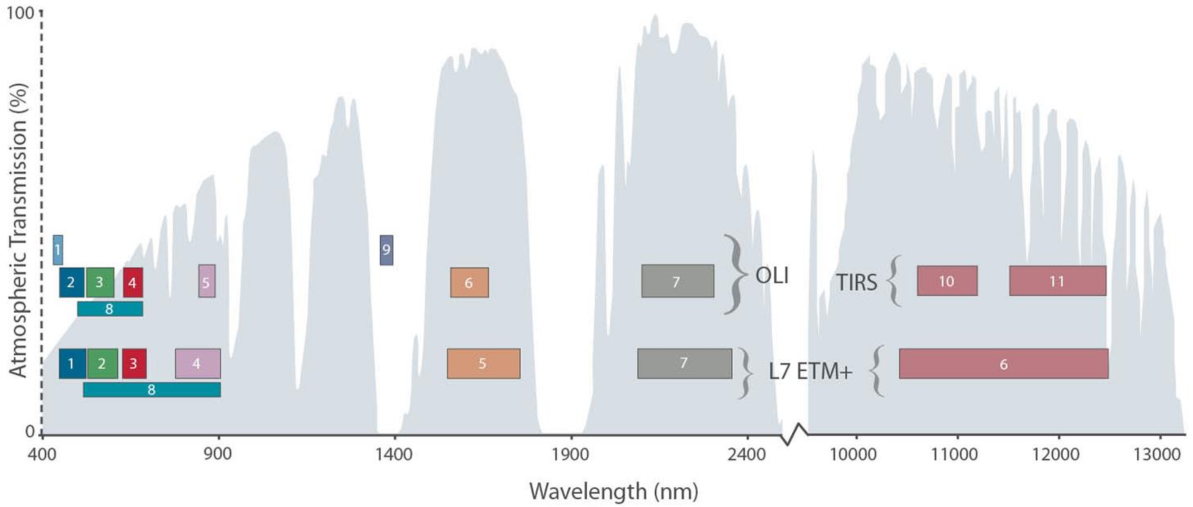
- In contrast to the “riparian rights” which grants water rights according the landowner’s proximity to water bodies and flowing streams

- In times of scarcity, senior water rights take priority over younger water rights, hence younger water rights in NUID had less water in summer 2021

- Water must be put to “beneficial use”, and not be wasted. Failure to use water on lands for a period of five continuous years in any fifteen-year period can result in a forfeiture of entire water right

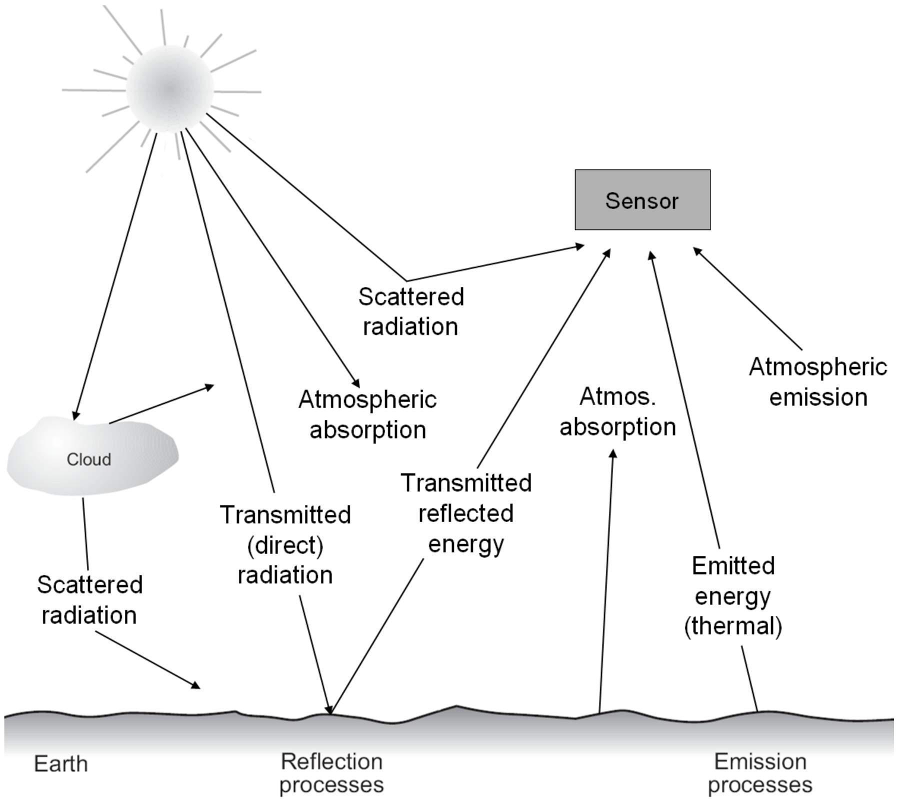
Recap from Quiz #1





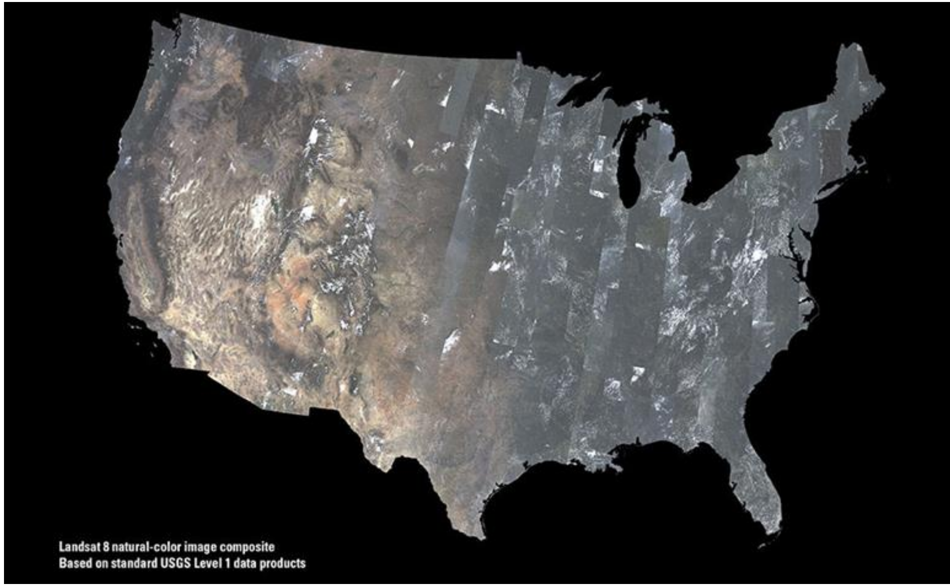
Overview

- What is atmospheric correction and why do we need it?
- Some terms
- Relative methods for computing surface reflectance
    - Empirical line correction
    - Dark-object subtraction
- Absolute methods for computing surface reflectance
    - Radiative transfer modeling



Landsat mosaics

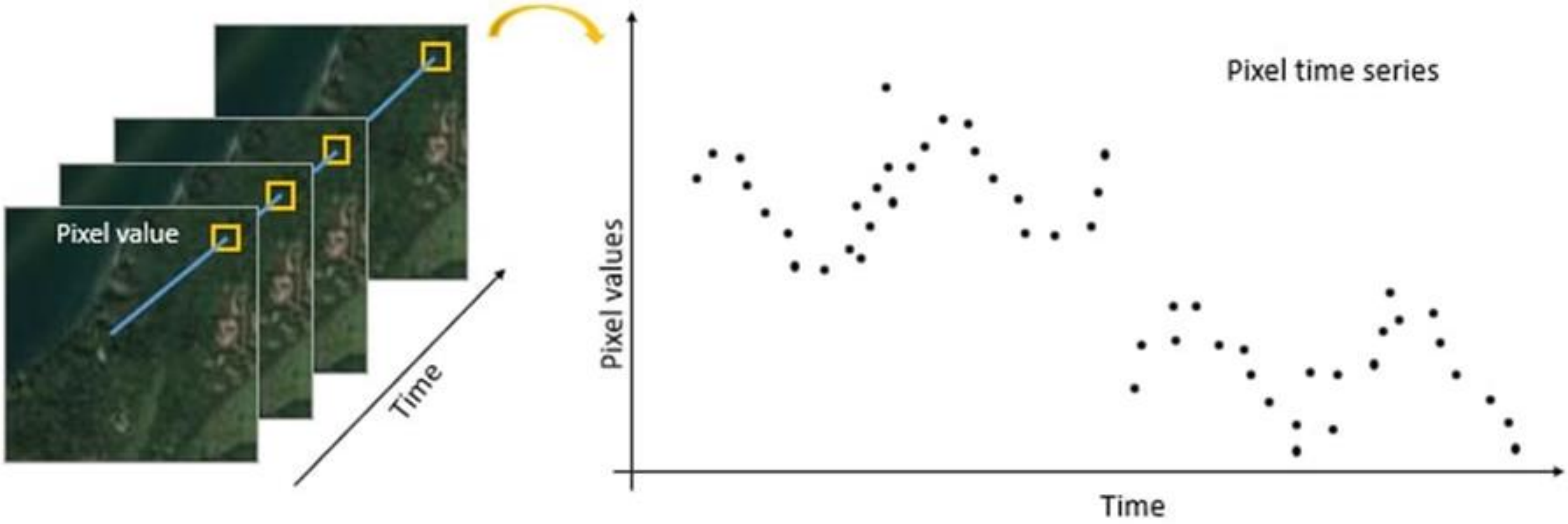
Landsat Level-1 product (digital numbers)



Landsat Level-2 product (surface reflectance)

How do we go from digital numbers to reflectance?

Why do we need atmospheric correction?



- Reduce or eliminate image-to-image variations caused by atmospheric effects so that we can detect real changes at the Earth's surface

Some terms

- Radiant energy (J) is the total amount of energy of electromagnetic radiation over a given time period

- Radiant flux (J per second <u>or</u> W) is the radiant energy emitted, reflected, transmitted or received, <u>per unit time</u>

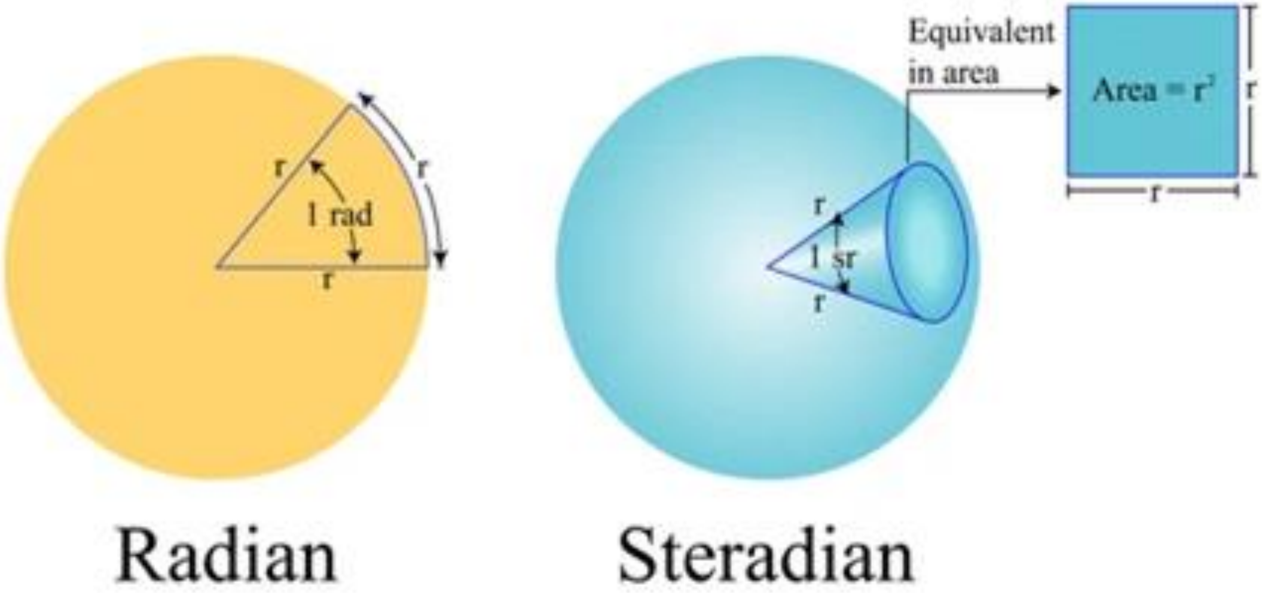
- Radiance (W sr^{-1} m^{-2}) is radiant flux emitted, reflected, transmitted or received by a given surface, per <u>unit solid angle</u> per <u>unit projected area</u>.

The word “spectral” is used to indicate a specific wavelength:

- Spectral radiance (W sr^{-1} m^{-2} nm^{-1}) is radiance <u>per unit wavelength</u>

Radian vs. steradian

- Radiance (W sr^{-1} m^{-2})



Some terms

- Digital numbers
  - Between 0 and 255 if 8-bit radiometric resolution
  - Correlate with energy that is measured by the sensor

- Radiance
  - Digital numbers converted to watts per steradian per square metre per nanometre ($W\ sr^{-1}\ m^{-2}\ nm^{-1}$) usually with simple scaling factors provided in metadata

- Top-of-atmosphere <u>radiance</u>
  - i.e. radiance independent of sun geometry

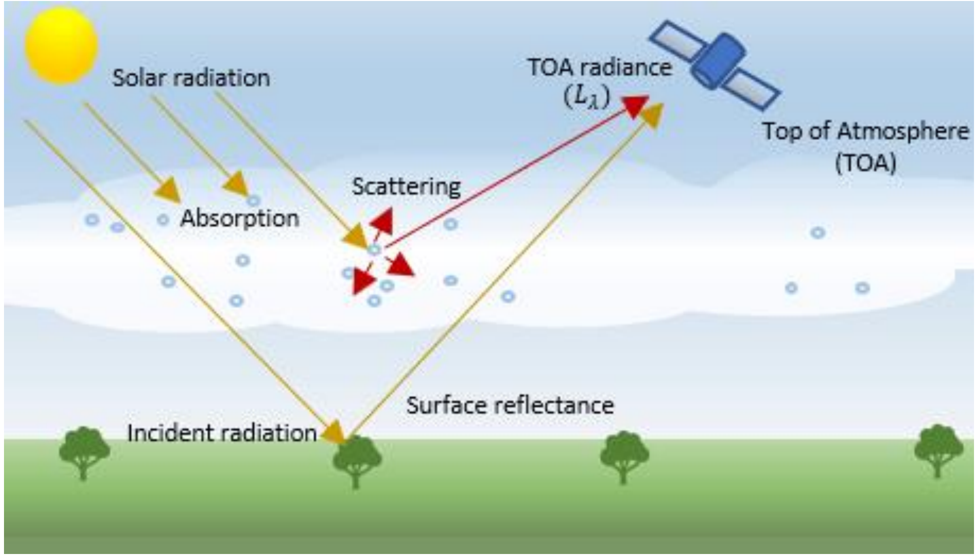
- Bottom-of-atmosphere <u>reflectance</u>
  - i.e. independent of atmospheric effects and sun geometry
  - Ratio of irradiance and radiance
  - Between 0 and 1

Radiance vs. reflectance

- Radiance in W sr^{-1} m^{-2} (at the sensor) depends on:
    1. Irradiance from Sun i.e. sun angle
    2. Surface reflectance
    3. Path radiance i.e. atmospheric scattered radiance

- Surface reflectance is the fraction of the Sun's irradiance that is reflected by a surface

    - Between 0 and 1



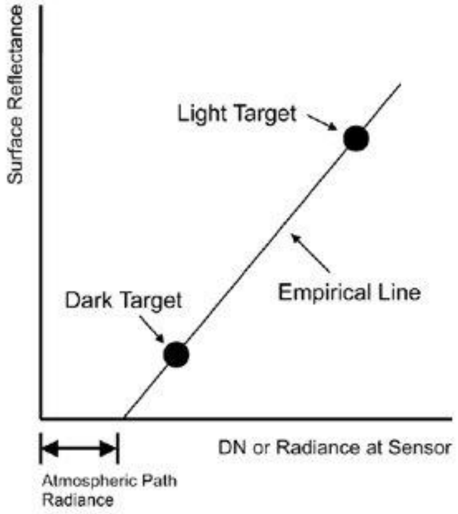
Empirical line correction

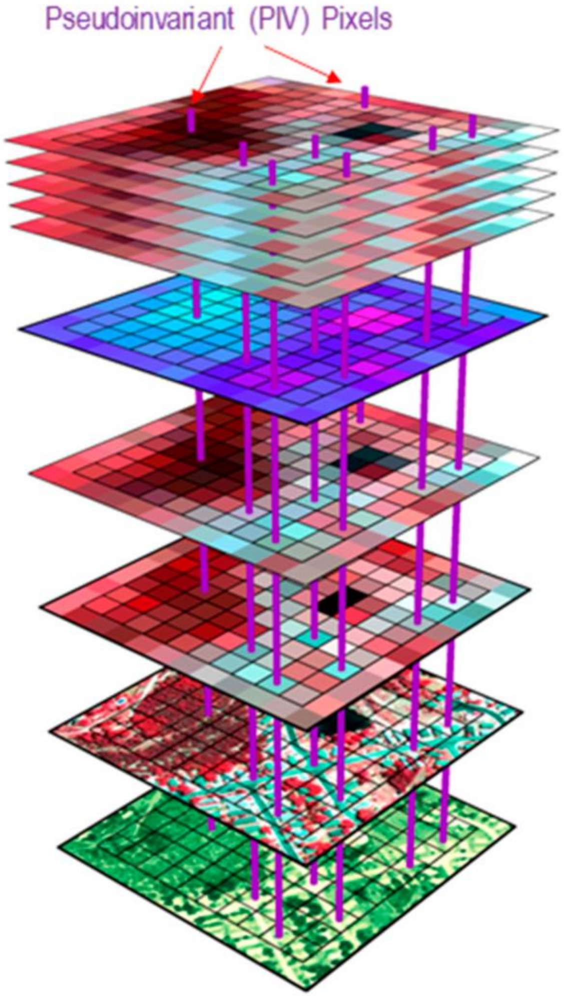
- Identify pseudo-invariant features (PIF) which are usually artificial structures that can be expected to have a constant reflectance over time

- Differences in PIF reflectance between dates can be assumed to be due to varying atmospheric conditions

- Match in situ measured spectral reflectance to pixel radiance

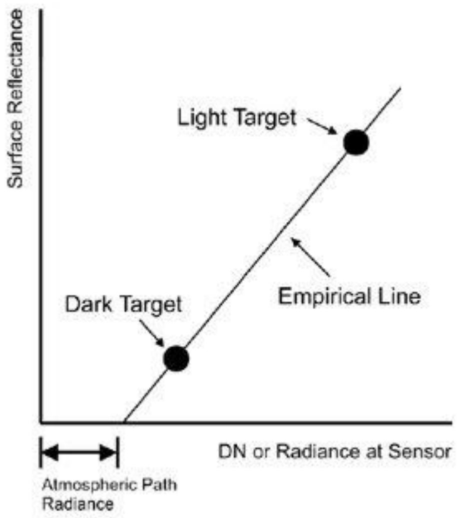
- Calibrate each band accordingly

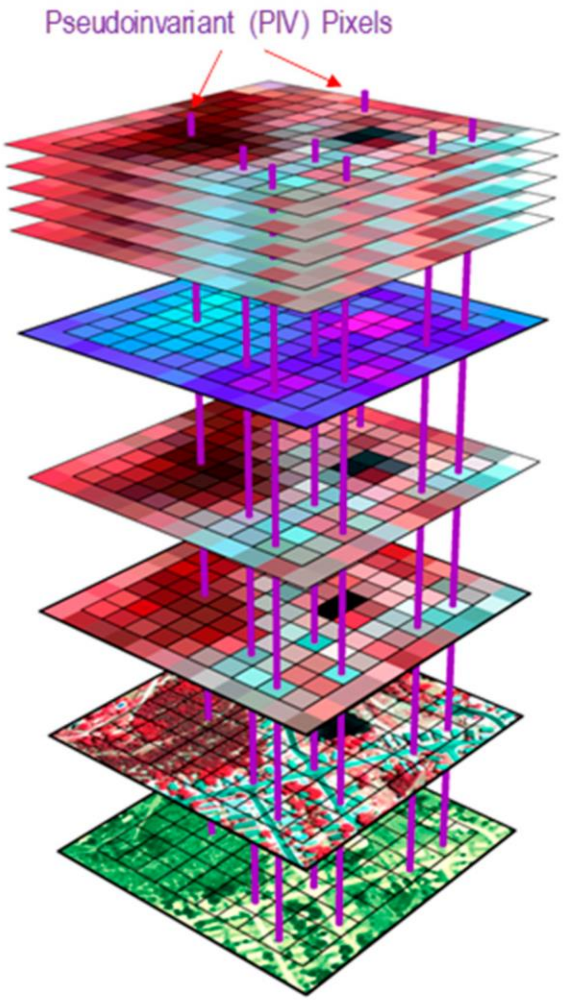




Empirical line correction

- But, we often do not have in situ spectral reflectance measurements...
- May be no artificial features (with constant reflectance values) in our image





Surface reflectance

Surface reflectance (i.e. the ratio of reflected versus total power energy) of a land surface is given by:

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

where:
L_{sat} = spectral radiance at the sensor's aperture (at-satellite radiance)
L_p = path radiance
d = Earth-Sun distance in astronomical units

T_v = atmospheric transmittance in the viewing direction
$ESUN_\lambda$ = Mean solar exo-atmospheric irradiances
T_z = atmospheric transmittance in the illumination direction
θ_s = Solar zenith angle in degrees
E_{down} = downwelling diffuse irradiance

Surface reflectance

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We can get the following pretty easily…

L_{sat} = spectral radiance at the sensor (values of image pixels)
d = Earth-Sun distance in astronomical units (image metadata)
$ESUN_\lambda$ = Mean solar exo-atmospheric irradiances (known constants from Thuillier et al., 2003)
θ_s = solar zenith angle in degrees (image metadata)

Surface reflectance

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

Band	Watts/(m² * µm)
1	1970
2	1842
3	1547
4	1044
5	225.7
7	82.06

$ESUN_\lambda$ = Mean solar exo-atmospheric irradiances i.e. brightness of the Sun in space

d = Earth-Sun distance in astronomical units

Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance
1	.98331	74	.99446	152	1.01403	227	1.01281	305	.99253
15	.98365	91	.99926	166	1.01577	242	1.00969	319	.98916
32	.98509	106	1.00353	182	1.01667	258	1.00566	335	.98608
46	.98774	121	1.00756	196	1.01646	274	1.00119	349	.98426
60	.99084	135	1.01087	213	1.01497	288	.99718	365	.98331

Surface reflectance

Surface reflectance (i.e. the ratio of reflected versus total power energy) of a land surface is given by:

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

But we need several atmospheric measurements for the others…

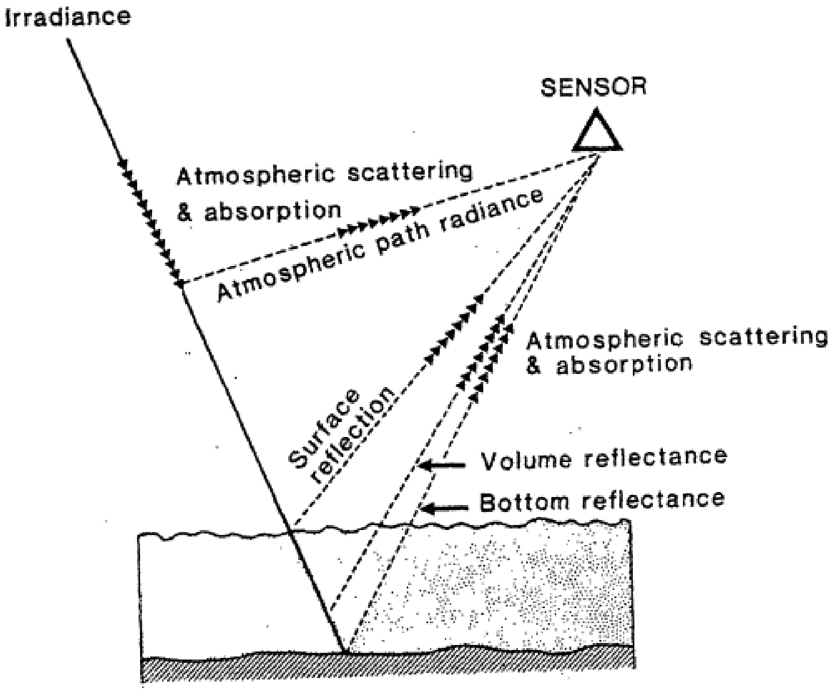
L_p (path radiance), T_v (atmospheric transmittance in the viewing direction), T_z (atmospheric transmittance in the illumination direction), and E_{down} (downwelling diffuse irradiance)

Path radiance

$$[\pi * (L_{sat} - L_p) * d^2]$$

- Atmospheric path radiance (L_p) is generated by scattering in the atmosphere (molecules and aerosols).

- Depends on:
    - Rayleigh scattering i.e. function of wavelength and number of molecules in atmosphere
    - Mie scattering i.e. function of quantity and type of aerosols like ozone, water vapour, and CO_2
    - Selective absorption also dependent on aerosols



Dark-object subtraction (DOS)

- It is possible to use image-based techniques to calculate path radiance without the need for in-situ measurements or models
- We can assume that the minimum radiance value from the entire scene can be solely attributed to atmospheric effects
- Requires features such as water which absorbs nearly all incident radiation

Dark-object subtraction (DOS)

- In reality very few targets on the Earth's surface are absolute black, so we assume a 1% reflectance of our dark object

- $L_{DO1\%}$ = radiance of an object with an assumed reflectance value of 0.01

$$L_{DO1\%} = 0.01 * [(ESUN_{\lambda} * \cos\theta_s * T_z) + E_{down}] * T_v / (\pi * d^2)$$

- L_{min} = radiance of the dark object in our image

$$L_p = L_{min} - 0.01 * [(ESUN_{\lambda} * \cos\theta_s * T_z) + E_{down}] * T_v / (\pi * d^2)$$

Reflectance from DOS1

The simplest technique is DOS1 we assume no atmospheric transmittance loss and no diffuse downward radiation at the surface.

$T_v = 1$ (atmospheric transmittance in the viewing direction)
$T_z = 1$ (atmospheric transmittance in the illumination direction)
$E_{down} = 0$ (downwelling diffuse irradiance)

Therefore the path radiance is:

$$L_p = L_{min} - 0.01 * ESUN_\lambda * \cos\theta_s / (\pi * d^2)$$

And the resulting land surface reflectance is given by:

$$p = [\pi * (L_{sat} - L_p) * d^2] / (ESUN_\lambda * \cos\theta_s)$$

Other DOS methods

- There are several DOS techniques (e.g. DOS1, DOS2, DOS3, DOS4), based on different assumption about T_v, T_z, and E_{down}.

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

Method	**T_v**	**T_z**	**E_{down}**
DOS1	1	1	0
DOS2	1	$\cos\theta_z$	0
DOS3	$e^{-\tau r/\cos(\theta\tau)}$	$e^{-\tau r/\cos(\theta z)}$	Rayleigh (6S)
DOS4	$e^{-\tau/\cos(\theta\tau)}$	$e^{-\tau/\cos(\theta z)}$	πL_p

- DOS2 assumes the transmittance in the illumination direction can be approximated, to a first order, by the cosine of solar zenith angle

Other DOS methods

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

Method	T_v	T_z	E_{down}
DOS1	1	1	0
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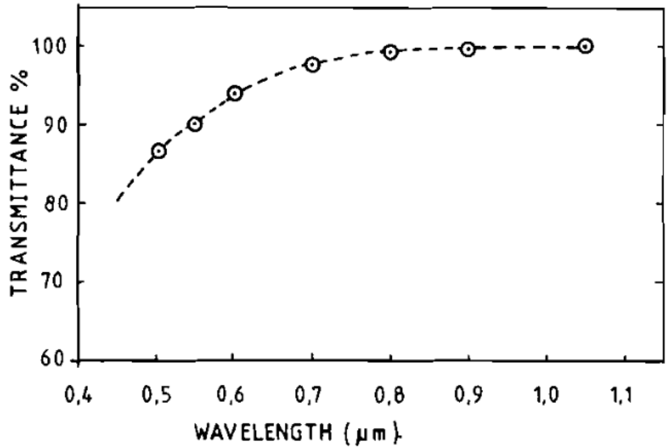


- DOS3 computes T_v and T_z assuming Rayleigh scattering only (i.e. no aerosols)
- Rayleigh scattering $\propto 1 / \lambda^4$ and atmospheric pressure
- E_{down} for a Rayleigh atmosphere can be estimated by an atmospheric radiative transfer model

Other DOS methods

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

Method	$\mathbf{T_v}$	$\mathbf{T_z}$	$\mathbf{E_{down}}$
DOS1	1	1	0
DOS2	1	$\cos\theta_z$	0
DOS3	$e^{-\tau r/\cos(\theta\tau)}$	$e^{-\tau r/\cos(\theta z)}$	Rayleigh (6S)
DOS4	$e^{-\tau/\cos(\theta\tau)}$	$e^{-\tau/\cos(\theta z)}$	πL_p

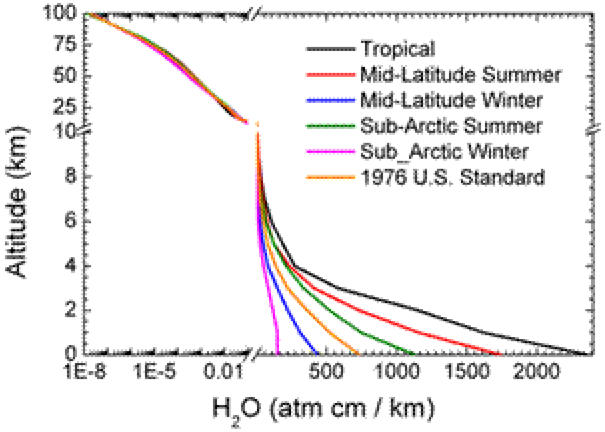
- DOS4 attempts to include the effects of atmospheric aerosols on Tv and Tz by assuming "isotropic sky radiance"
- That is, the transmittance loss from sun-to-surface is the same as surface-to-sensor and can be computed from directly from the path radiance

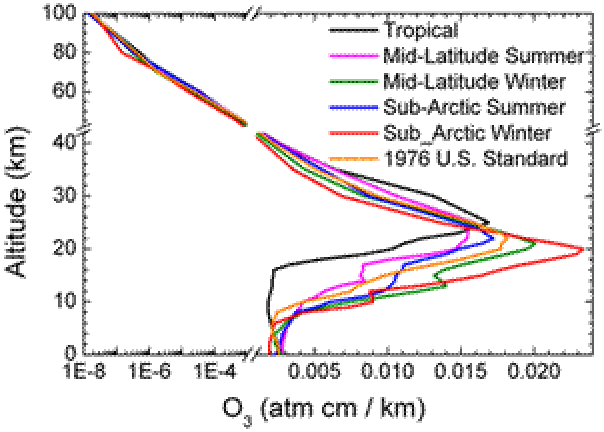
Radiative transfer modeling

- Aims to directly compute L_p, T_v, T_z and E_{down} based on theory and knowledge of atmospheric properties at the time of satellite image acquisition

$$p = [\pi * (L_{sat} - L_p) * d^2] / [T_v * ((ESUN_\lambda * \cos\theta_s * T_z) + E_{down})]$$

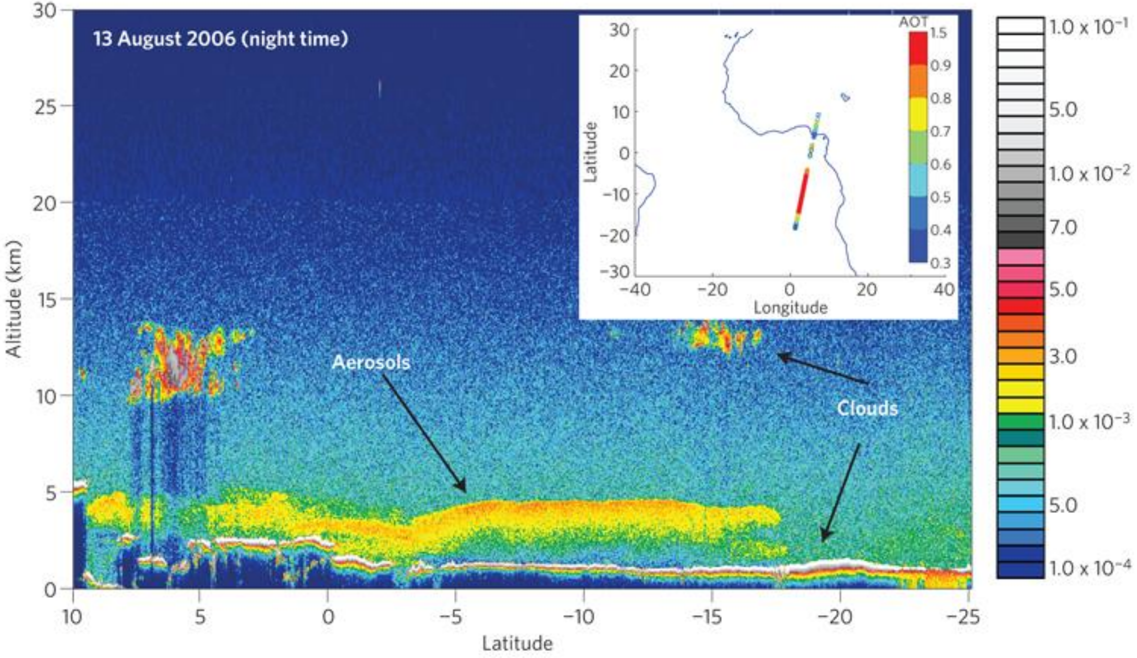
- e.g. 6S, MODTRAN4, SPCTRAL2, FAR, SCIATRAN, libRADTRAN, LIDORT/VLIDORT





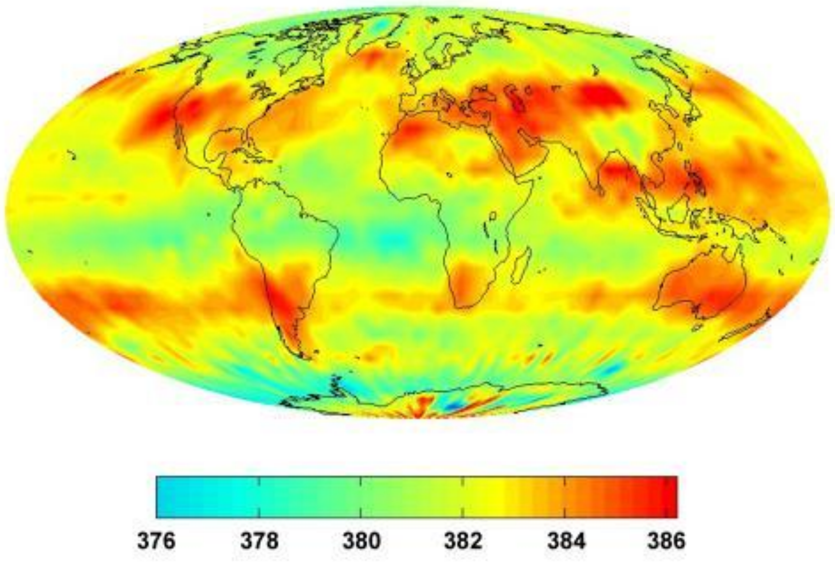
Radiative transfer modeling

- The difficulty is that aerosols (quantity and type) often vary substantially in time and space



Remote sensing of atmospheric profiles

- Atmospheric Infrared Sounder (AIRS) onboard Aqua
- AIRS uses infrared technology to produce 3D maps of air temperature, water vapor, and cloud properties
- AIRS can also measure trace greenhouse gases such as ozone, carbon monoxide, carbon dioxide, and methane.



AIRS July 2008 CO_2 (ppmv)

Do you need atmospheric correction?

- Atmospheric correction is not necessary when:
  - classifying a single image
  - multiple images are classified individually and the resulting maps are compared to identify changes

- But usually required for most other tasks (e.g. change detection)

Check if satellite product is atmospherically corrected!

- Both Landsat Collection 2 Level-2 products, MODIS Level-2 (MOD09) and Sentinel-2 Level-2 products are atmospherically corrected by NASA/ESA

- Other imagery such as that from PlanetScope CubeSats may not be!

Summary

Relative atmospheric correction (e.g. dark-object subtraction)

Advantages

- Rely only on data from image itself

Disadvantages

- Possible that no dark objects or invariant features exist in image
- Surface reflectances are unique to your particular study

Absolute atmospheric correction (i.e. radiative transfer modeling)

Advantages

- Produces “universal” surface reflectances that could be used by other studies

Disadvantages

- Require ancillary data (e.g. atmospheric profiles) at the time of satellite image acquisition