National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

10–14 September 2018
University of Leicester | United Kingdom

INTRO: OPTICAL REMOTE SENSING AND ATMOSPHERIC CORRECTION

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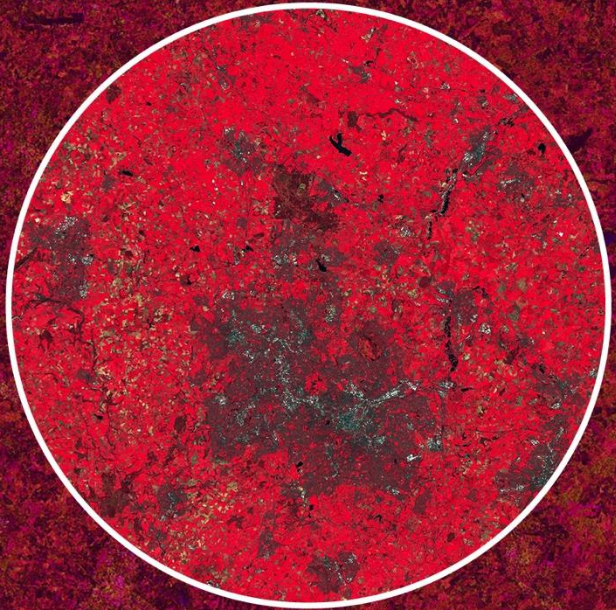
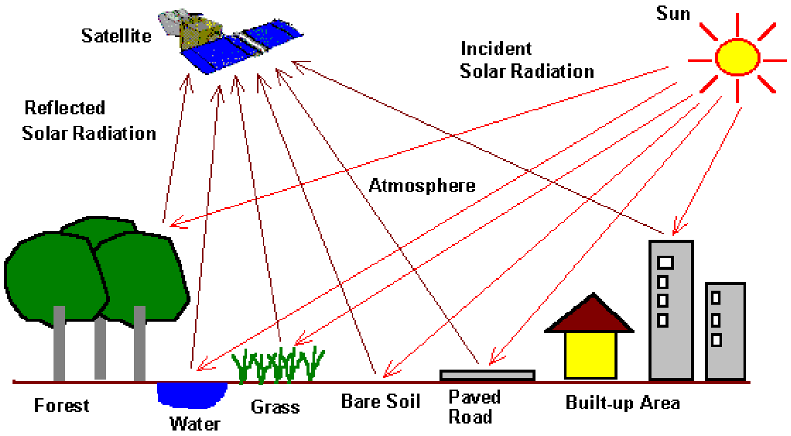
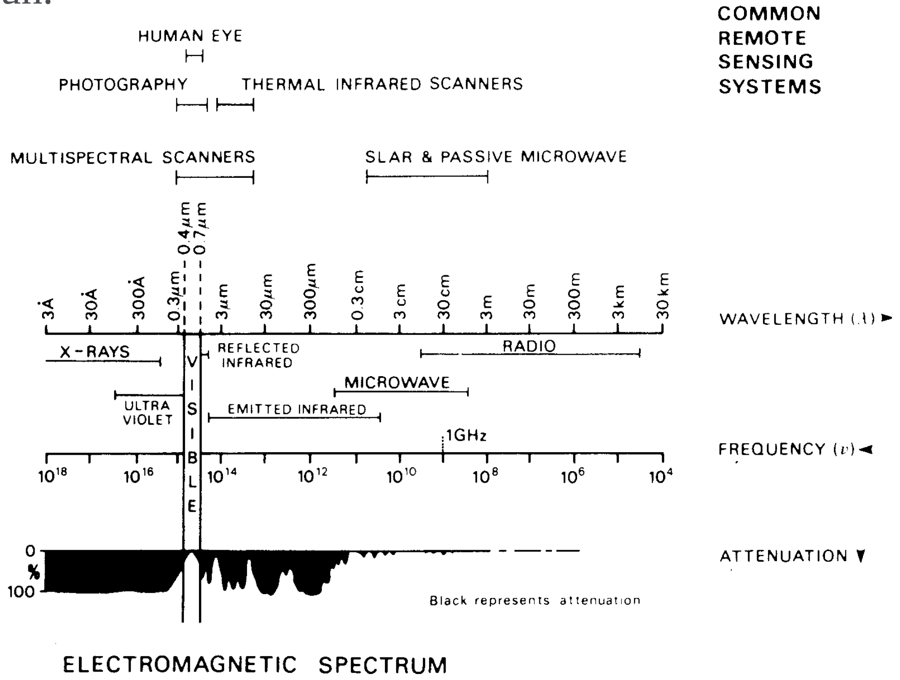
10/09/2018



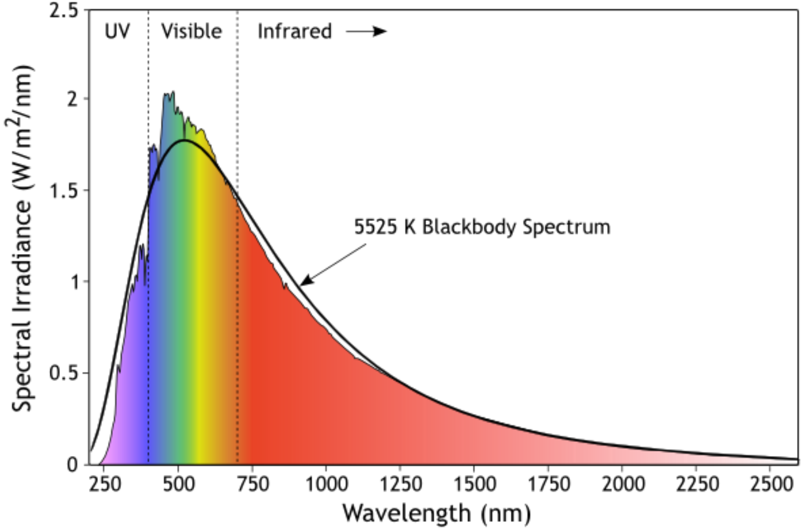
Optical Sensors

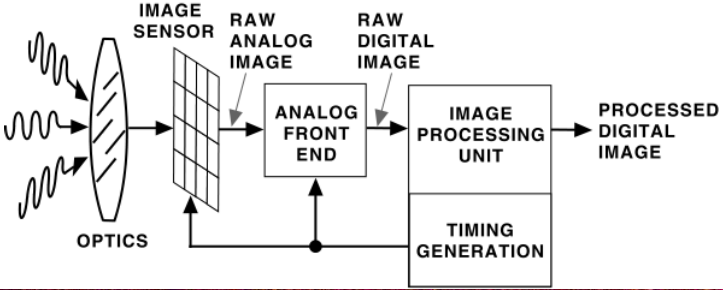
- Measure light from blue (~400 nm) to shortwave infrared (SWIR; ~2500 nm).
- Passive sensors where the energy source is the Sun.





Solar Spectrum: Spectral vs Spatial Resolution





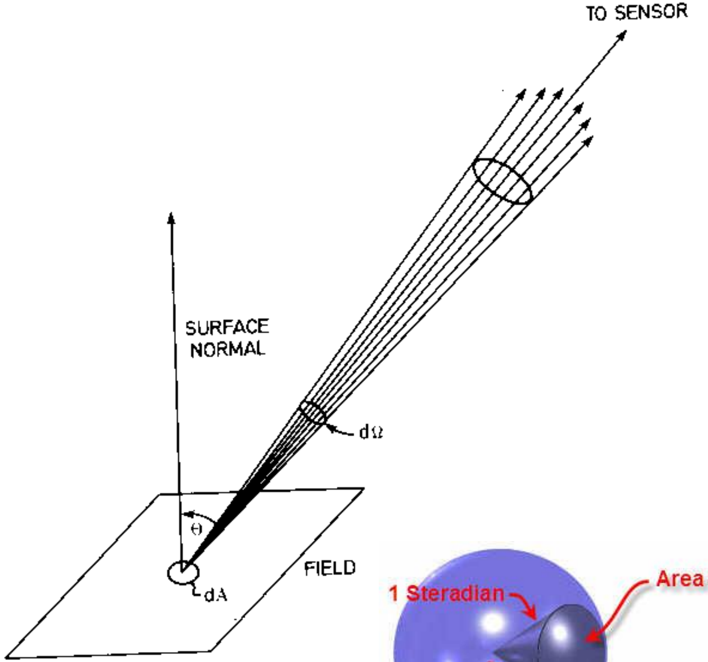
- Visible wavelengths have the most energy being transmitted.
- More energy equals a higher signal to noise ratio when signal is measured by sensor.
- Therefore, pixel resolution is proportional to the energy available.
  - Higher spectral and/or spatial resolutions are possible in visible wavelengths
  - NIR and SWIR bands have lower spectral and/or spatial resolutions as the is less energy.
  - Panchromatic sensors measure across whole VIS+NIR to increase spatial resolution.

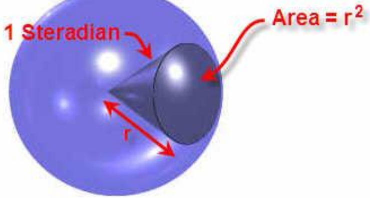
What is being measured?

Radiance

A measure of the quantity of radiation passing through or emitted from a surface and falls within a given solid angle in a specified direction.

The sensor receives radiant flux (ϕ) with a solid angle ($d\Omega$; Steradian) from an area within the field (dA)





What is being measured?

Radiance

Total energy per solid angle (Steradian) of measurement – *($Wm^{-2} sr^{-1}$)*

Spectral Radiance

The energy within a wavelength band radiated by a unit area per solid angle (Steradian) of measurement – *($Wm^{-2} sr^{-1} \mu m^{-1}$)*

What is being measured?

Radiance Energy

Total energy radiated in all directions - *Joules (J)*

Radiant Density

Total energy radiated by a unit area in all directions – *Joules per cubic metre (Jm^3)*

Radiant Flux

Total energy radiated in all directions for a unit of time – *Watt (W)*

Radiant Existence

Total energy radiated in all direction by unit (out) area in a unit time – (*Wm^{-2}*)

Irradiance

Total energy radiated onto a unit area in a unit of (in) time – *(Wm^{-2})*

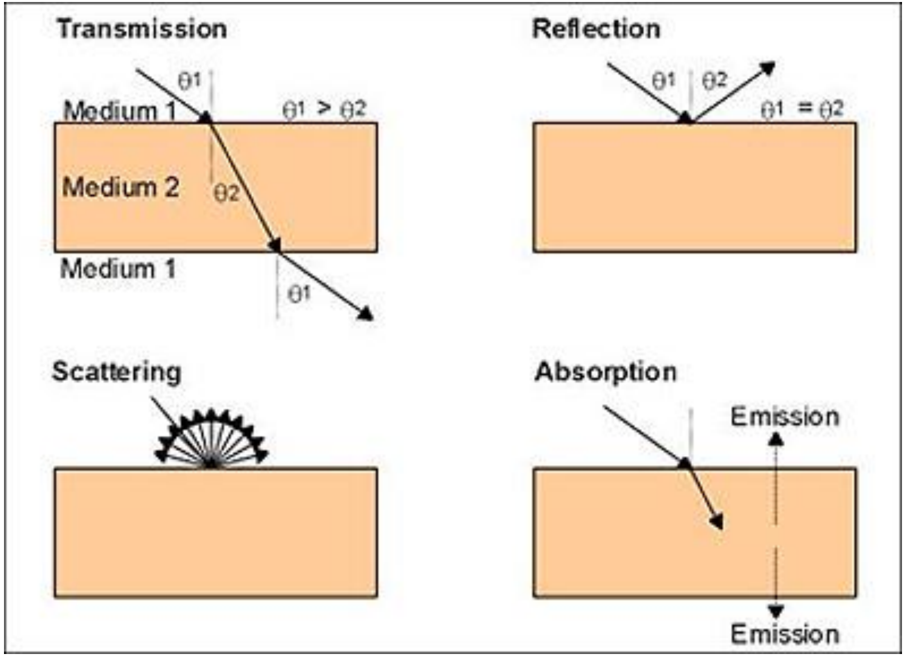
Radiant Intensity

Total energy per solid angle (Steradian) of measurement – (Wsr^{-1})

How does energy interact?

- As light passes between two mediums one of the following will occur:
    - Transmission
    - Absorption
    - Reflected / Scattering

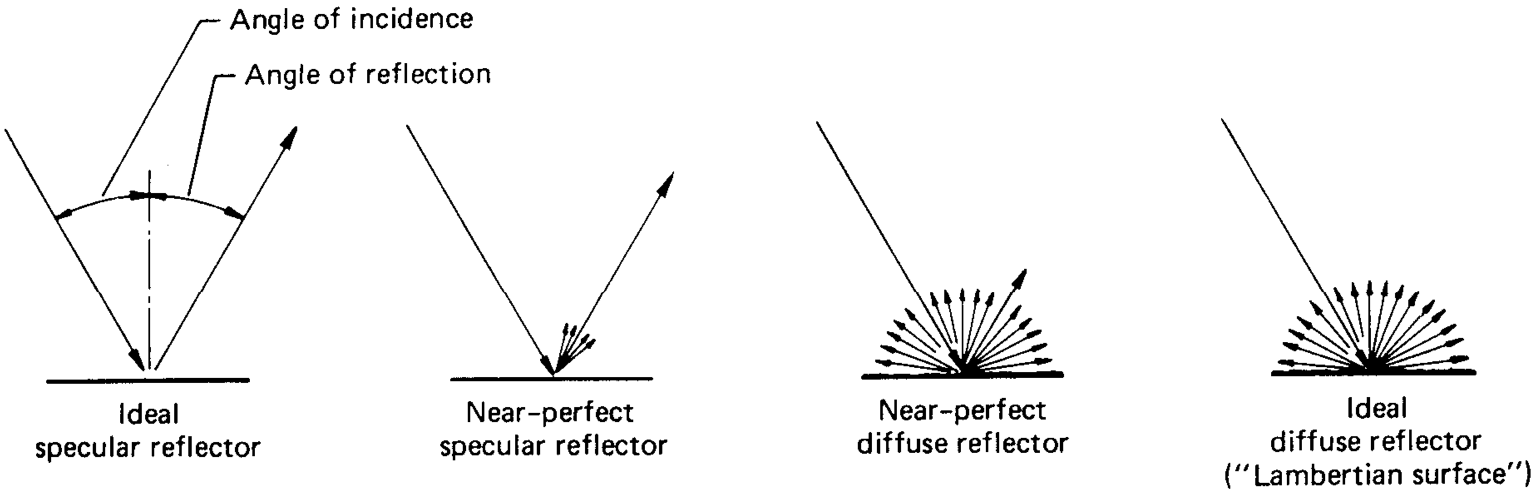
- The process is controlled by the wavelength of light and the medium/surface.
    - e.g., Roughness
    - Particle size



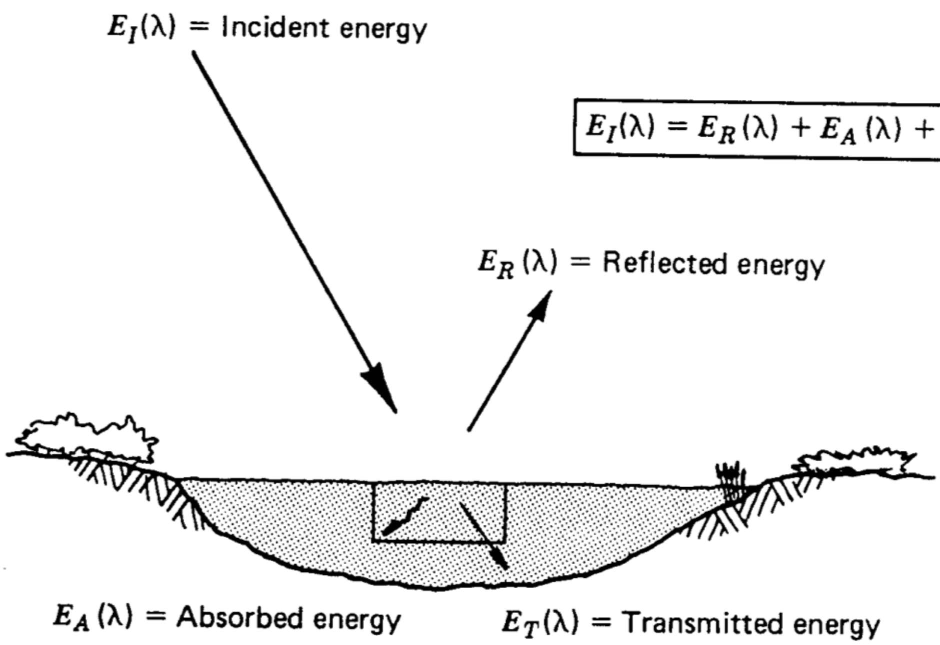
Surface Reflection / Scattering

There are 2 scattering mechanisms

- Diffuse
- Specular



Energy Transfer Model: Spectral Reflectance (ρ_λ)



Spectral Reflectance (ρ_λ) is the proportion of the energy reflected.

$$r_l = \frac{E_R l}{E_I l}$$

Where,

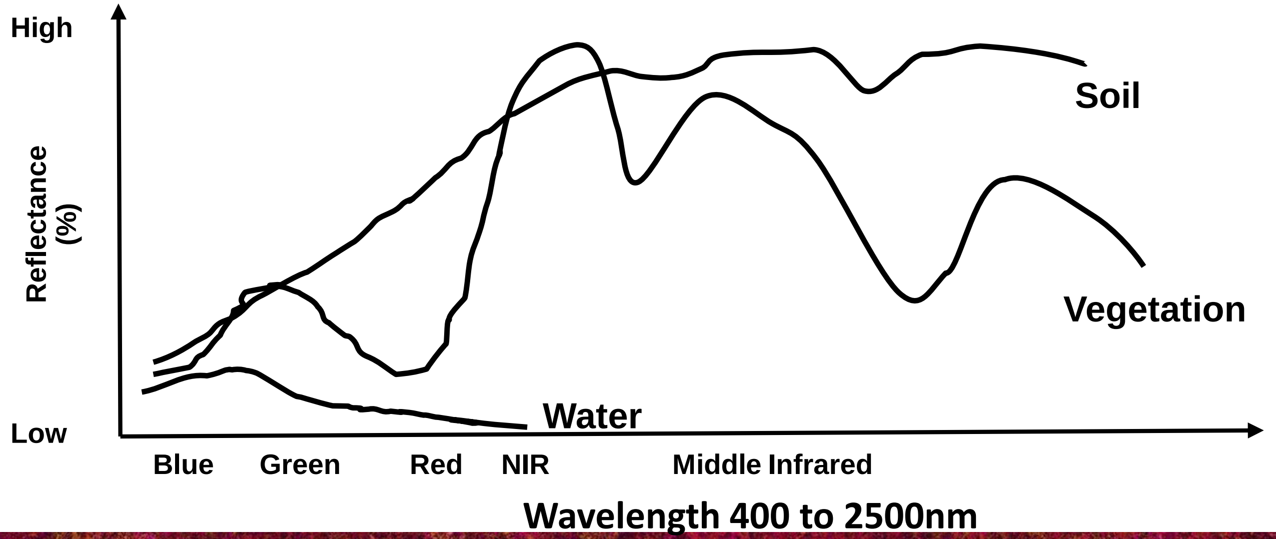
$E_R\lambda$ is the energy of wavelength (λ) reflected from the object.

$E_I\lambda$ is the energy of wavelength (λ) incident on the object.

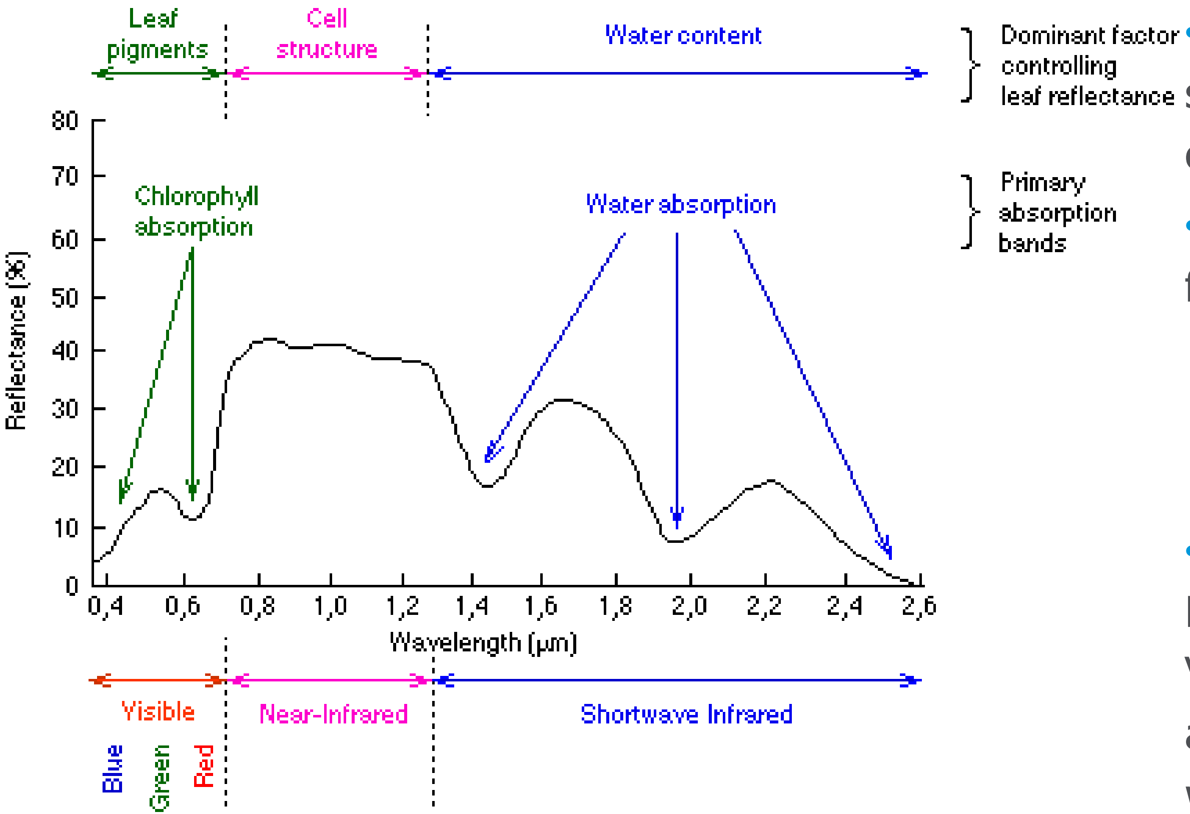
Spectral Signatures

The graphical representation of the spectral response of an object as a function of spectral wavelength is called **<u>spectral response</u>** - characteristic for each object.

Generalised Spectral Signatures of different objects



Vegetation Spectra



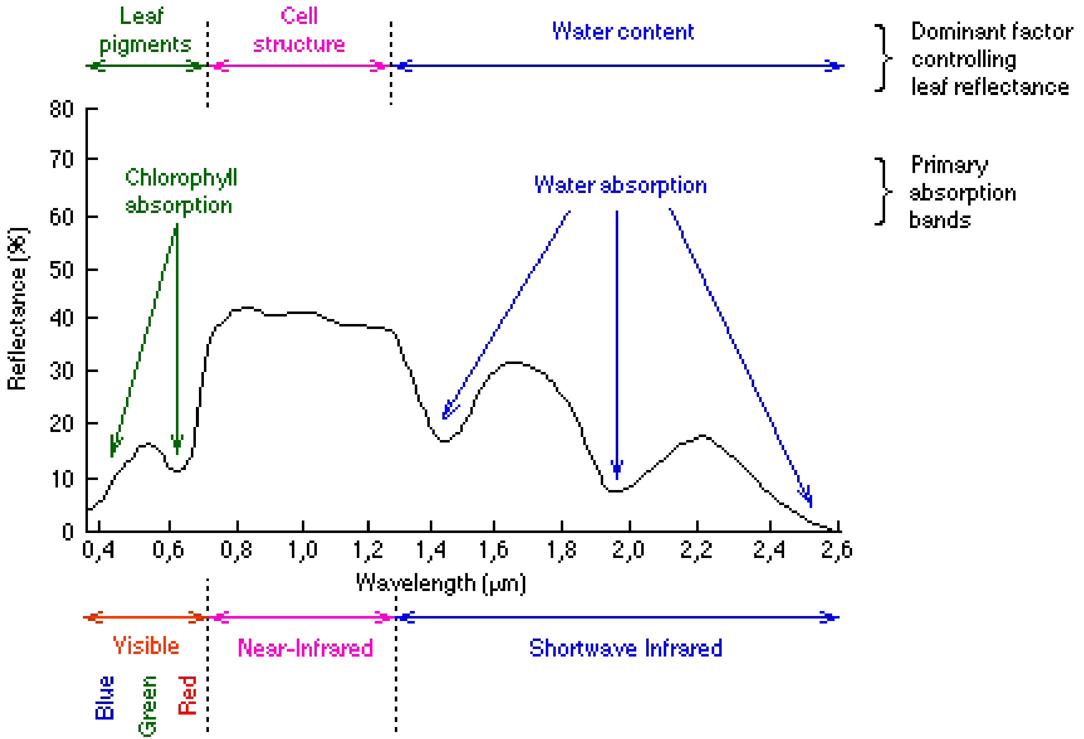
- Particular wavelengths are sensitive to particular chemicals and compounds.
- Result in absorption features.
  - Can be used to make measurements related to those compounds.
- Indexes such as the Normalised Difference Vegetation Index (NDVI) take advantage of these wavelength features.

Normalised Difference Vegetation Index (NDVI)

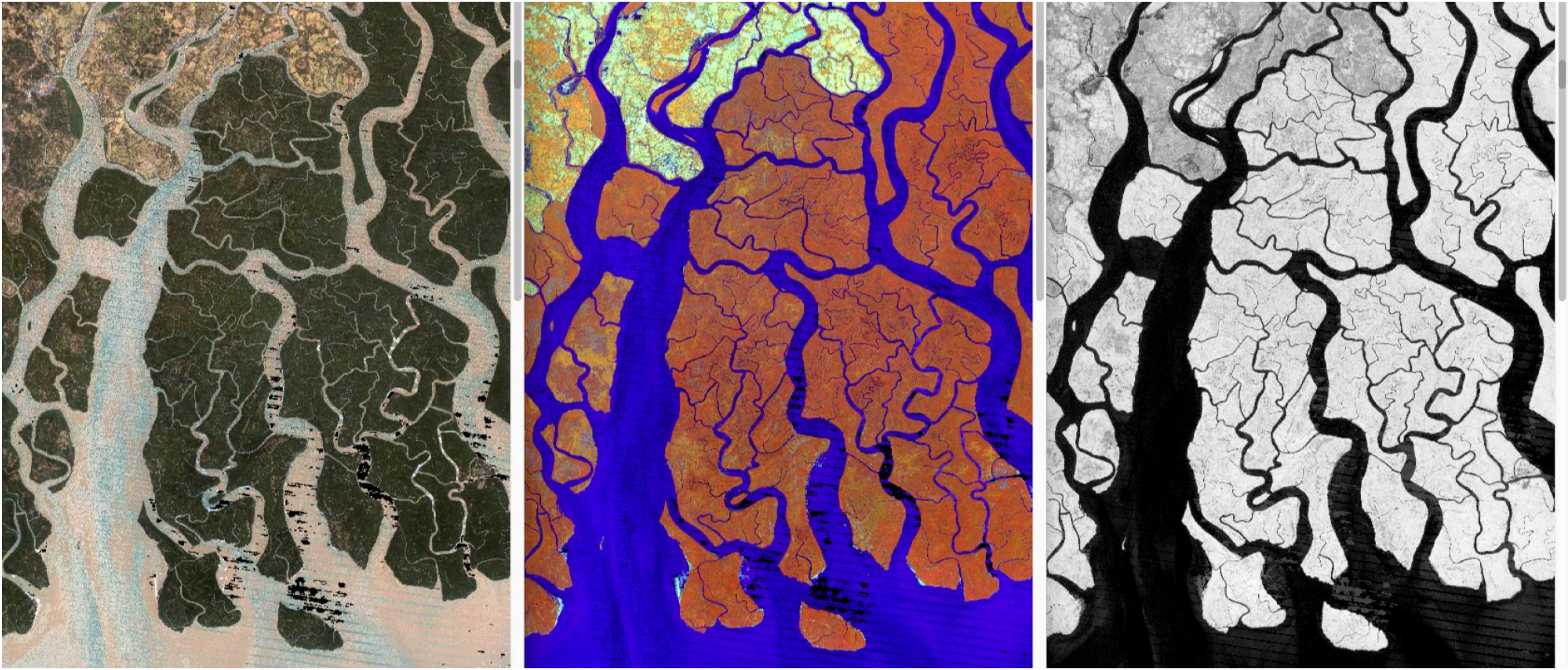
$$\text{NDVI} = \frac{(NIR - Red)}{(NIR + Red)}$$

- Vegetation has high NIR and low Red reflectance.

- Other land cover have NIR and Red which are much close together

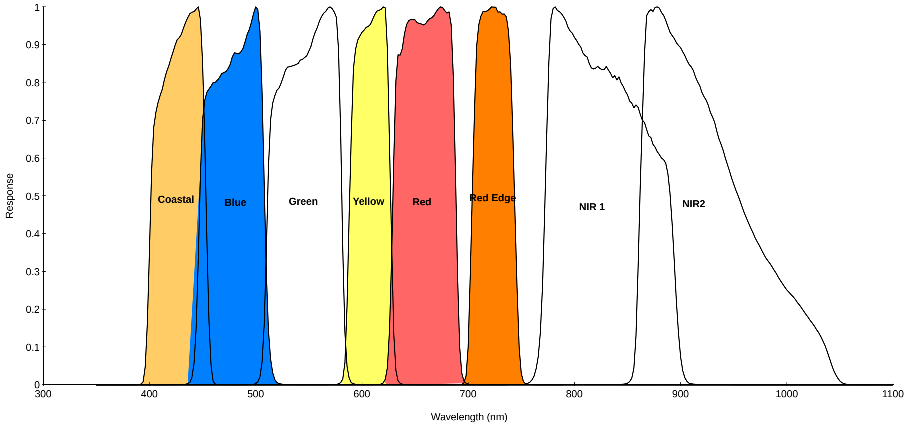


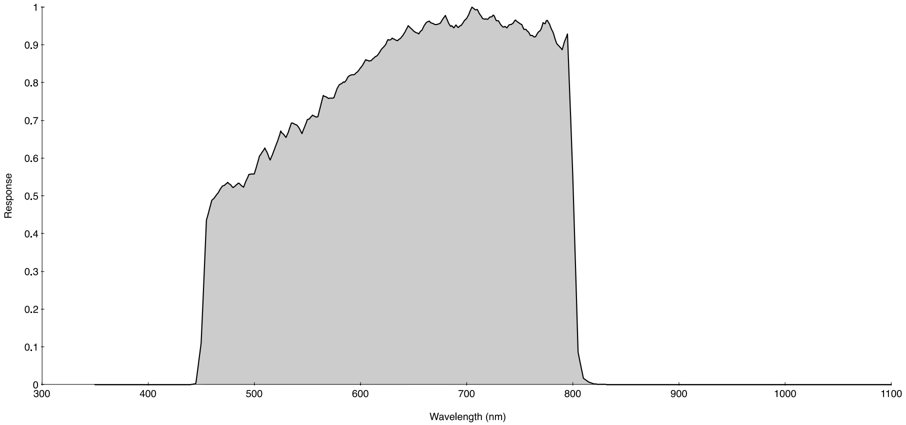
Normalised Difference Vegetation Index (NDVI)



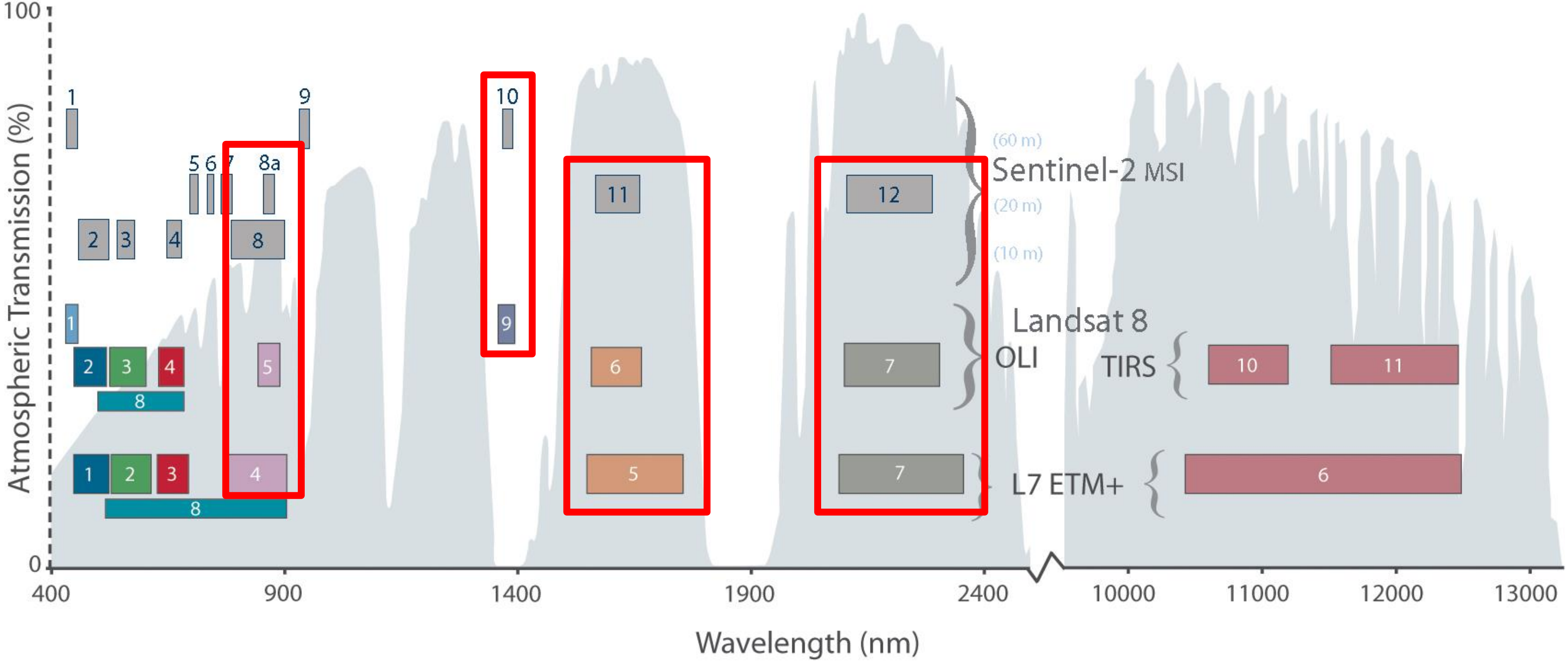
What Wavelengths are Measured

- A sensor is often characterised as having a set of ‘bands’ or wavelengths which are being measured.
- *For example Worldview 2 has*: Panchromatic, Coastal, Blue, Green, Yellow, Red, Red-Edge, NIR-1 and NIR-2 bands
- Sensor response functions represent the sensitivity with respect to wavelength





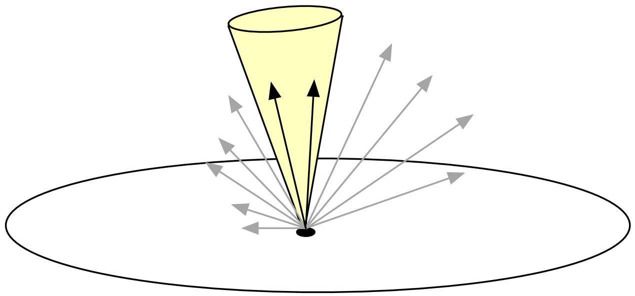
Comparison of Sentinel-2 and Landsat 7 & 8



Albedo vs Surface Reflectance

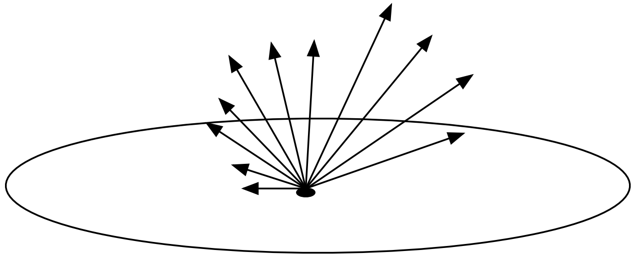
Surface Reflectance:

The ratio of the energy within a wavelength band radiated by a unit area per solid angle (Steradian) of measurement ($Wm^{-2}\ sr^{-1}\ \mu m^{-1}$) with the incoming energy.



Albedo:

The ratio of the all energy (practically bound by wavelengths measured) radiated by a surface ($Wm^{-2}\ \mu m^{-1}$) with the incoming energy.



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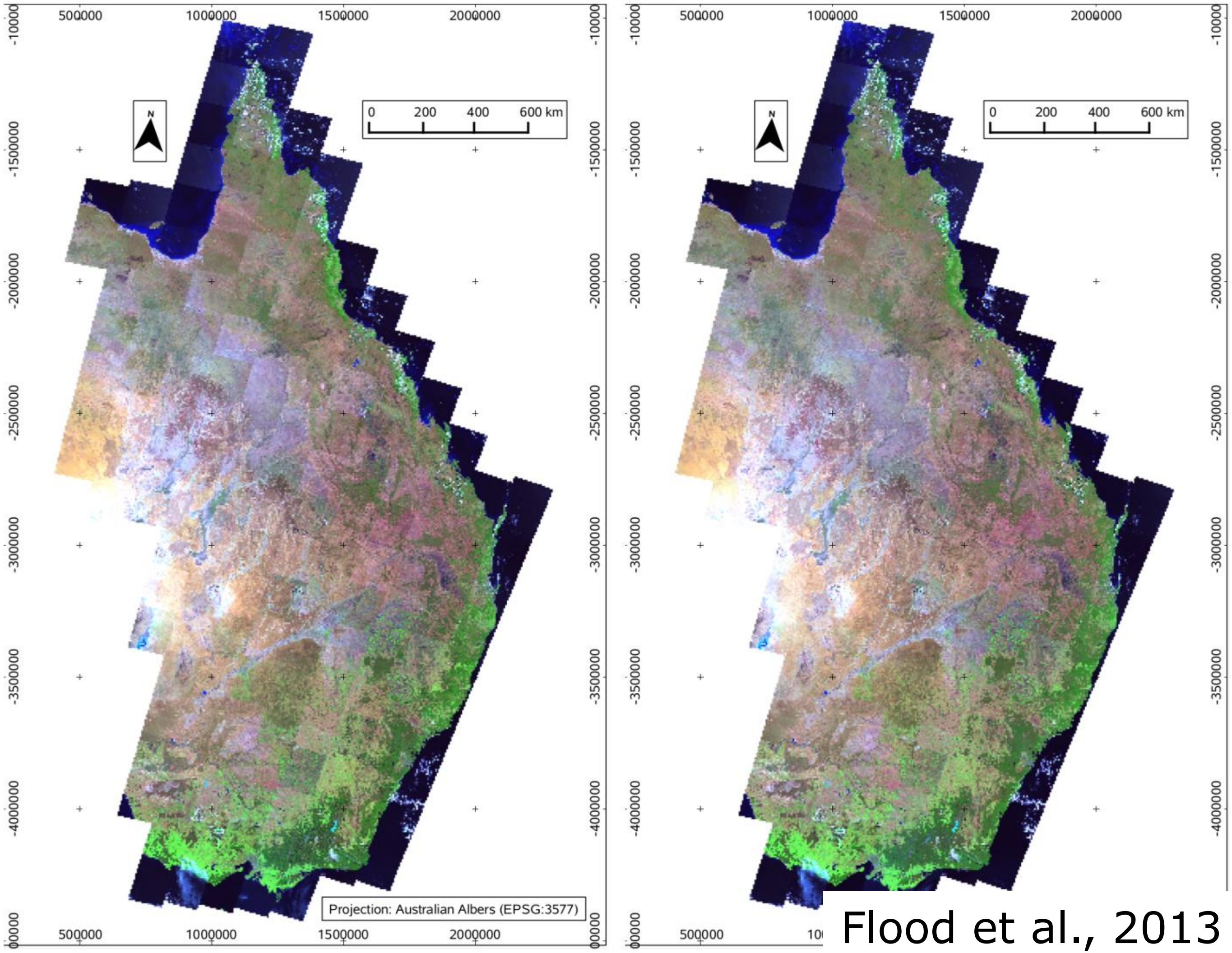
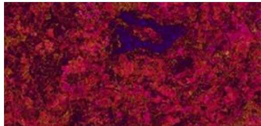
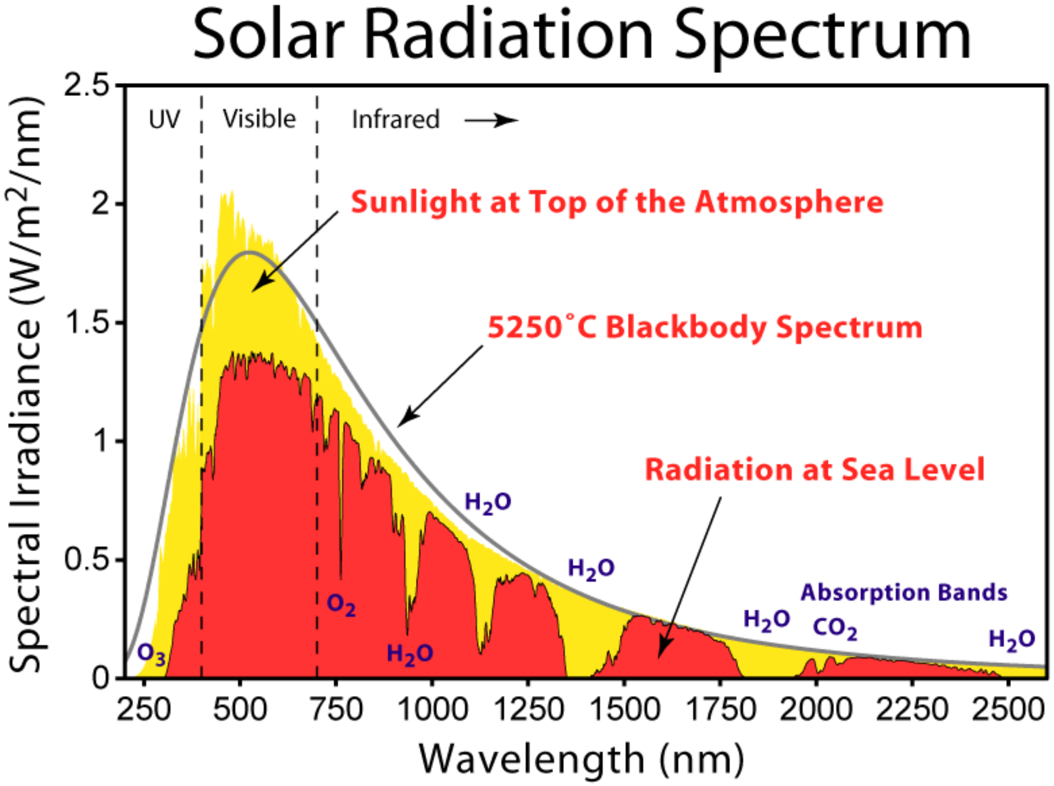


Flood et al., 2013



But what about the atmosphere?



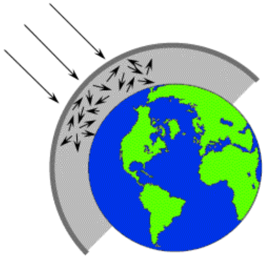
Interactions with particles within the atmosphere cause:

- Absorption
- Reflectance
- Transmission

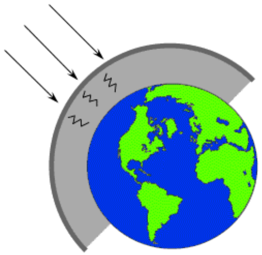
Interactions with the Atmosphere

- Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere
- Particles and gases in the atmosphere can affect the incoming light and radiation:

A) Scattering



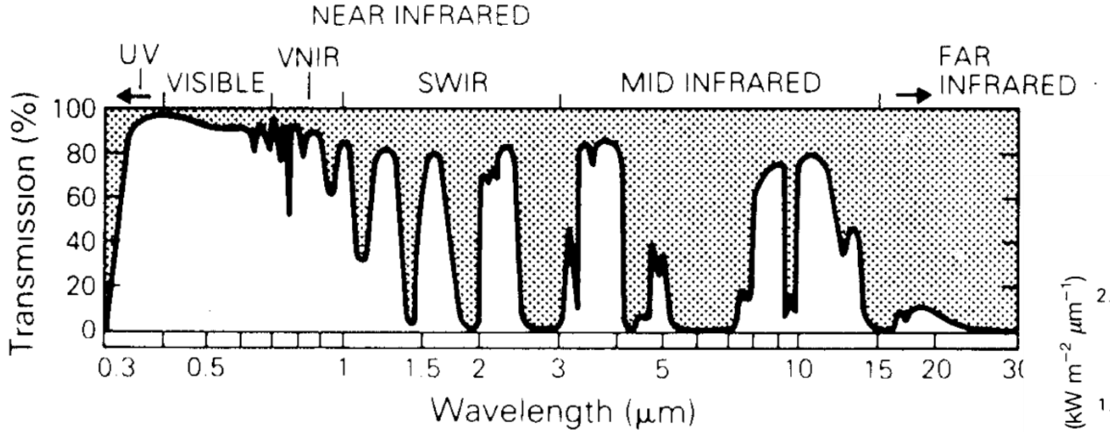
B) Absorption

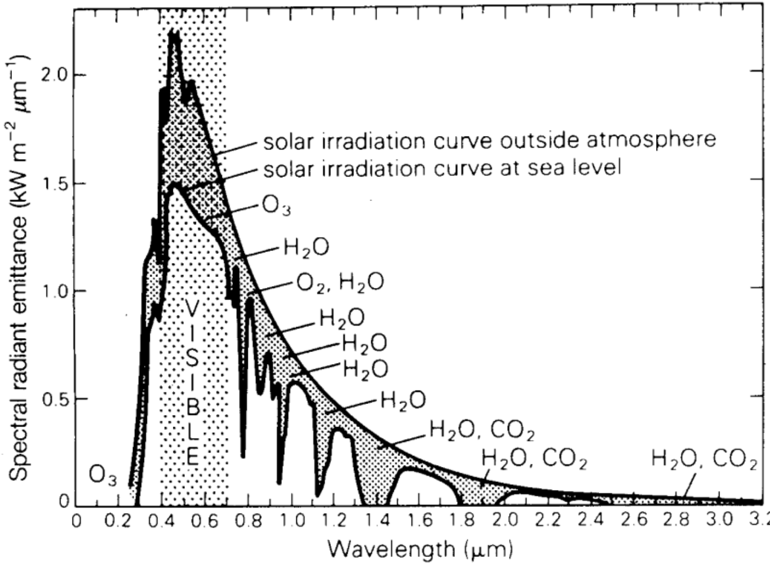


Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path

Absorption causes molecules in the atmosphere to absorb energy at various wavelengths.

Atmospheric Windows





Some wavelengths are more effected by the atmosphere than others

Those with little effect on signal are 'windows' for remote sensing.

Retrieval of Surface Reflectance

For further analysis we want to use a surface reflectance product

1. Allows comparison between images
2. Allows repeatable measurements (e.g., ground spectra comparison to satellite observations)
3. Represents a known physical unit.

To retrieve surface reflectance we need to 'add back' the component 'lost' in the atmosphere.

At Sensor Refl = Surface Refl + Atmospheric Refl

Top of Atmosphere (TOA) Reflectance

Also called 'At Sensor Reflectance'

$$\rho = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos(\theta_s)}$$

L_λ – At sensor radiance

d – Earth-Sun distance – astronomical units

$ESUN_\lambda$ – Solar exoatmospheric irradiance

θ - the solar zenith angle

What is in the atmosphere?

Aerosols

E.g., fine dust, sea salt, water droplets, smoke, pollen, spores, bacteria

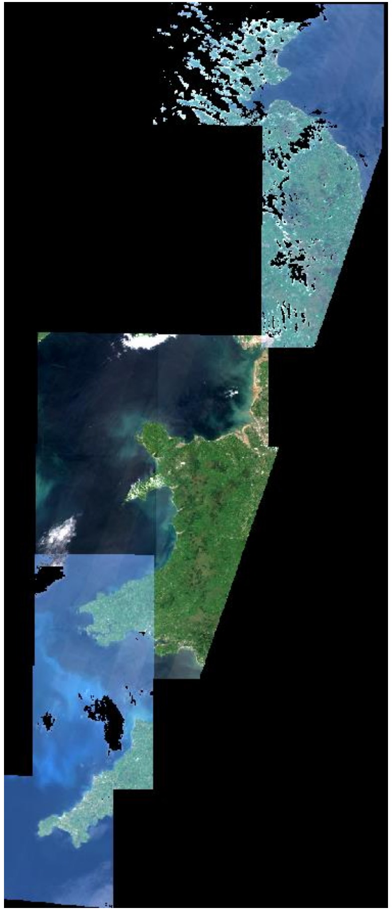
Has a significant effect on the visible wavelengths (Blue, Green and Red).

Aerosol Optical Depth (AOD)

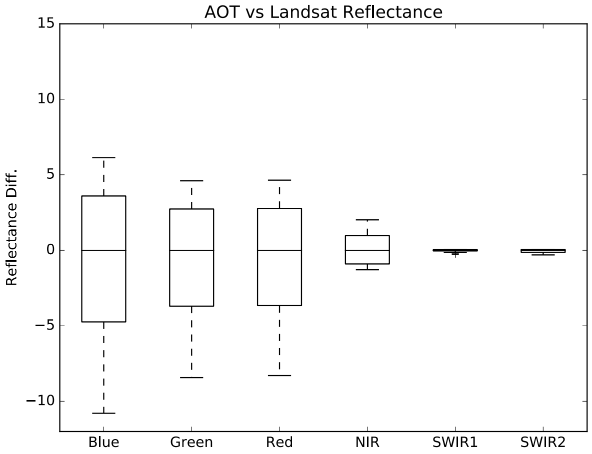
Aerosol Optical Thickness (AOT)

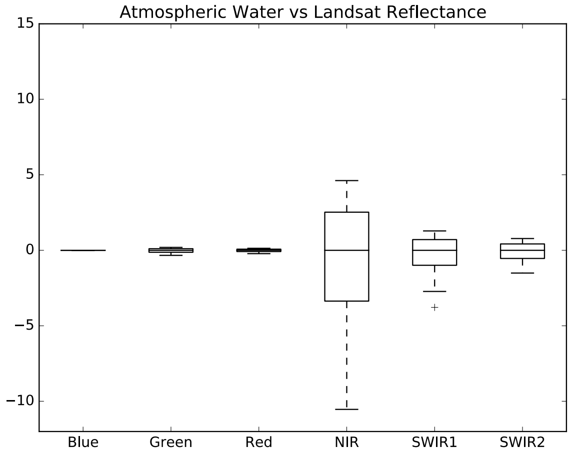
Water Vapour

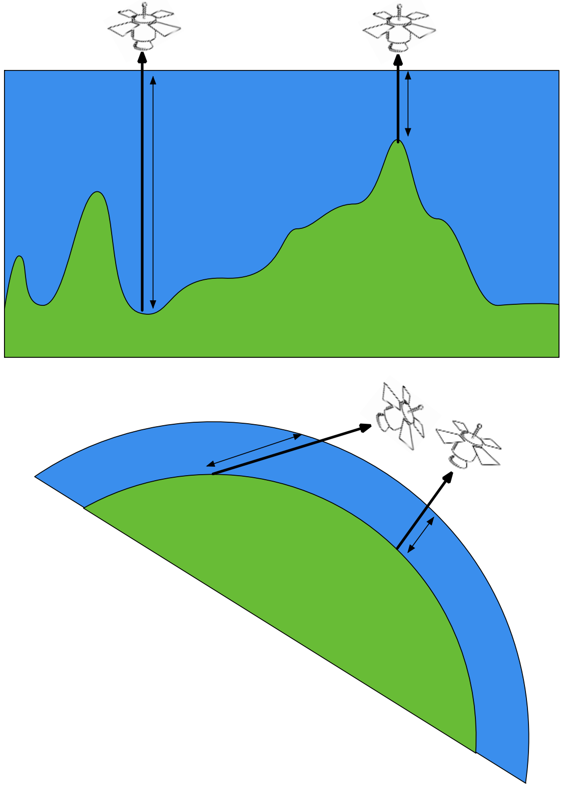
Particularly, effects the SWIR bands.



What is effects atmospheric Correction?







Relative contributions:

AOT = 80 %

Water Vapour = 15 %

Altitude = 4 %

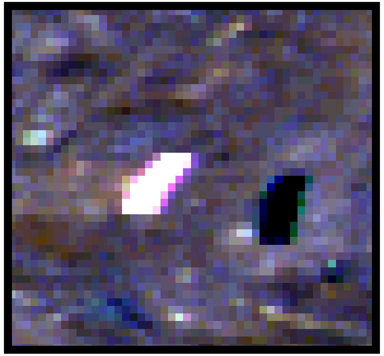
Options for Atmospheric Correction

1. Empirical Line Calibration
2. Dark Object Subtraction
3. Modelled Atmosphere

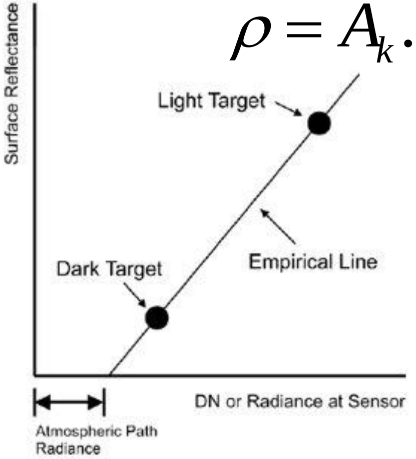
Empirical Line Calibration

- ρ is the in situ surface reflectance of materials at a specific wavelength.
- A_k is a multiplicative term (gain) affecting the BV_k and is associated primarily with atmospheric transmittance and instrumental factors
- BV_k = digital brightness value for a pixel of band k,
- B_k is an additive term (offset) which deals with atmospheric path radiance and instrument offset.
- Applied band by band, not pixel by pixel

- **Normally used for high resolution data.**
  - **Need to see the targets on the ground.**



$$\rho = A_k . BV_k + B_k$$



Dark Object Subtraction (DOS)

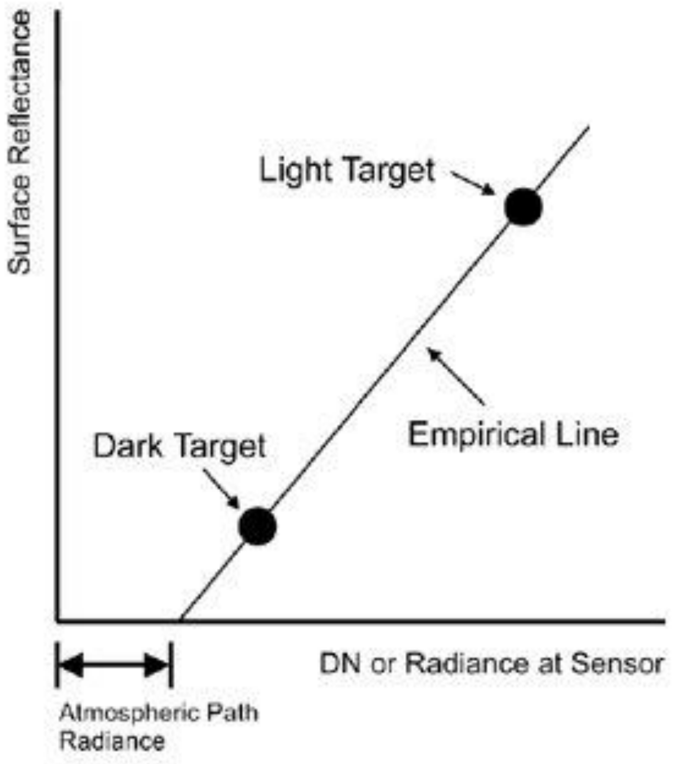
TOA Refl = Surface Refl + Atmospheric Refl

Find regions of the scene which have 'no' surface reflectance.

Assumption: *The very darkest objects in the scene can be assumed to have 'no' surface reflectance.*

Find these regions and remove the reflectance of these pixels from the whole scene.

Surface Refl = TOA Refl – Dark Obj Refl



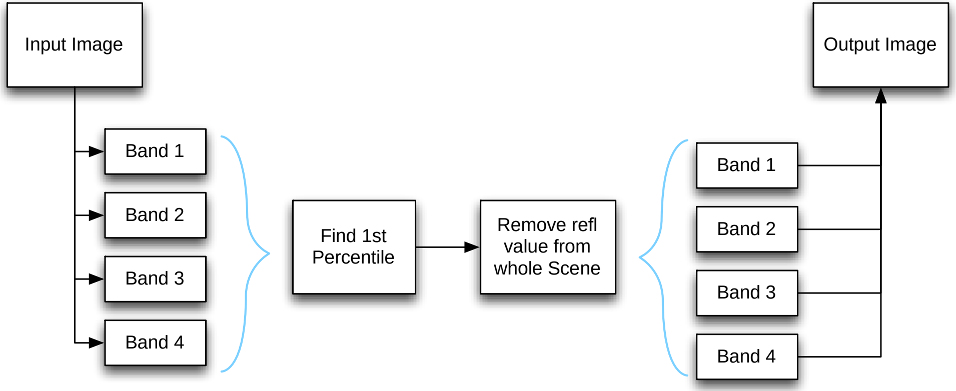
Dark Object Subtraction (DOS)

Advantages:

- Easy to implemented
- Fast to apply
- Requires very little (if any) parameterisation
- No further data required (e.g., elevation model or atmospheric or ground)

Disadvantages:

- Applied to the image bands independently.
- Does the assumption really hold?



Modelled Atmosphere

Use an atmospheric radiative transfer model to calculate the amount of atmospheric reflectance to be removed from the TOA to get surface reflectance.

Number of models are available but the main two are:

1. Modtran (Commercial)
2. 6S (Open Source)

Modelled Atmosphere: Key Parameters

Aerosol Optical Depth

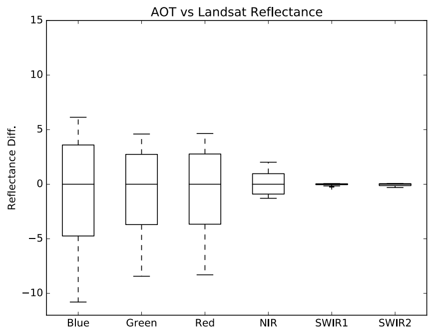
- Amount and proportion of aerosols within the atmosphere
- Varies over small spatial distances and temporal baselines.

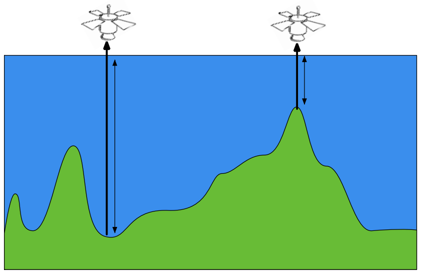
Water Vapour

- Amount within the vertical column

Surface Elevation

- Thickness of the atmosphere



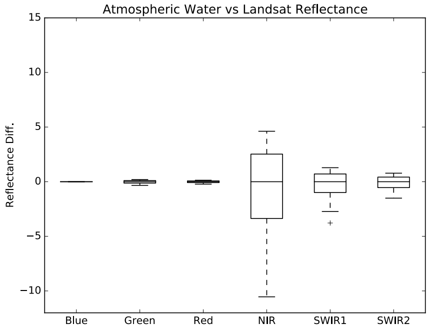


Relative contributions:

AOT = 80 %

Water Vapour = 15 %

Altitude = 4 %

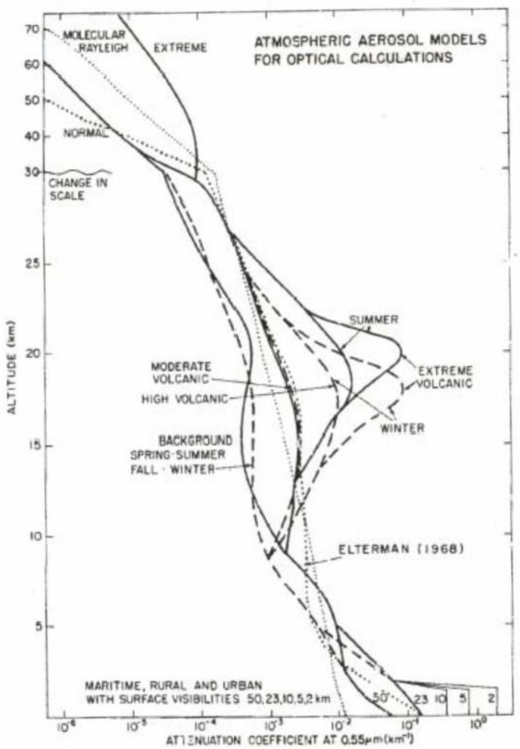


Atmosphere and Aerosol Profiles

- The atmosphere and aerosols vary vertically and over different land covers.

- Commonly ‘standard’ atmosphere and aerosol profiles are generally used.
- 6S has the following standard aerosol profiles:
    - Continental, Maritime, Urban, Desert, Biomass Burning, Stratospheric

- 6S has the following standard atmosphere profiles:
    - Tropical, Mid-latitude Summer, Mid-latitude inter, Sub-arctic Summer, Sub-arctic Winter, US Standard 1962



Aerosol Profiles in Modtran

Sources of Water Vapour

Source	Description	Reference / URL
MODIS	Satellite-based measurement of total column water vapour. Freely available download.	http://modis-atmos.gsfc.nasa.gov/MOD05_L2
Global Precipitation Measurement (GPM)	NASA owned satellite that includes instruments for the measurement of total column water vapour.	http://www.nasa.gov/mission_pages/GPM/main Draper et al., 2015
AMSR-2	JAXA owned satellite that includes instruments for the measurement of total column water vapour.	http://suzaku.eorc.jaxa.jp/GCOM_W
Seasonal Average	Where satellite estimates are not available for that date of acquisition Frantz et al., (2016) uses a local average.	Frantz et al., 2016

Sources of Aerosol Optical Depth (AOD) at 550nm

Source	Description	Reference / URL
AERONET	A network of sun photometers providing AOD measurements globally.	http://aeronet.gsfc.nasa.gov
Met Office Integrated Data Archive System (MIDAS)	Specific to the UK, the Met Office makes ground measurements publically available.	http://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0
MODIS	Satellite-based measurement of AOD at 550nm, available for free download.	http://modis-atmos.gsfc.nasa.gov/MOD04_L2/
LEDAPS	Estimates AOD for Landsat using dense dark vegetation (DDV) targets and relationship from the SWIR to visible wavelengths.	http://ledaps.nascom.nasa.gov
ARCSI	Multiple algorithms, including DDV method, but primarily uses a DOS based method to estimate surface reflectance in the blue wavelengths used for inversion.	http://www.rsgislib.org/arcsi
SEN2COR	Estimates AOD for Sentinel-2 using dense dark vegetation (DDV) targets and relationship from the SWIR to visible wavelengths.	http://step.esa.int/main/third-party-plugins-2/sen2cor/
Frantz et al., (2016)	Time series analysis to identify persistently dark targets that are used for AOD inversion.	Frantz et al., (2016)
Constant	For Australia and New Zealand a constant AOD value of 0.05 is used.	Gillingham et al (2013)

Aerosol Optical Depth (AOD) Estimation

- AOD varies both spatial and temporally

- Therefore, ideally an atmospheric correction processing chain would:
    1. Derive the AOD estimate from the input image directly
    2. Derive an AOD surface for the input image.

- AOD estimation involves numerically inverting the radiative transfer model (e.g., 6S) using a look up table (LUT).
    - **Estimate surface reflectance for a feature(s) in the image**
    - Test a set of AOD values to find the value which gets closest to the estimated surface reflectance value.

Methods of Estimating Surface Reflectance

Dense Dark Vegetation (DDV):

- Derives a relationship between TOA SWIR and SREF Visible for DDV targets.
- Typically, a linear relationship multiplying by 0.33, although ranges from 0.25-0.45.
- Some areas don’t have suitable DDV targets (e.g., Australia; Gillingham et al 2013)

Dark Object Subtraction (DOS):

- Performs a DOS on blue (or other visible channel) to estimate the SREF value.
- Typically only calculates a single AOD value for the scene rather than a surface.

Methods of Estimating Surface Reflectance

MODIS Reflectance Product:

- Uses the SREF 8 day composites (500 m), resample the TOA radiance image.
- Landsat bands are a good match to MODIS – other sensors might not be.
- Only available since MODIS launch (2002)
- Error propagation from MODIS product - probably most reliable product available

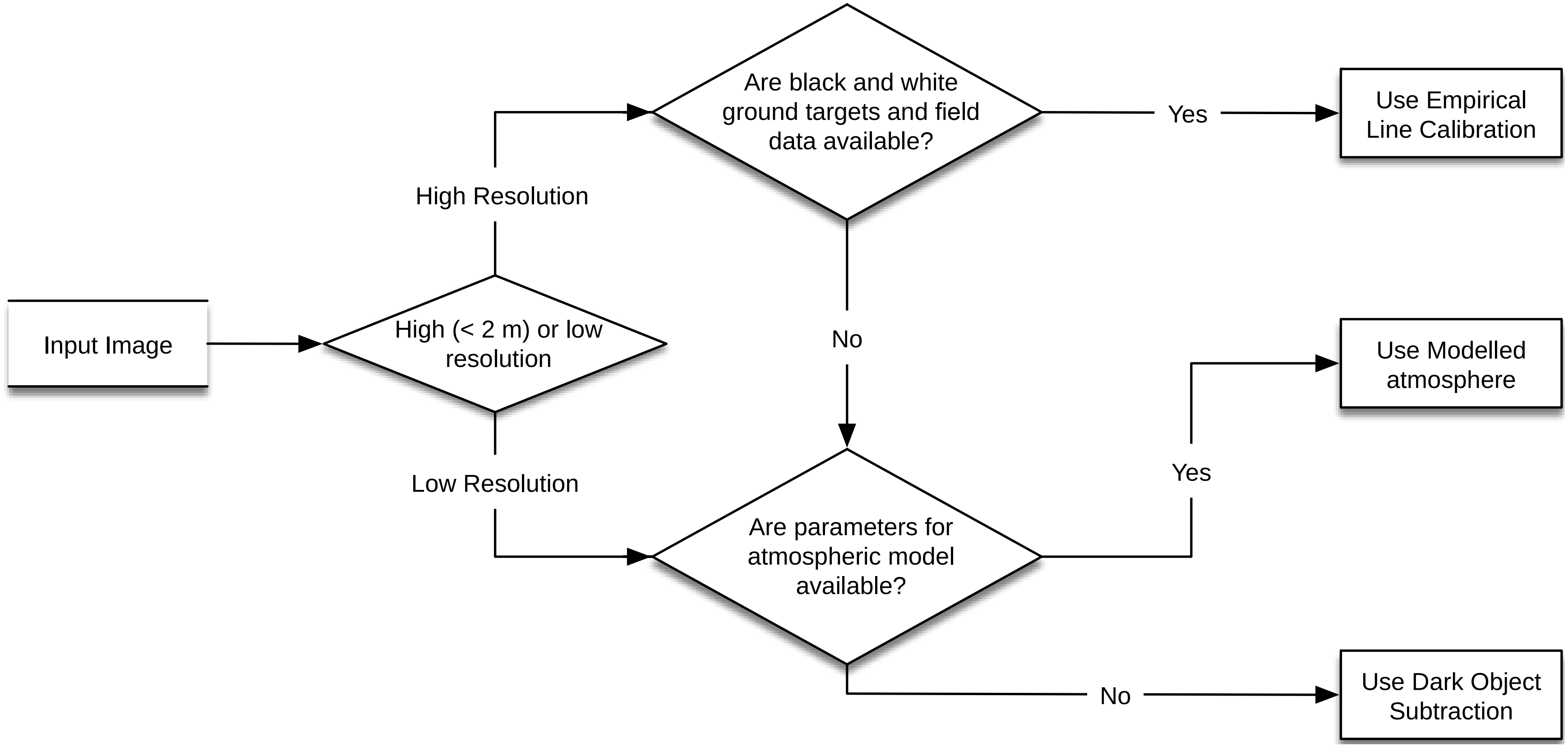
Persistently Dark Targets:

- Use a timeseries to find targets which have not changed and are persistently dark. Use darkest value within the timeseries as SREF estimate.
- Might underestimate true SREF value.
- Require timeseries processing – significant if just processing a few scenes.

Available Software Tools

Software	RT Model	Sensors	License	URL
ATCOR-4 (Airborne)	MODTRAN	Many – see website	Commercial	https://www.rese-apps.com/software/atcor-4-airborne
ATCOR-3 (Satellite)	MODTRAN	Many – see website	Commercial	https://www.rese-apps.com/software/atcor-3-satellites
FLAASH	MODTRAN	Many – see website	Commercial	http://www.harrisgeospatial.com/docs/FLAASH.html
LEDAPS	6S	Landsat (TM, ETM+)	Partly Open Source	http://ledaps.nascom.nasa.gov
SEN2COR	MODTRAN	Sentinel-2	Partly Open Source	http://step.esa.int/main/third-party-plugins-2/sen2cor/
ARCSI	6S	Landsat (MSS, TM, ETM+, OLI), Rapideye, SPOT5, SPOT6, SPOT7, WorldView-2, WorldView-3, Pleiades, Sentinel-2	Open Source	http://arcsi.remotesensing.info

What to use for atmospheric correction?

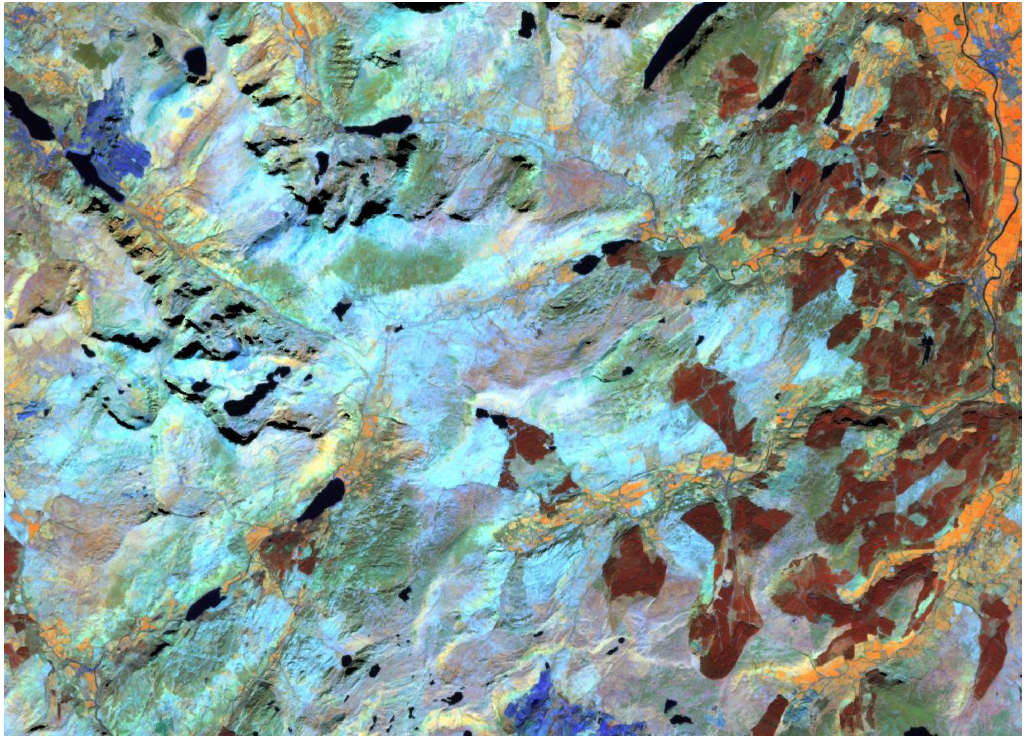


Topographic Normalisation

Two main approaches:

1. Numeric Normalisation Correction
   - COSINE Correction

2. BRDF Based Correction
   - Shepherd and Dymond 2003
   - Flood et al., 2013
   - Also referred to as standardised reflectance



Analysis Ready Data (ARD)

"Data which is ready to use for the analysis you want to undertaken."

- This may differ between applications

- However, for optical data this is typically:
  - Surface reflectance (%); as accurately as possible with illumination correct (e.g., topographic normalisation)
  - Removal of 'invalid' image pixels
    - Cloud cover
    - Shadowing
    - Saturation

Cloud and Cloud Shadow Masking

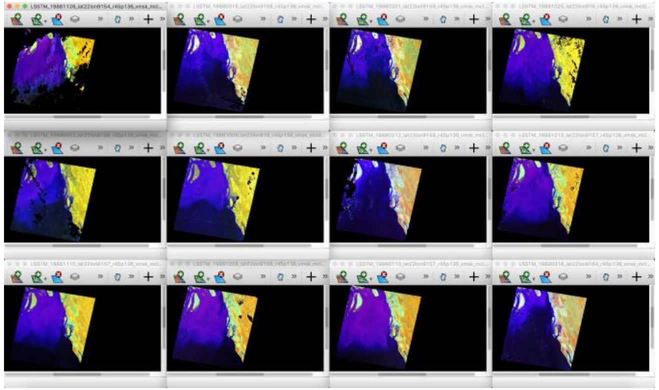
- This is a huge topic in itself but of key importance in terms of making optical data useful for operational applications.
- Thermal very useful – clouds are cold because they are high.
- Landsat has a robust approach, Fmask (Zhu and Woodcock 2012), but it is far from perfect.
- Sentinel-2 has some approaches available but none yet to be considered robust.

Compositing

- For some an analysis ready dataset (ARD) is an image where the holes associated with cloud and other invalid pixels are filled with data from another images.
- This process is called compositing.
- Generally, needs some care to ensure that compositing is going to provide the expected result for a given application.
    - For example, compositing images across seasons can mask important information which aids class separation.

- Maximum NDVI composites is widely used and does a good job and minimising any remaining cloud in the composite – although cloud shadow pixels can often be selected.

Compositing



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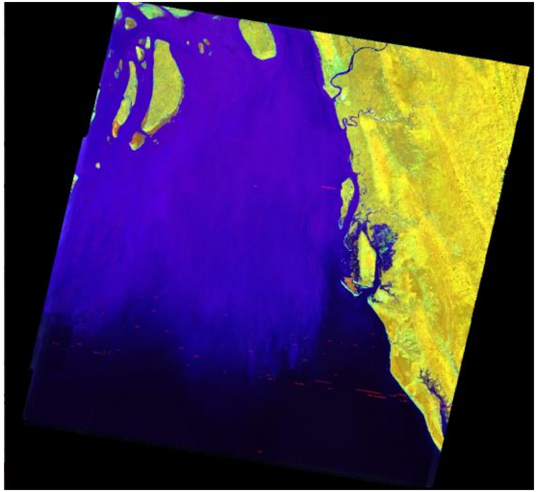
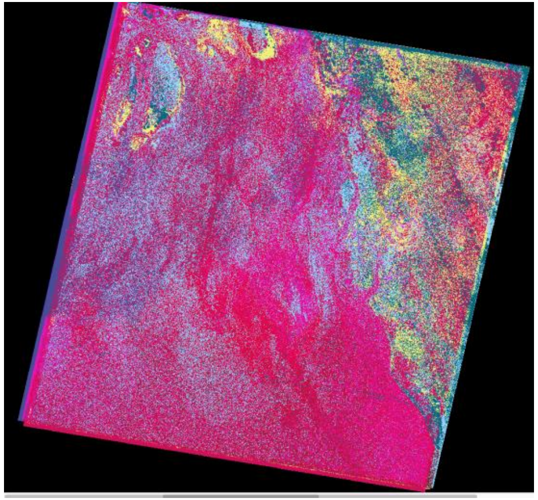


Max. NDVI Composite

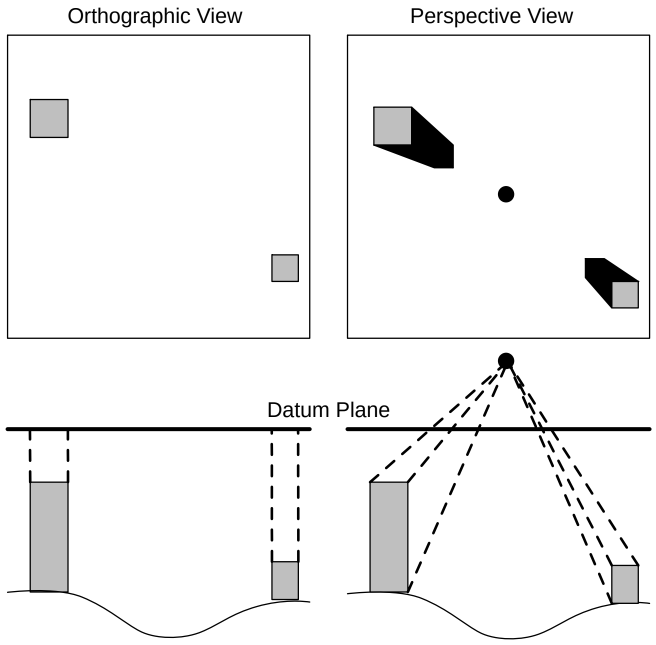


Pixel Reference

1. On a per pixel basis find the image with the maximum NDVI from the input images.
2. Extract the band values from image and write to the output image.

Don’t Forget Geo-location…

- Without accurate orthorectification:
  - Any derived products will be incorrectly geo-located
  - Very difficult to use images together (e.g., change detection) without good registration.



Conclusions

- What does Analysis Ready Data (ARD) look like for you and your application?
    - Unlikely to be too different to what I've outlined.
- There are now CEOS standards being formed for ARD.
    - It is likely that in the future ARD data will be centrally generated by the data providers.
- Generating the ARD products is computationally demanding.
    - Hence the interest in centrally producing ARD products.
- Validating surface reflectance ARD products is difficult.
    - How do we know we've got the correct result?
- Cloud and cloud shadow masking is difficult but key to making optical data useful.

Questions

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