Remotely Sensing Cities and Environments

Lecture 3: Remote sensing data

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PDF presentation

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Before we begin

A Trip Through Time With Landsat 9

A Trip Through Time With Landsat 9 .Source:NASA Goddard

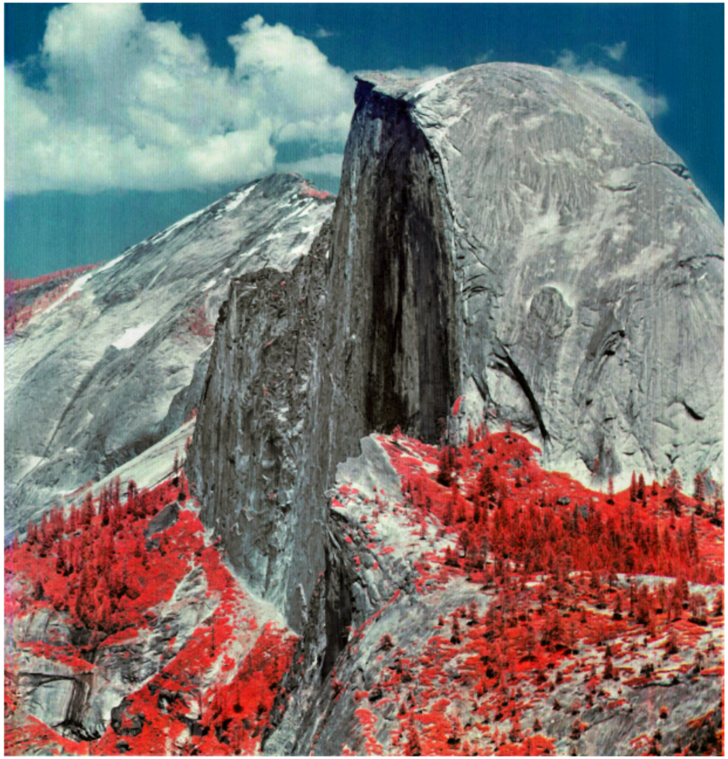
The woman who brought us the world

- NASA wanted to use a RBV camera - TV camera with Green, Red and NIR of the spectrum.
- Norwood thought that a digital Multispectral camera (MSS) would be much better.
- MSS could get both visible and "invisible"
- Norwood given $100,000

Norwood and Labor Secretary James Hodgson discuss how Landsat's multispectral scanner works at a conference in 1972.Source:MIT Technology Review. COURTESY OF VIRGINIA NORWOOD

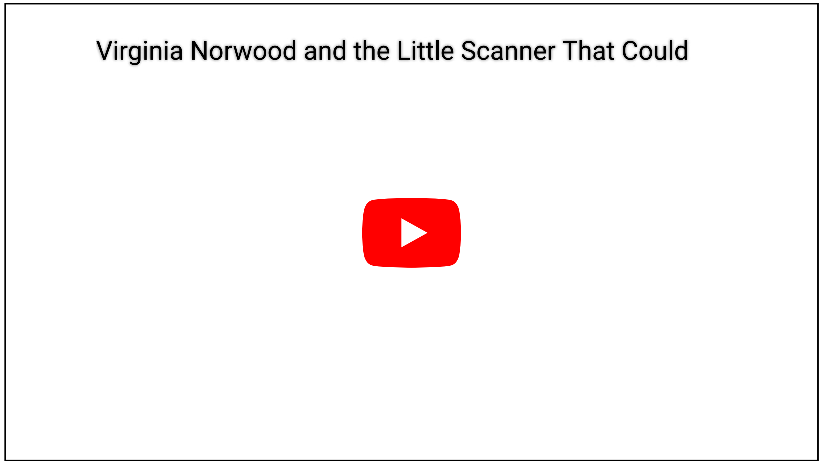
The woman who brought us the world 2

- NASA doubted it could be digital they wanted **analogue**!
- NASA wanted three detectors with different filters
- Used a pivoting mirror not scanner to
- NASA would use this and it became **the standard for the future of remote sensing**
- No time for a final product
- The prototype was used on the satellite
- Still, most people thought the tv cameras were more useful 😜



A test version of Norwood's multispectral scanner captured this false-color image of Half Dome from a truck two months before Landsat 1's launch.Source:MIT Technology Review. COURTESY OF NASA

Virginia Norwood



Virginia Norwood and the Little Scanner That Could .Source:NASA Goddard

The different sensors...

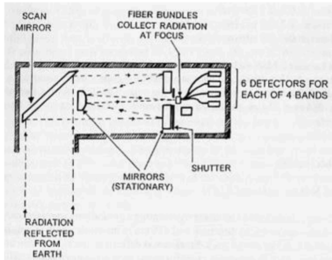


Figure 11: Alternate view of the MSS scanning concept (image credit: J. Campbell, Georgia Tech)

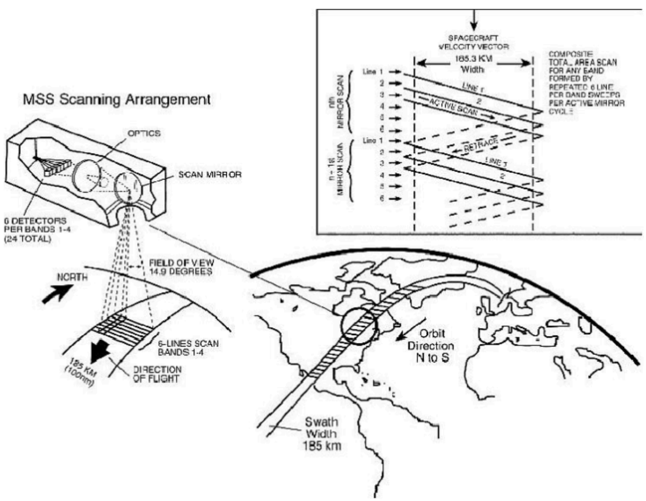


Figure 12: Enlarged view of MSS scanning geometry and image projection (image credit: NASA)

MSS sensor.Source:eoportal

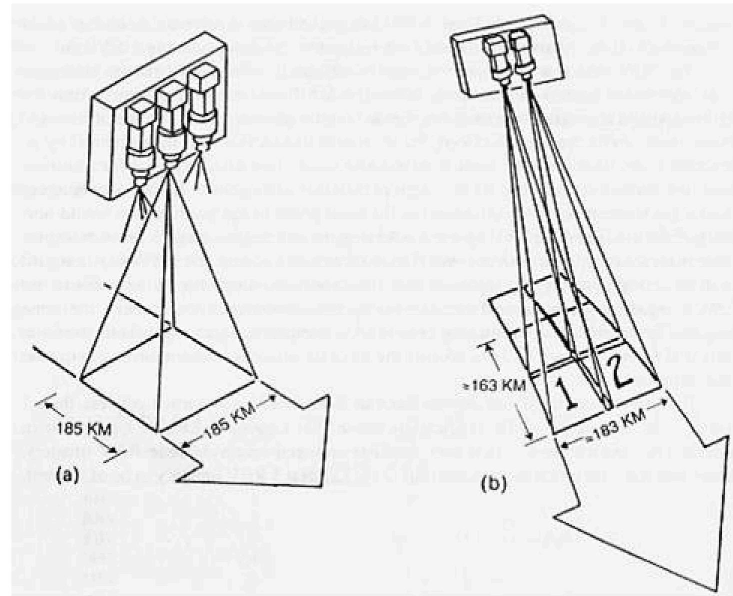


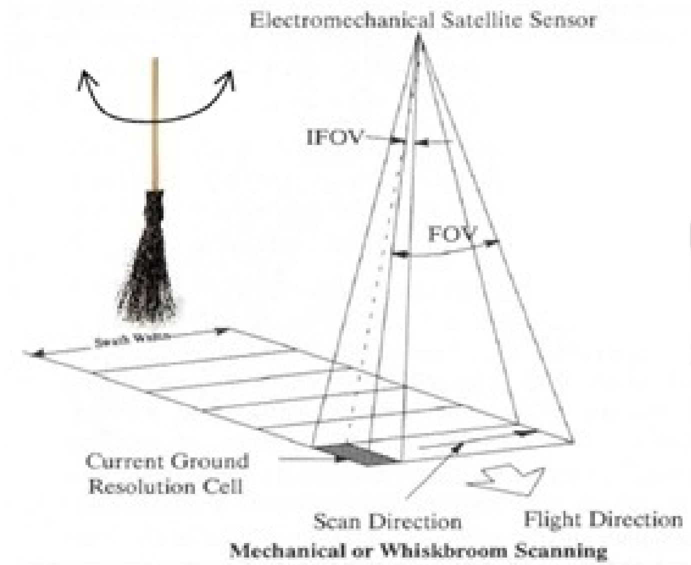
Figure 14: Schematic view of coaligned RBVs taking imagery of a target region (image credit: J. Campbell, Georgia Tech)

RBV sensor.Source:eoportal

Push broom vs Whisk broom

Whisk broom or spotlight or across track scanners

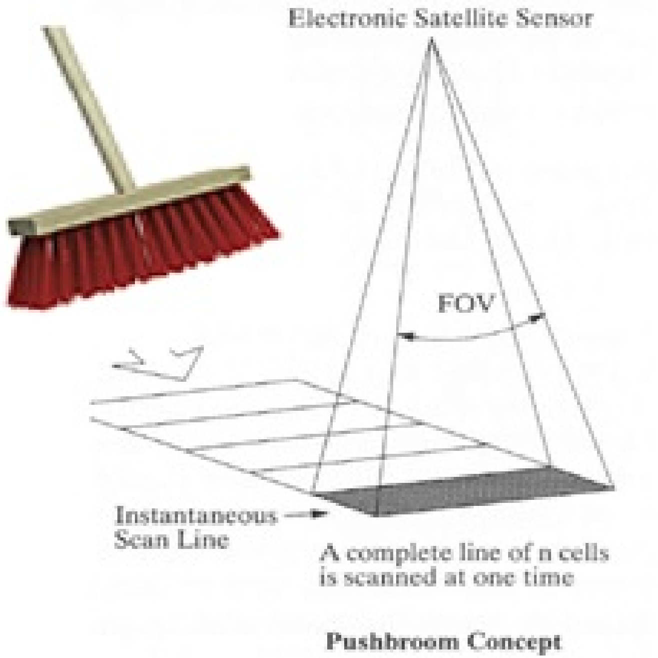
Mirror reflects light onto 1 detector - Landsat



Push Broom and Whisk Broom Sensors. Source:NV5.)

Push broom or along track scanners

several detectors that are pushed along - SPOT, Quickbird

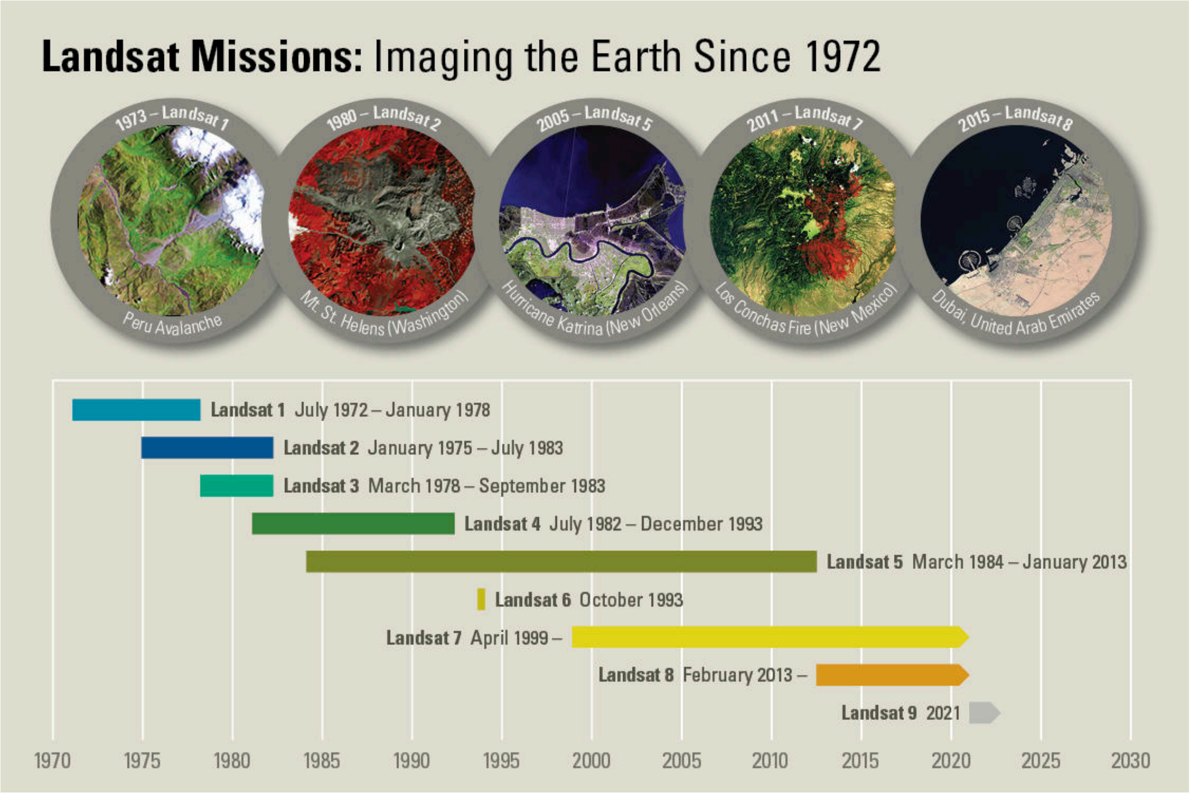


Push Broom and Whisk Broom Sensors. Source:NV5.)

Half Dome

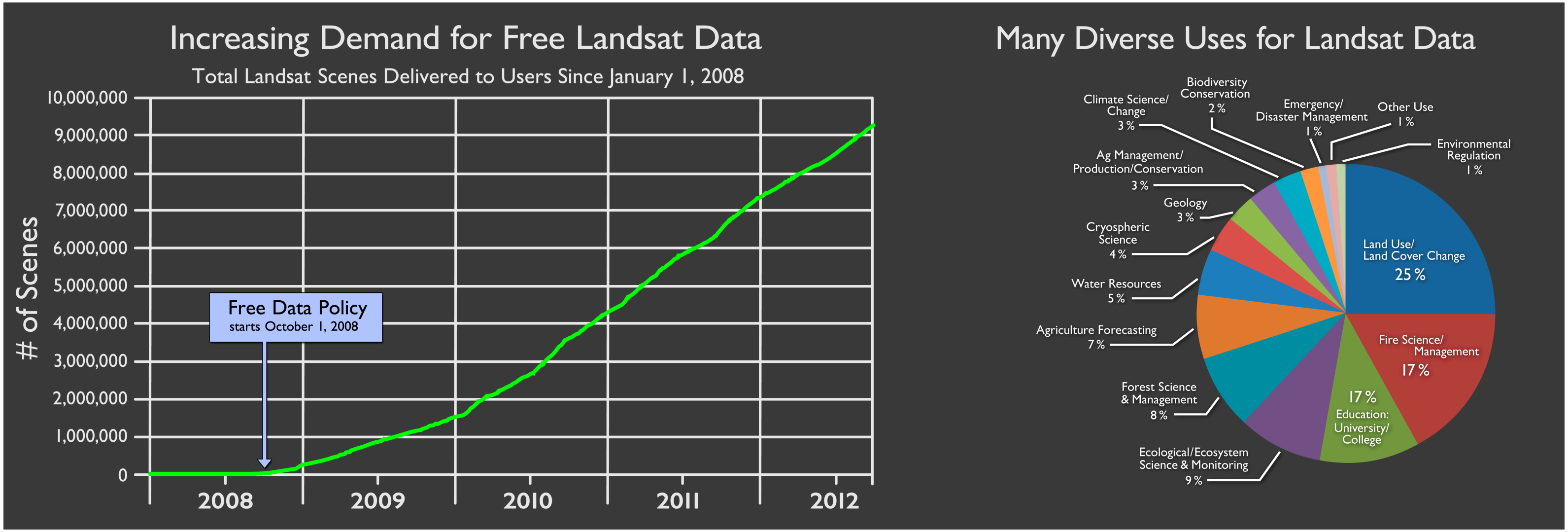
Half Dome September 2022. Source: Andy MacLachlan

The woman who brought us the world 3



Landsat Satellite Missions.Source:USGS

The woman who brought us the world 4



Landsat Downloads and Use Data .Source:Goddard Media Studios

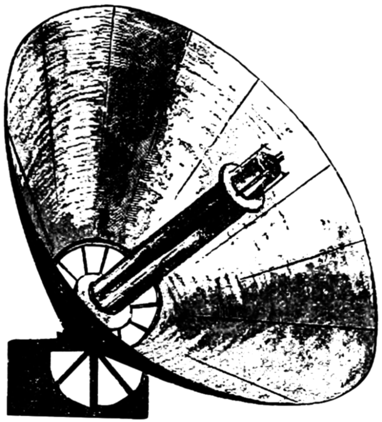
Lecture outline

Part 1: corrections

- Geometric
- Atmospheric
- Orthorectification / Topographic correction
- Radiometric

Part 2: data joining and enhancement

- Feathering
- Image enhancement



Source:Original from the British Library. Digitally enhanced by rawpixel.

Pre-processing requirements

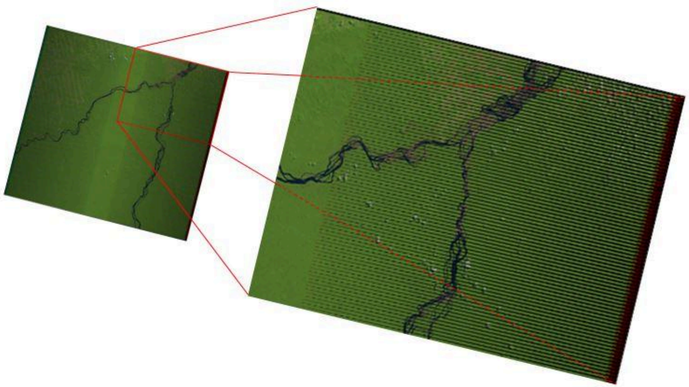
Occasionally remotely sensed images can contain flaws within them

These can be from the sensor, the atmopshere, the terrain ...and more!

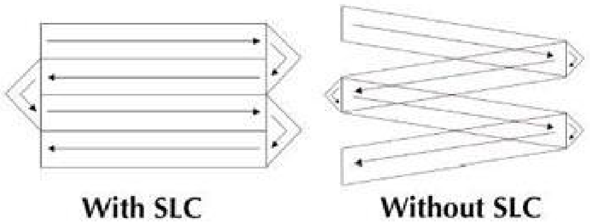
Scan lines

A rather famous example is when the scan line corrector on Landsat 7 failed...

As satellite moves forward whilst scanning it must be corrected...



Source:USGS



Source:USGS

Imagery was still distributed but it is hard to use with methods developed to estimate the gaps, termed gap filling.

Recall regression....

We will see this **three times** throughout the next few slides...

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i$$

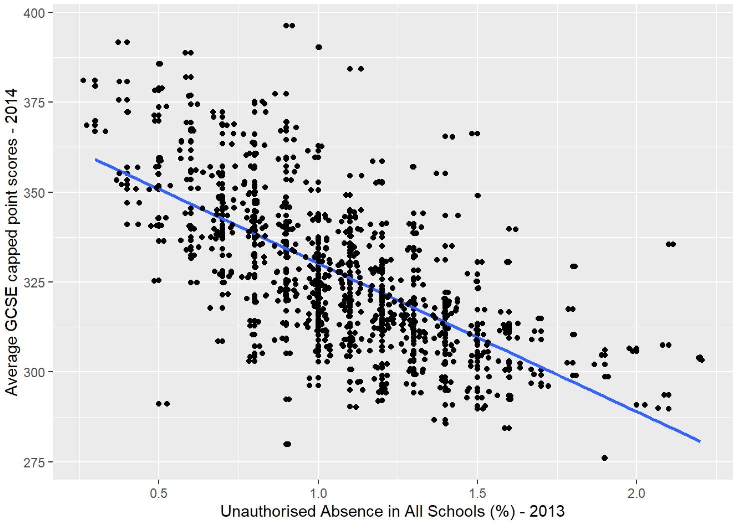
where:

β_0 is the intercept (the value of y when $x = 0$)

β_1 the 'slope' the change in the value of y for a 1 unit change in the value of x (the slope of the blue line)

ϵ_i is a random error term (positive or negative)- if you add all of the vertical differences between the blue line and all of the residuals, it should sum to 0.

Any value of y along the blue line can be modeled using the corresponding value of x



Source:CASA0005

what are the factors that might lead to variation in Average GCSE point scores:

- independent **predictor** variable (unauthorised absence)
- dependent variable (GCSE point score)

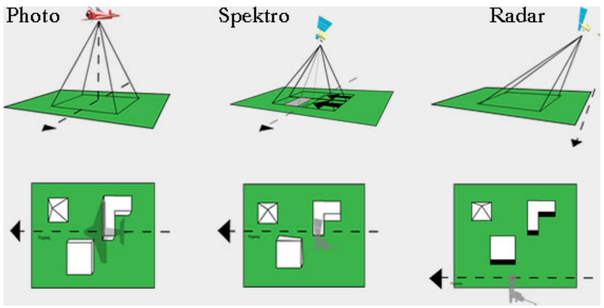
Geometric correction

Geometric correction

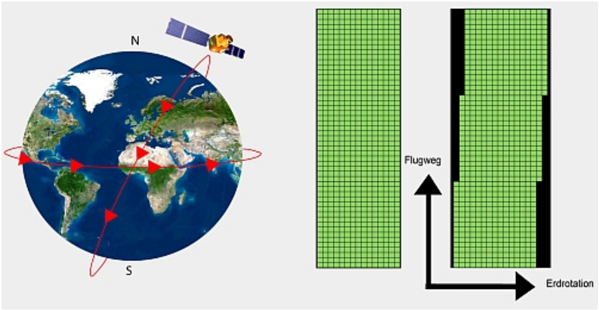
We have seen in GIS that a satellite image is given a coordinate reference system.

But when remotely sensed data is collected image distortions can be introduced due to:

- View angle (off-nadir)* - Nadir means directly down
- Topography (e.g. hills not flat ground)
- Wind (if from a plane)
- Rotation of the earth (from satellite)

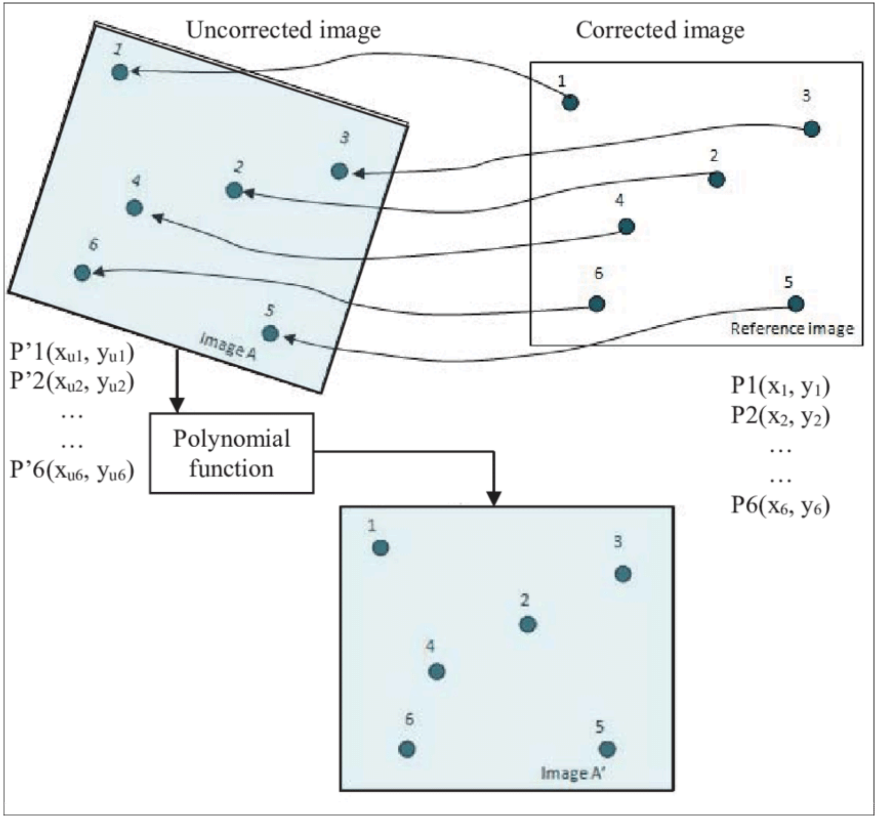


Geometric distortion from sensor view angles. Source:Remote Sensing in Schools



Geometric distortion from Earth rotation. Source:Remote Sensing in Schools

Geometric correction



Source:Abdul Basith

Geometric correction solution

- We identify Ground Control Points (GPS) to match known points in the image and a reference dataset
  - local map
  - another image
  - GPS data from handheld device

- We take the coordinates and model them to give geometric transformation coefficients

- Think back to GIS - **linear regression with our distorted x or y as the dependent or independent***

- We then plot these and try to minimise the RMSE (in 3 slides) - Jensen sets a RMSE value of 0.5

- There are many transformation algorithms available to model the actual coordinates

- This is the same process if you have ever seen an old map sheet overlaid to in a GIS.

Geometric correction solution modelling

Jensen page 244-247 describes:

input to output (forward mapping), for the new x:

$$x = a_0 + a_1 x^i + a_2 y^i + \epsilon_i$$

for the new y:

$$y = b_0 + b_1 x^i + b_2 y^i + \epsilon_i$$

Where

- x and y are positions in the rectified (gold standard) map
- x^i and y^i are positions in the original image

Each pixel in input is transformed to a new x and y based on the formula made from the **GCPs**

But the issue with this is that we are modelling the rectified x and y which could fall anywhere on the gold standard map (e.g. not on a grid square or at a floating point - must be integer). Can result with no values!

Geometric correction solution modelling

Jensen page 244 describes:

output to input (backward mapping), for the new x:

$$x^i = a_0 + a_1 x + a_2 y + \epsilon_i$$

for the new y:

$$y^i = b_0 + b_1 x + b_2 y + \epsilon_i$$

See the image of Jensen, page 247

Take a value in the gold standard image -> input to equation -> it returns a value in the unrectified image.

This means for **every value** in the output (gold standard) pixel we can get a value in the original input image. **The images are distorted as so might not completely overlap**

The goal is to match the distorted image with the gold standard image....so we want the pixels to line up

Geometric correction solution 2...

RMSE

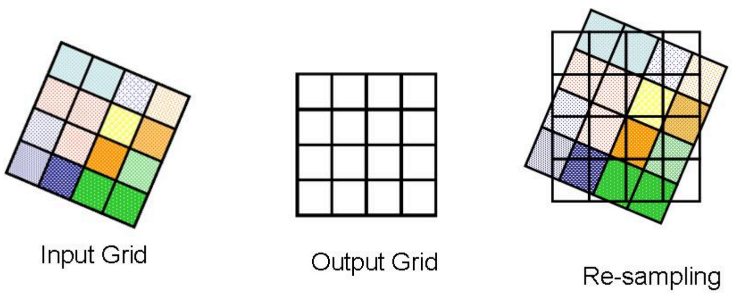
- (observed - predicted (the residual))^2
- sum them and divide by number of data points
- square root that total

- The model with the lowest RMSE will fit best ... Jensen sets a RMSE value of 0.5...typically you might add more GCPs to reduce the RMSE.

When we do this we also might shift the data slightly ...so we must re-sample the final raster:

Resample methods

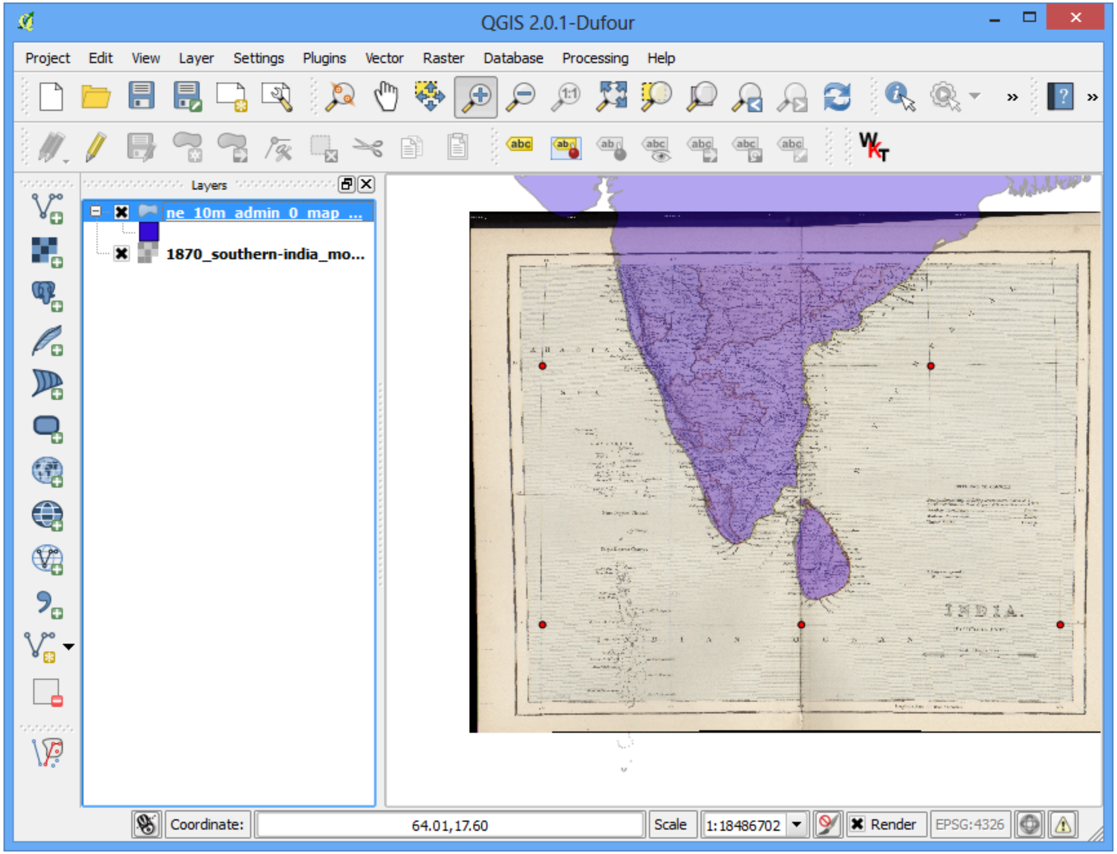
- Nearest Neighbor
- Linear
- Cubic
- Cubic spline



Resampling. Source:Richard Treves

Geometric correction solution 2...

This is the same process used when you see an old map (e.g. printed or manual) in a GIS



Source:QGIS Tutorials and Tips

Atmospheric correction

Atmospheric correction

According to Jensen the two most important sources of environmental attenuation are:

- Atmospheric scattering (as we saw in week 1)
- Topographic attenuation (up next)

Jensen goes on to discuss necessary and unnecessary atmospheric correction:

Unnecessary

- Classification of a single image
- Independent classification of multi date imagery
- Composite images (combining images)
- Single dates or where training data extracted from all data

Necessary

- Biophysical parameters needed (e.g. temperature, leaf area index, NDVI)
- E.g. .. .NDVI is used in the Africa Famine Early Warning System and Livestock Early Warning System
- Using spectral signatures through time and space

Atmospheric correction in action

Fig. 6. Atmospheric correction examples of three scenes (Bands 1, 2, and 3). The first row shows the true color composite images before atmospheric correction, and the second row after atmospheric correction.

Atmospheric correction examples of three scenes (Bands 1, 2, and 3). Source:Liang et al. 2001

Absorption and scattering create the haze = reduces contrast of image.

Scattering = can create the “adjacency effect”, radiance from pixels nearby mixed into pixel of interest.

Source:Newcastle Univesrity

Atmospheric correction types

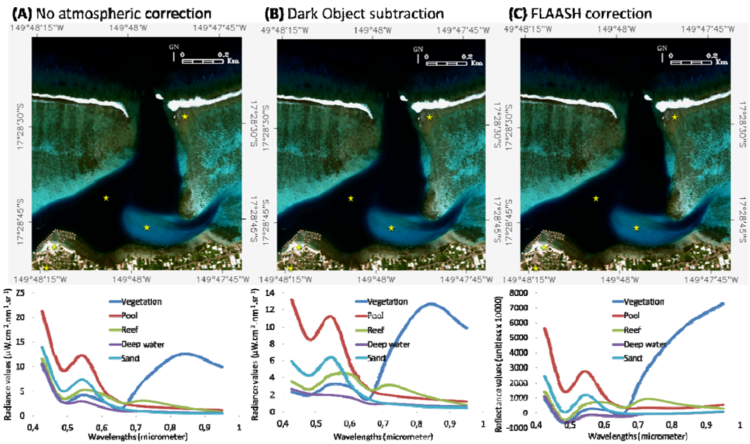
Relative (to something)

- Normalize intensities of different bands within a single image
- Normalise intensities of bands from many dates to one date

- Dark object subtraction (DOS) or histogram adjustment
  - Searches each band for the darkest value then subtracts that from each pixel
  - Landsat bands 1-3 (visible) have increased scattering vs longer wavelengths

- Psuedo-invariant Features (PIFs)
  - Assume brightness pixels linearly related to a base image...
  - Regression per band $y = 1.025x + 21.152$
  - Adjust the image based on the regression result.
  - Here y is the value of our base. To get an equivalent to y (base) we multiply our new date pixel (x) by the coefficient and add the intercept value.
  - Apply this to the rest of the pixels..

Atmospheric correction types 2



Three modalities regarding the atmospheric correction have been retained: (A) none; (B) empirical Dark object Subtraction (DS); and (C) analytical FLAASH correction. Lower plots represent spectral signatures of five features (golden stars over images) against the three modalities. Source:Collin and Hench, 2012

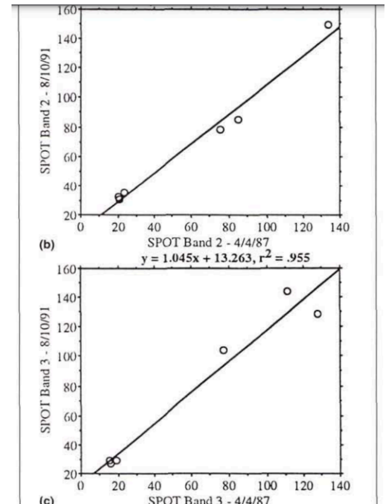


Figure 2. (a) Relationship between the same wet and dry regions found in both the 4 April 1987 and 10 August 1991 SPOT band 1 (green) dataset. The equation was used to normalize the 4 April 1987 data to the 10 August 1991 SPOT data as per methods described in Eckhardt *et al.* (1990). (b) Relationship between wet and dry regions found in both the 4 April 1987 and 10 August 1991 SPOT band 2 (red) dataset. (c) Relationship between wet and dry regions found in both the 4 April 1987 and 10 August 1991 SPOT band 3 (near-infrared) dataset.

PIFs between datasets from different dates - Inland Wetland Change Detection in the Everglades Water Conservation Area 2A Using a Time Series of Normalized Remotely Sensed Data. Source:Jensen et al. 1995, 2012

Pause...

Why is the figure on the left of the previous slide not so great and misleading...?

Always be critical

Even of published work

Atmospheric correction types 3

Absolute (definitive)

- Change digital brightness values into scaled surface reflectance. We can **then compare these scaled surface reflectance values across the planet**
- We do this through **atmospheric radiative transfer models** and there are many to select from
- **However, nearly all assume atmospheric measurements are available** which are used to "invert" the image radiance to scaled surface reflectance
- The scattering and absorption information comes from atmopshierc radiative transfer code such as MODTRAN 4+ and the Second Simulation of the Satellite Signal in the Solar Spectrum (6S), which can now be used through python - called Py6S

Atmospheric correction types 4

Absolute Data requirements

- An atmopsheric model (summer, tropical) - usually you can select from the tool
- Local atmopsheric visibility - from a weather station, like airports
- Image altitude

Absolute Tools $$$

- ACORN - Atmopsehic CORection Now
- FLAASH - Fast Line of-sight Atmopsheric Analysis
- QUAC - Quick Atmopsheric Correction
- ATCOR - The ATmospheric CORrection program
- See Jensen page 216

Free

- SMAC - Simplified Model for Atmospheric Correction (SMAC)
- Orfeo Toolbox

Atmospheric correction types 5

Empirical Line Correction

- We can go and take measurements in situ using a field spectrometer
- This does require measurements at the same time as the satellite overpass....

Source: Andy MacLachlan

Source: Andy MacLachlan

Empirical Line Correction

Then use these measurements in linear regression against the satellite data raw digital number

$$Reflectance(fieldspectrum) = gain * radiance(inputdata) + offset$$

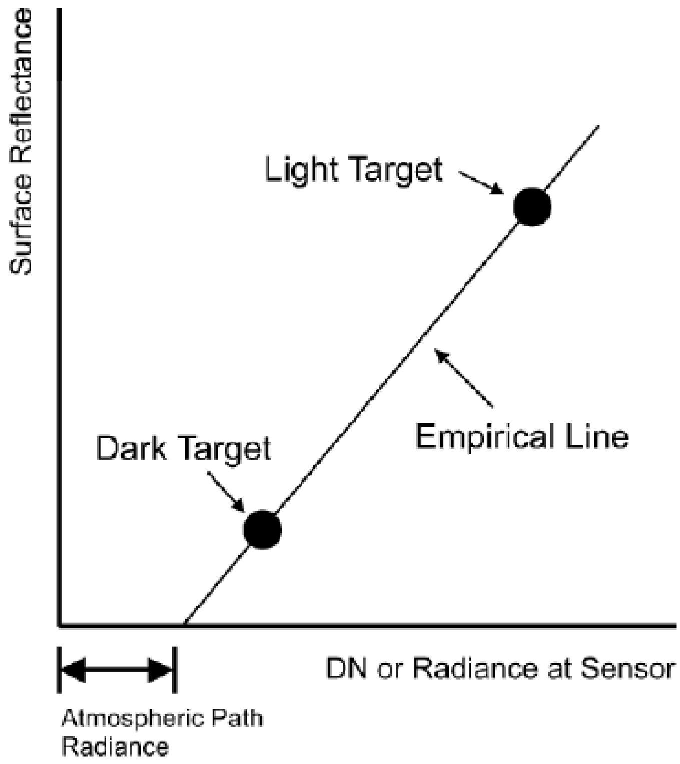
Intercept (missing) is the additive term, depicting the atmospheric path radiance component (scattering) across different paths of reflectance...see next slides...(the value of y when $x = 0$)

The slope = attenuated (dimming and blurring from scattering of light) atmospheric correction. This is the electromagnetic wave absorption and scattering by the atmosphere.

...or...

Empirical Line Correction 2

$$Reflectance(fieldspectrum) = gain * radiance(inputdata) + offset$$

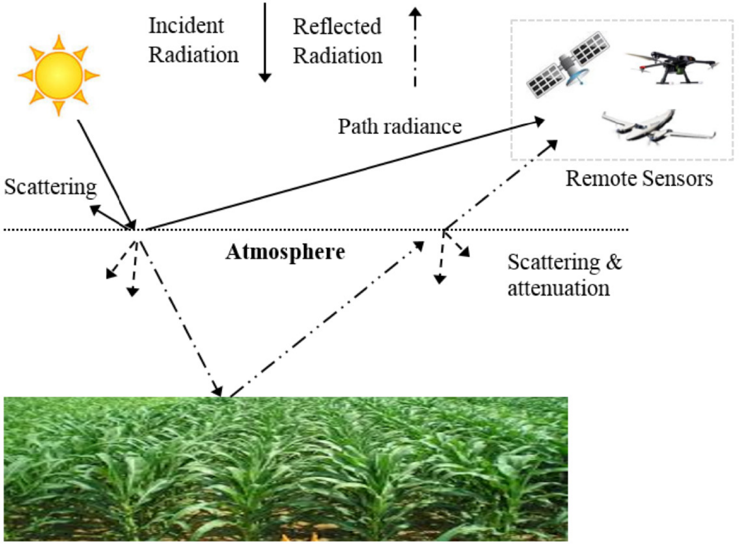


Source:Source: David P. Groeneveld

Empirical Line Correction 3

Path radiance

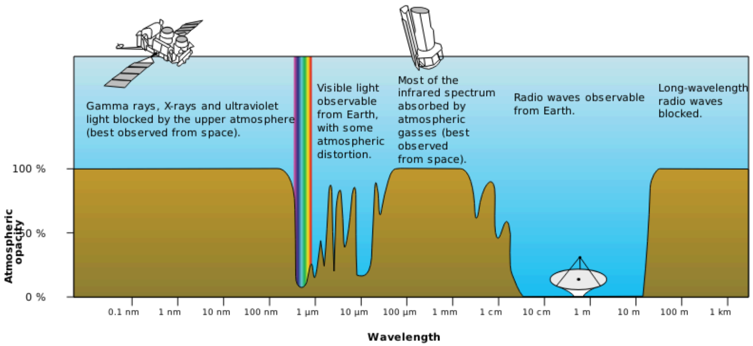
- radiance reflected above the surface (e.g. scattering)



Atmospheric effect on radiation measured by remote sensors

Atmospheric attenuation

- absorption of EMR due to materials in atmosphere (e.g. water vapour)

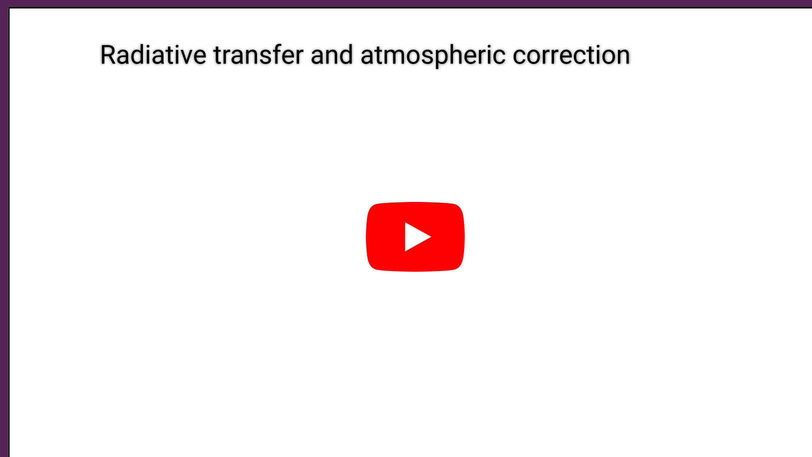


Source: GIS geography

Field work hazards

Cows and calibration targets, New Forest, 2017.Source:Dr Luke Brown

Review of atmospheric correction



Orthorectification correction / topographic correction

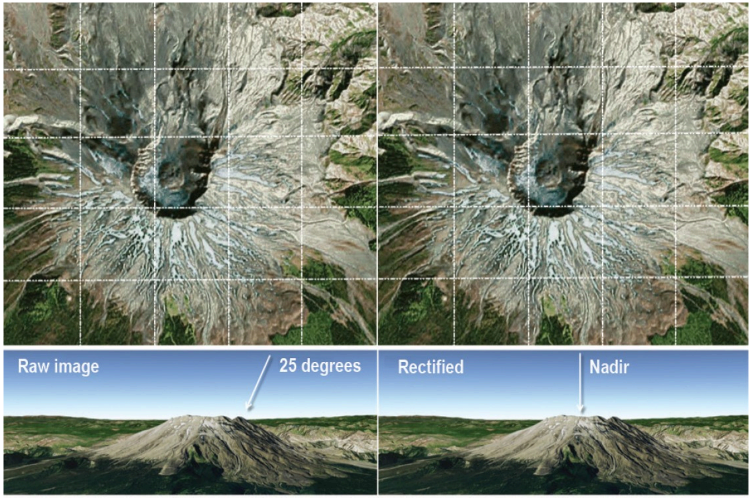
Orthorectification correction

A **subset** of georectification

- georectification = giving coordinates to an image
- orthorectification = removing distortions... making the pixels viewed at nadir (straight down)

Requires:

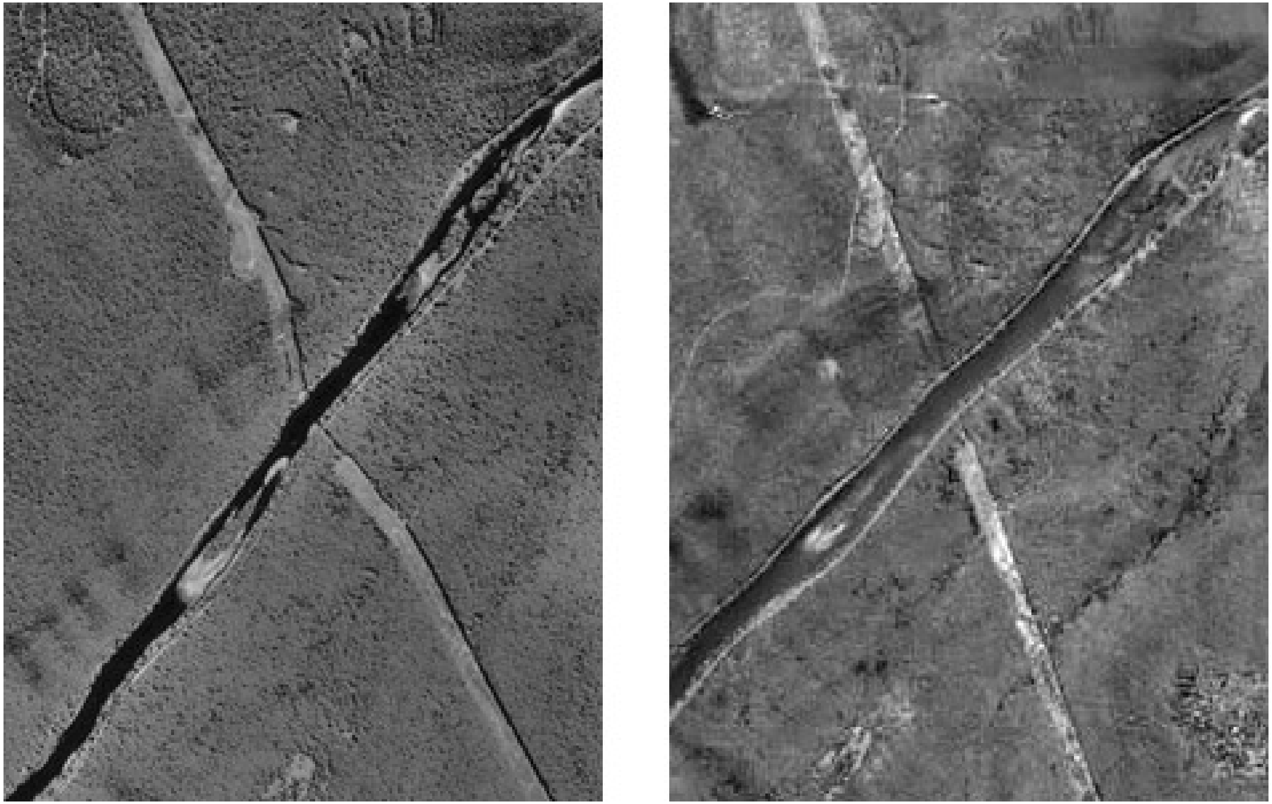
- Sensor geometry
- An elevation model



A view captured from an oblique angle (for example, 25°, left) must be corrected for relief displacement caused by terrain to generate the orthorectified view (looking straight down, right). Orthoimagery is produced by calculating the nadir view for every pixel. Source:Esri Insider, 2016

Spot the **main** difference

Orthorectification correction 2



Orthorectification creates a final product whereby each pixel in the image is depicted as if it were collected from directly overhead or as close to this as possible. In the graphic above, you can see a path through the forest going from the northwest to the southeast. On the left is the original image, and on the right is the orthorectified image. In the orthorectified version, you can see that the path is now nearly straight after the influence of topography has been removed from the image. (Graphic Credit: David DiBiase, Penn State University). Source:Apollo Mapping, 2016

Orthorectification correction 3

Software / formulas to do this...

Jensen covers the following formulas:

- Cosine correction
    - $L_H = L_T \frac{cos\theta_O}{\cos_i}$

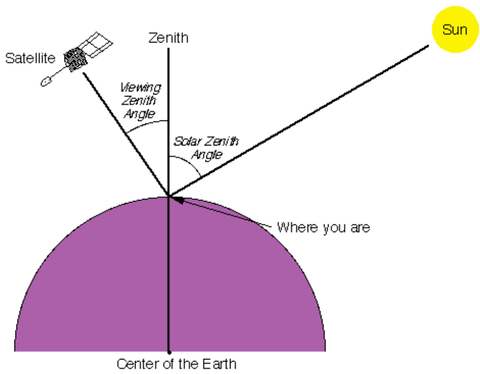
  Where

    - L_T = radiance (DN to TOA) from sloped terrain
    - θ_O = Sun's zenith angle
    - i = Sun's incidence angle - cosine of the angle between the solar zenith and the normal line of the slope
    - solar incidence is angle of sun's rays and normal on surface. For horizontal surface this equals the zenith
    - Latter two found in angle coefficient files (e.g. Landsat data ANG.txt)

Others:

- Minnaert correction, Statistical Empirical correction, C Correction (advancing the Cosine)

Orthorectification correction 4



Schematic illustration of the Solar Zenith Angle (SZA) and Viewing Zenith Angle (VZA) for observations from satellite-based instrument. image taken from a NASA page

To get cos_i

$$cos_i = cos\theta_p cos\theta_z + sin\theta_p sin\theta_z cos(\phi_a - \phi_o)$$

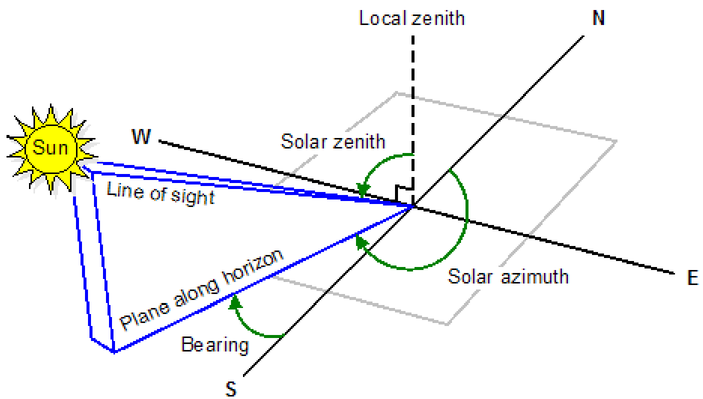
Where:

θ_p = slope angle (from DEM) θ_z = solar zenith ϕ_a = slope aspect (orientation of the slope from DEM (e.g. S =180)) ϕ_o = solar azimuth

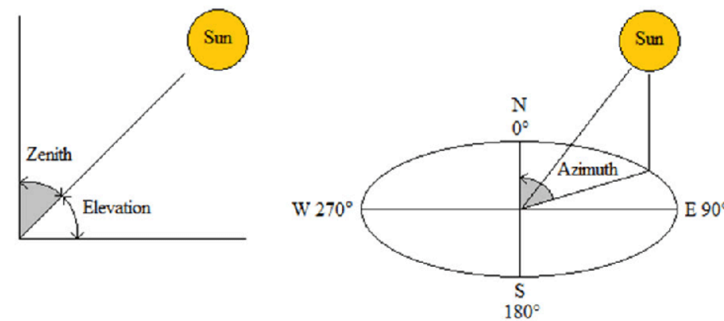
Orthorectification correction 5

solar azimuth = compass angle of the sun (N =0°) 90° (E) at sunrise and 270° (W) at sunset. See Azimuth Angle animation

solar zenith = angle of local zenith (above the point on ground) and sun from vertical (90° - elevation)



Solar zenith and solar azimuth Source:catalyst.earth



Solar azimuth and zenith angles Source:Khurum Nazir Junejo

Orthorectification correction 6

Software:

- QGIS
- SAGA GIS
- R package topocorr
- R package RStoolbox

Note: Atmospheric correction happens before topographic correction.

Radiometric Calibration

Radiometric Calibration

- Sensors capture image brightness and distributed as a Digital Number (or DN) - allows for efficient storage but **has no units!**
- Spectral radiance is the amount of light within a band from a sensor in the field of view (FOV)
- It is independent of the sensor
- Measured in Watts (power of light here), per metre squared (surface within FOV) per steradian (angle of the view) per nanometre (wavelength) = $Wm^2sr^-1\mu m^1$
- DN to **spectral radiance** = "radiometric calibration"
- Sensor calibration = the relationship between

$$L\lambda = Bias + (Gain * DN)$$

$Gain$ and $Bias$ are usually provided but we can calcaulte them.

Source:Richard Treves and University of Newcastle

Remote sensing jargon

We saw in CASA0005 and we will see in this module the terms gain and offset...

Before a sensor is launched it is calibrated in a lab - we then use these measurements to adjust the data from the sensor...

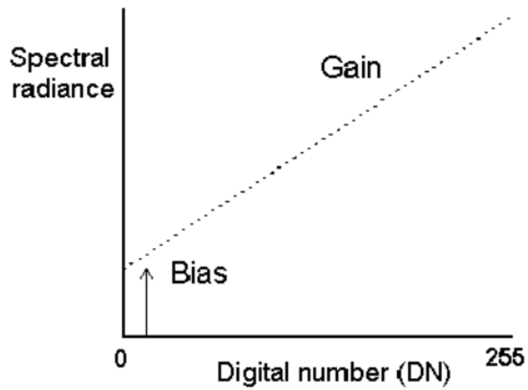


Figure 3.3. Calibration of 8-bit satellite data. Gain represents the gradient of the calibration. Bias defines the spectral radiance of the sensor for a DN of zero.

The calibration is given by the following expression for at satellite spectral radiance, L_λ:

$$L_\lambda = \text{Bias} + (\text{Gain} \times \text{DN}) \qquad \textit{Equation 3.1}$$

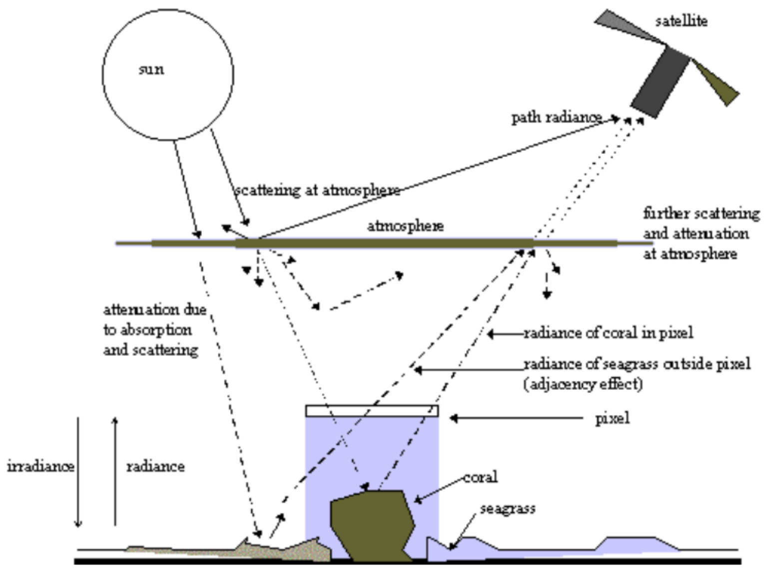
units: mW cm^{-2} $ster^{-1}$ μm^{-1} (for Landsat)

Calibration of 8-bit satellite data. Gain represents the gradient of the calibration. Bias defines the spectral radiance of the sensor for a DN of zero. Source:Lesson 3: Radiometric correction of satellite images

Remote sensing jargon 2

- radiance refers to any radiation leaving the Earth (i.e. upwelling, toward the sensor
- irradiance, is used to describe downwelling radiation reaching the Earth from the sun

Figure 3.1. Simplified schematic of atmospheric interference and the passage of electromagnetic radiation from the Sun to the satellite sensor.



Source:Newcastle Univesrity

Remote sensing jargon 2

To clarify...

DN | Radiance | Reflectance | Reflectance 2 | If/But | Example

Digital number (DN):

- Intensity of the electromagnetic radiation per pixel
- Pixel values that aren't calibrated and have no unit
- Have light source
- Effects of sensor + atmosphere + material
- Values range from 0 - 255 (Lansat 5) = 8 bit or 0 - 65536 Landsat 8 (12 bit)

The good news

Remote sensing products now come "corrected" - e.g. "Analysis Ready Data" or ARD

Landsat ARD - surface reflectance

> Landsat data are
>
> **distributed as a surface reflectance product achieved through the Landsat Ecosystem Disturbance Adaptive Processing System (LEDPAS) and the Landsat 8 Surface Reflectance algorithm (L8SR)**
>
> otherwise known as the Landsat 8 Surface Reflectance Code (LaSRC) for correction of atmospheric conditions (Hansen and Loveland, 2012; USGS, 2015). The former corrects for atmospheric effects using the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer model, whilst the latter implements an internally developed algorithm (Hansen and Loveland, 2012; USGS, 2015).

- LEDPAS
- L8SR

Now also

- LaSRC (Landsat 8-9) level 2 product: https://www.usgs.gov/landsat-missions/landsat-collection-2-surface-reflectance

What is a level 2 product?

Means something has changed or advanced ...

Here it's the data and algorthims used to create the data, see the collection level summary for specific details

So why did you just make us go through all that?

In future you might come across data that isn't ARD (e.g. very high resolution, drone)

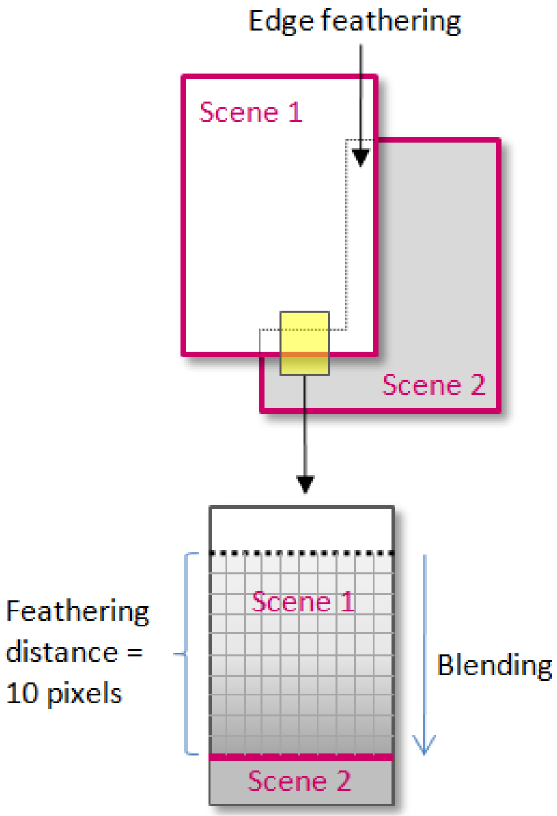
Just because someone gives you data doesn't mean you don't need to know how they created it.

Part 2: Joining data sets / enhancements

Part 2: Joining data sets

- This is termed "Mosaicking" in remote sensing - but it's not much different to merging in GIS
- In Remote Sensing we usually **feather** the images together
- This creates a **seamless** mosaic or image(s)
- The dividing line is termed the **seamline**
- We have a base image and "other" or second image

Joining data sets 2



Source:NV5

Joining data sets 3

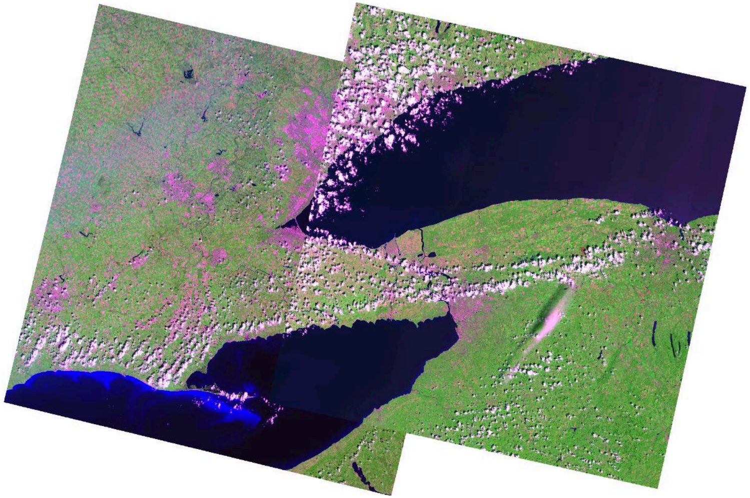
The base and second image over lap - 20 to 30%

From this point there are slight variations on how the method actually feathers...

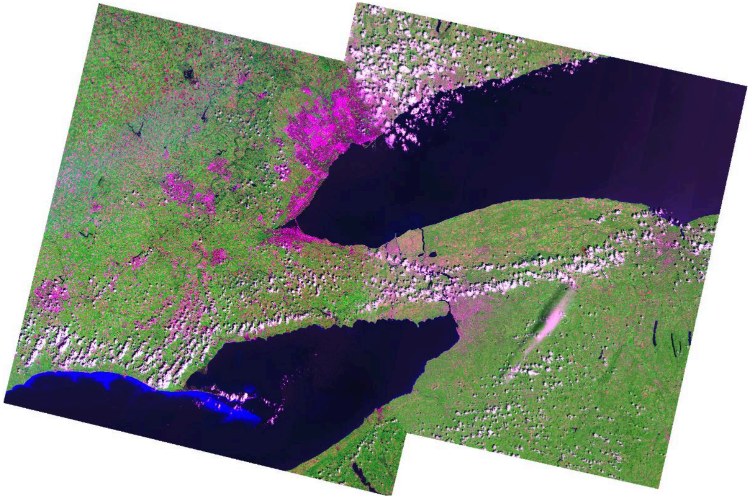
According to Jensen

- Within the overlap area an representative sample is taken
- A histogram is extracted from the base image
- It is then applied to image to using a **histogram matching algorithm**
- This gives similar brightness values of the two images
- Next feathering is conducted

Joining data sets 4



Source:WhiteboxDev, stackexchange



Source:WhiteboxDev, stackexchange

Joining data sets 5

Typically surface reflectance products are considered to

> improves comparison between multiple images over the same region by accounting for atmospheric effects such as aerosol scattering and thin clouds, which can help in the detection and characterization of Earth surface change

However, in practice this may differ...

Probably due to each image using a model to remove the atmosphere.

Joining data sets 6

I have encountered this when trying to classify landcover over several years with 1 model. Approaches to dealing with this:

- Standardization (dividing the SR value by a maximum value per band) and normalization (divide the standarised value by the sum of values across all bands) applied to each image
- Undertake further relative radiometric normalization - e.g. with PIFs. Similar (but different idea) to Chen et al. 2009
- Classify each image alone
- Calculate other metrics from the image...

While we are here let's look at other iamge enhancements

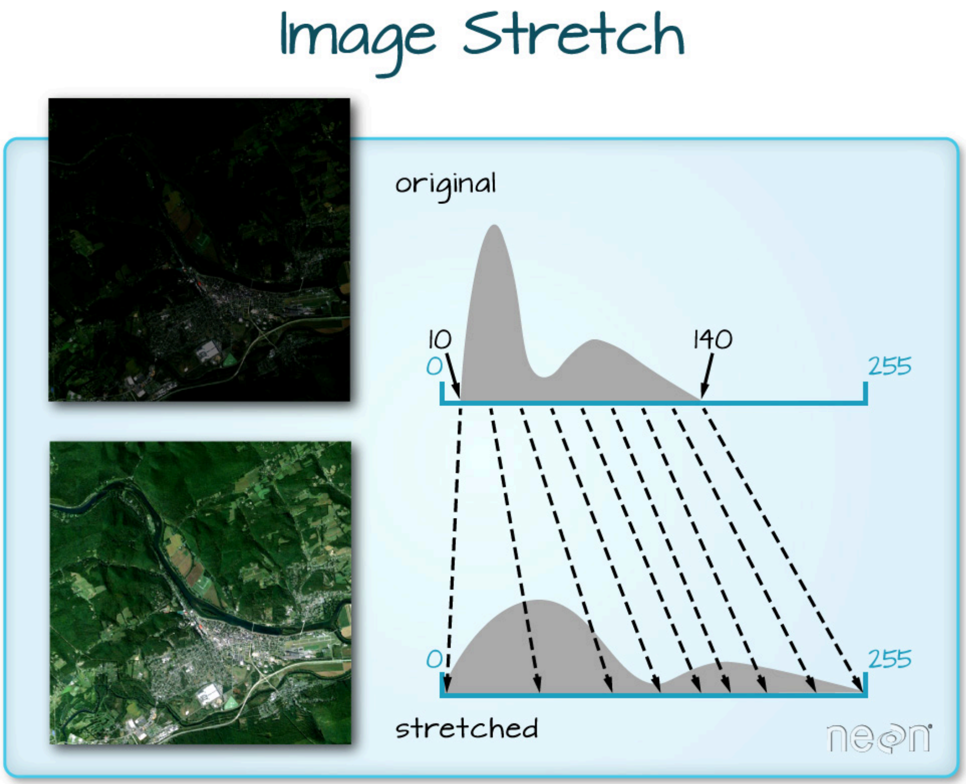
Image Enhancement

Contrast Enhancement

- Do materials reflect different amounts of energy in the same wavelengths?
- If they did we would have good contrast, usually they don't
- Sensors are also made to avoid saturation = when the maximum DN value is exceeded, so most images have a low range.
- E.g., from Jensen...
    - Image band has a range of 4 to 105
    - 0-3 and 106-255 aren't used
    - We can expand the range
- Many methods to do this:
    - Minimum - Maximum
    - Percentage Linear and Standard Deviation
    - Piecewise Linear Contrast Stretch

Image Enhancement 2

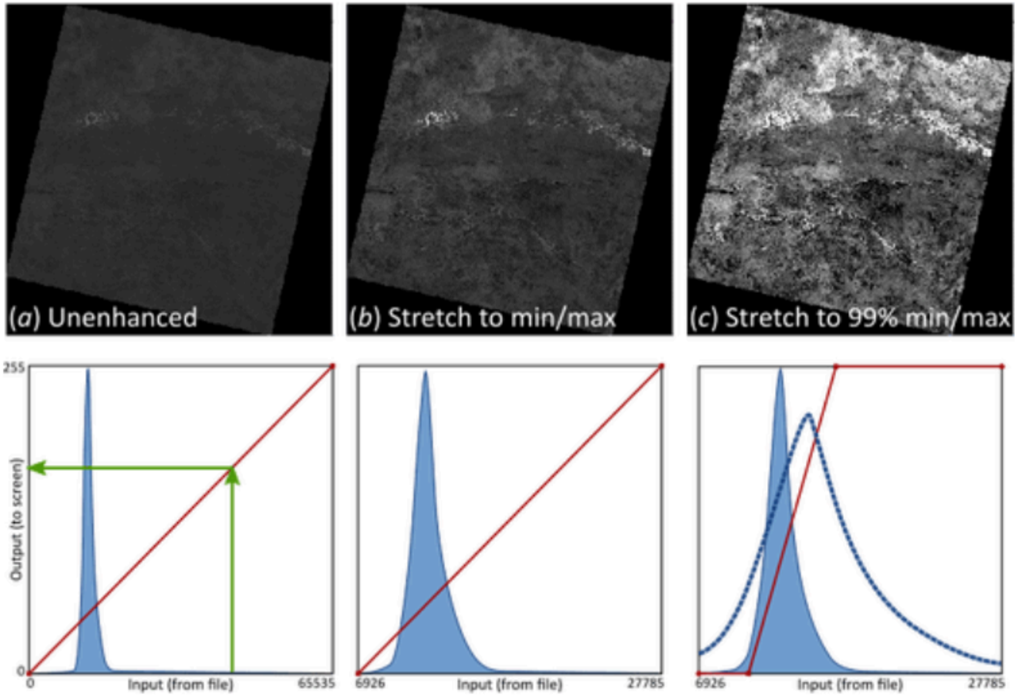
Only applied to digital numbers



Source:EarthLab

Image Enhancement 3

For example....in QGIS this will look like



Source:Atilo Francois

- Jensen, Chapter 8, page 283 provides a nice example!

Other enhancements

There are many enhancements that we can apply to imagery to improve the visual appearance or results....

Local = specific to pixel, neighbourhood = pixels within a range (nearby)

Ratio | Ratio 2 | Filtering | Filtering 2 | Filtering 3

Band ratioing

$$BV_{i,j,r} = \frac{BV_{i,j,k}}{BV_{i,j,l}}$$

Where $BV_{i,j,r}$ is the ratio and $BV_{i,j,k}$ and $BV_{i,j,l}$ are the values in two other bands

- note, you may need to add .1 to 0 values and it should be atmospherically corrected
- can use the Sheffield Index and optimum index to select the best ratios...e.g. NDVI is a ratio of two bands and tasselled cap is also really.

See Jensen, Chapter 8, page 291 for a nice example.

Other enhancements 2

PCA | PCA 2 | Texture | Texture 2nd | Texture 3 | Fusion

Principal Component

- Transform multi-spectral data into uncorrelated and smaller dataset
- Has most of the original information
- Reduces future computation "dimensionatliy reduction"
- The first component will capture most of the variance within the dataset
- In R this is `prcomp()` from the terra package

For PCA explained watch Josh Starmer's video or consult the lecture slides for GEOG 4110

Warning

Some of these concepts could have a dedicated lecture

Summary

Part 1: corrections

- Imagery may contain error from a variety of sources
- We must correct where appropriate
- We must contextualise the use of the imagery

Part 2: data joining and enhancement

- Mosaicing in with a standard method isn't appropriate for satellite imagery
- Imagery can be "improved/enhanced" based on the energy reflected and the contrast between features
- But...
  - How do these methods help **in urban environments**
  - Does adding complexity to imagery (or creating new datasets) **assist us** in our aim?