



# Remotely Sensing Cities and Environments

## Lecture 3: Remote sensing data

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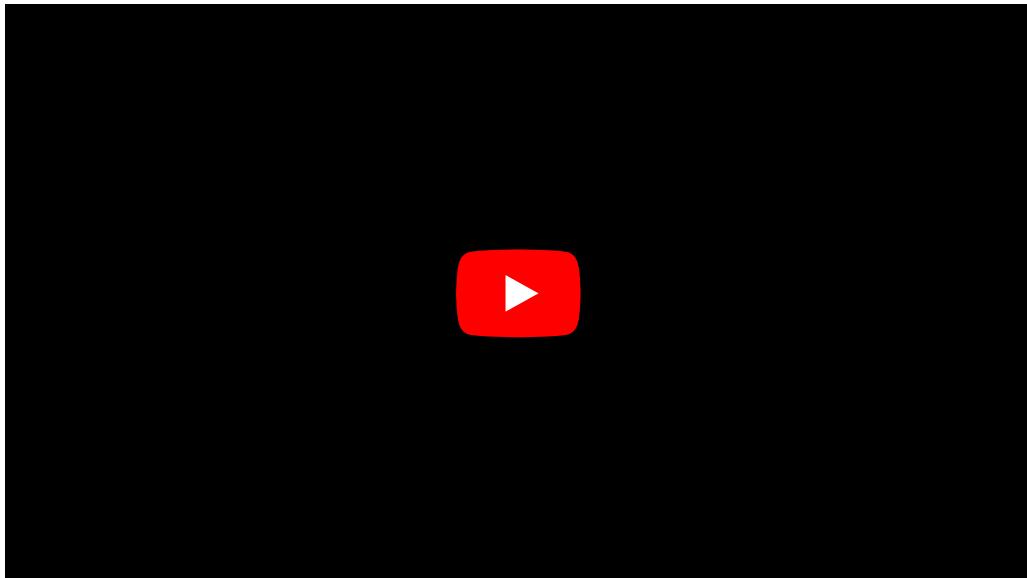
 Centre for Advanced Spatial Analysis, UCL

# How to use the lectures

- Fastcups:<https://cups.fast.ai/CASA0023>)
- Slides are made with `xaringan`
-  In the bottom left there is a search tool which will search all content of presentation
- Control + F will also search
- Press enter to move to the next result
-  In the top right let's you draw on the slides, although these aren't saved.
- Pressing the letter `o` (for overview) will allow you to see an overview of the whole presentation and go to a slide
- Alternatively just typing the slide number e.g. 10 on the website will take you to that slide
- Pressing alt+F will fit the slide to the screen, this is useful if you have resized the window and have another open - side by side.

# 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

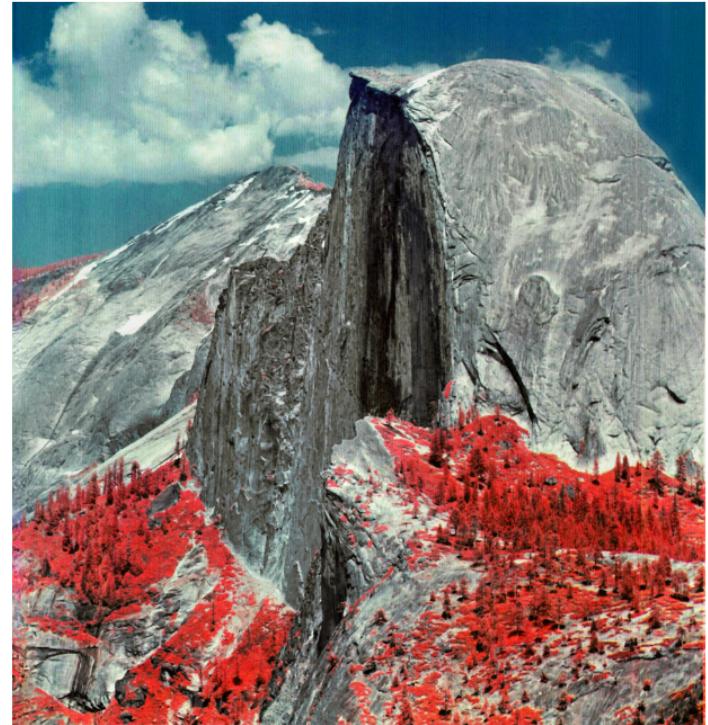
- NASA wanted to use a RBV camera - TV camera with Green, Red and NIR of the spectrum.
- Norwood thought that a digital Multispectral camera (MSS) would be much better.
- MSS could get both visible and "invisible"
- Norwood given \$100,000



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

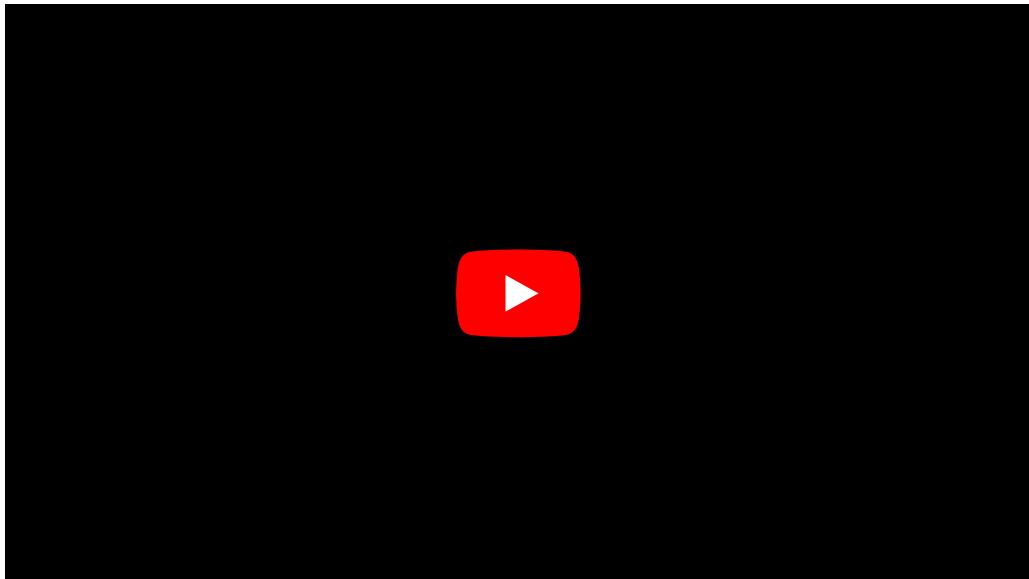
# The woman who brought us the world 2

- 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...

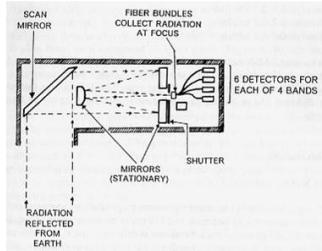


Figure 11: Alternate view of the MSS scanning concept  
(image credit: J. Campbell, Georgia Tech)

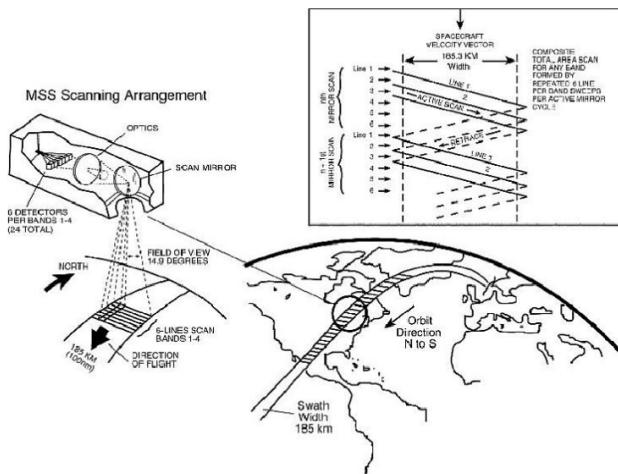


Figure 12: Enlarged view of MSS scanning geometry and image projection (image credit: NASA)

MSS sensor. Source: [eoportal](#)

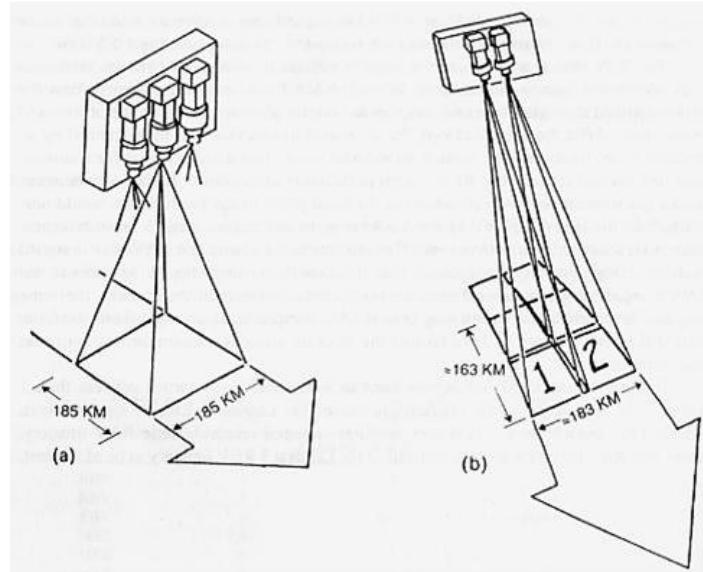


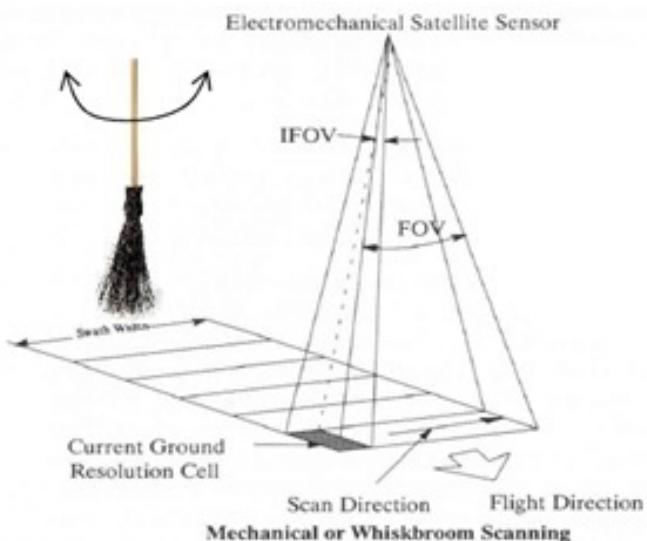
Figure 14: Schematic view of coaligned RBVs taking imagery of a target region (image credit: J. Campbell, Georgia Tech)

RBV sensor. Source: [eoportal](#)

# Push broom vs Whisk broom

**Whisk broom or spotlight or across track scanners**

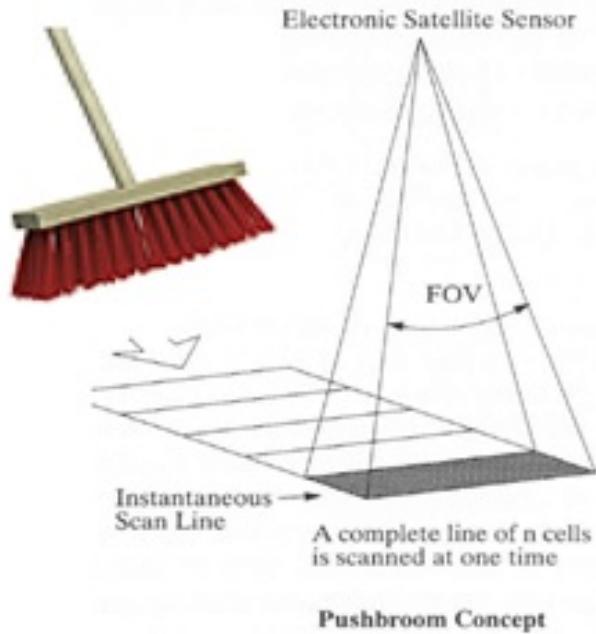
Mirror reflects light onto 1 detector -  
Landsat



Push Broom and Whisk Broom Sensors. Source:[L3Harris](#).)

**Push broom or along track scanners**

several detectors that are pushed along -  
SPOT, Quickbird



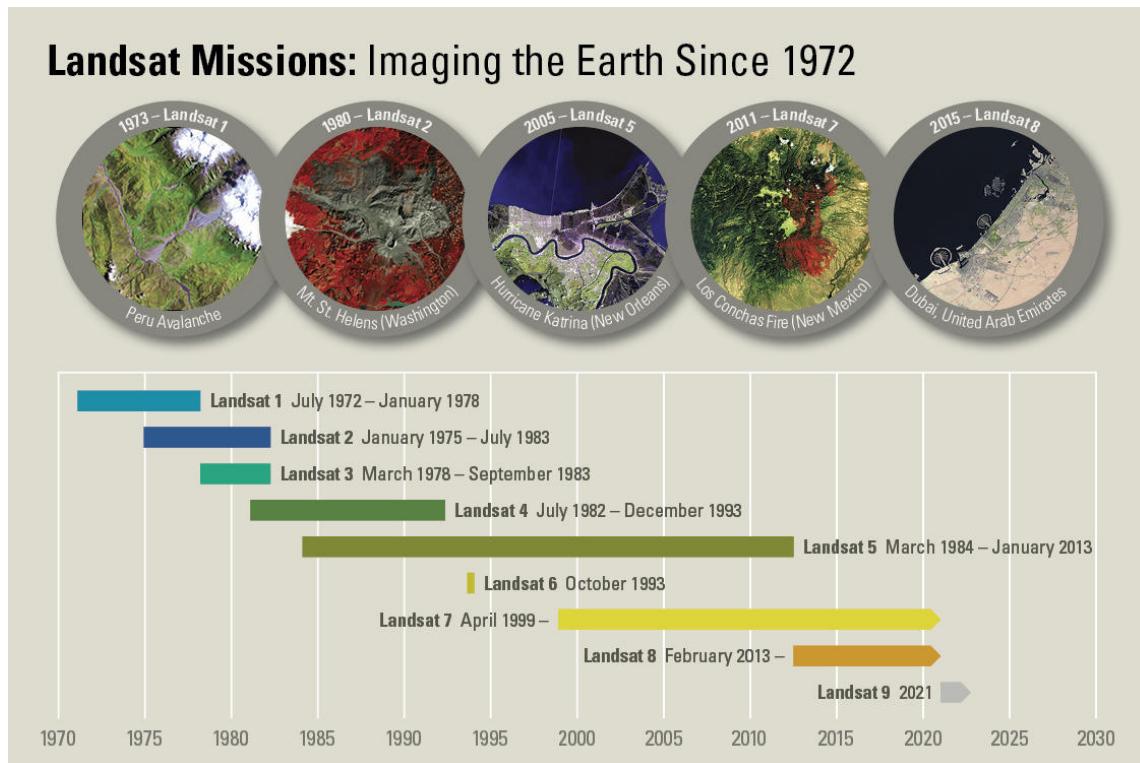
Push Broom and Whisk Broom Sensors. Source:[L3Harris](#).)

# Half Dome



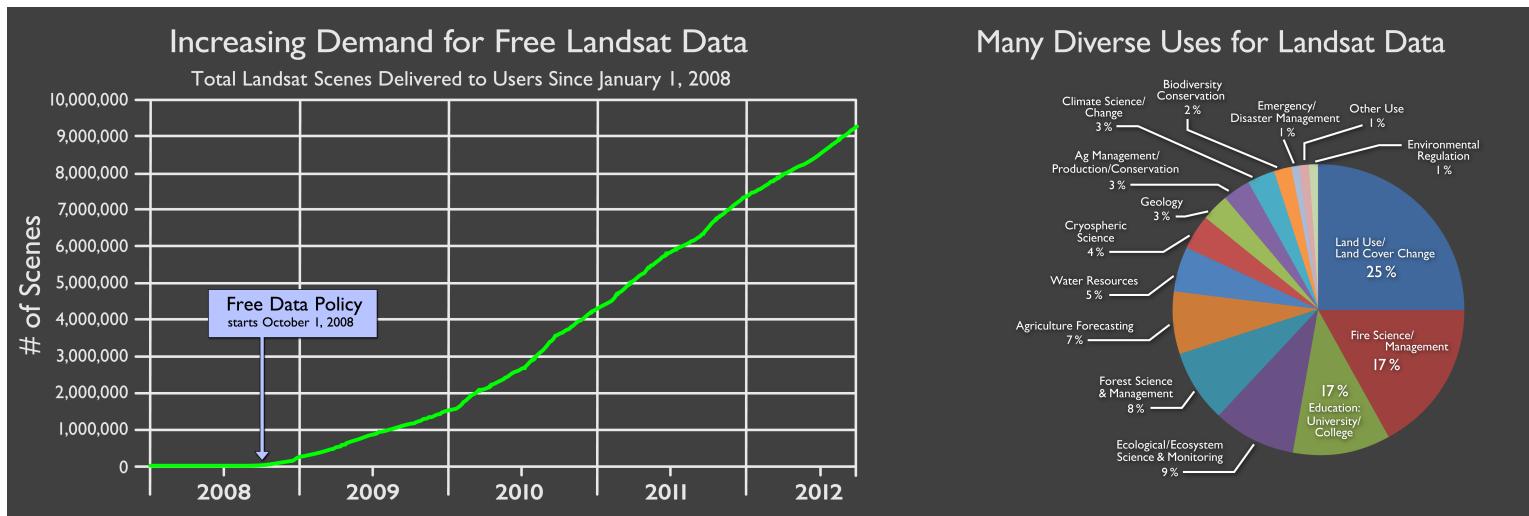
Half Dome September 2022. Source: Andy MacLachlan

# 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](#)

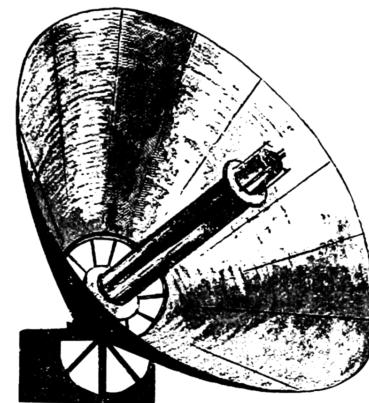
# Lecture outline

## 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

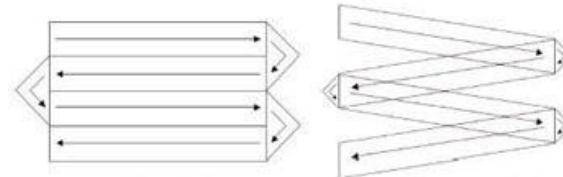
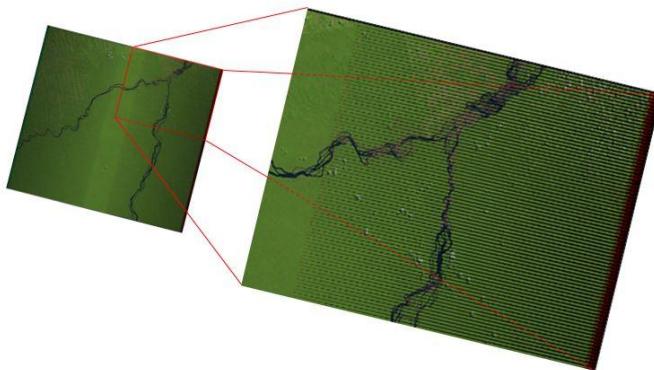
Occasionally remotely sensed images can contain flaws  
within them

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

# Scan lines

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

It moves in a zig zag and the corrector made the image normal



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...

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

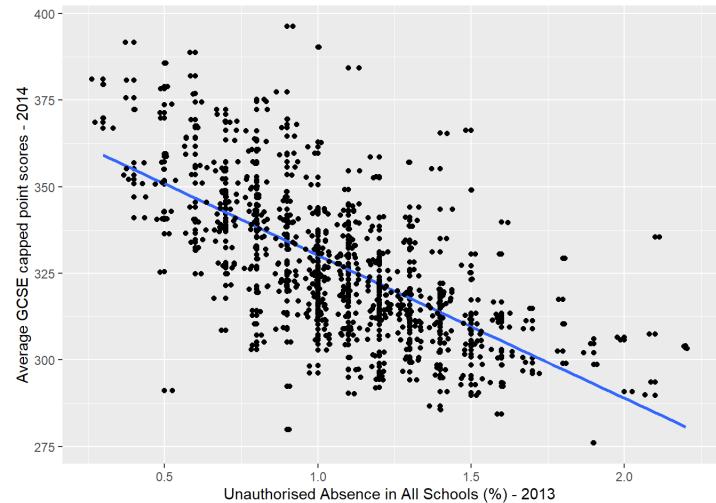
where:

$\beta_0$  is the intercept (the value of  $y$  when  $x = 0$ )

$\beta_1$  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)

$\epsilon_i$  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)

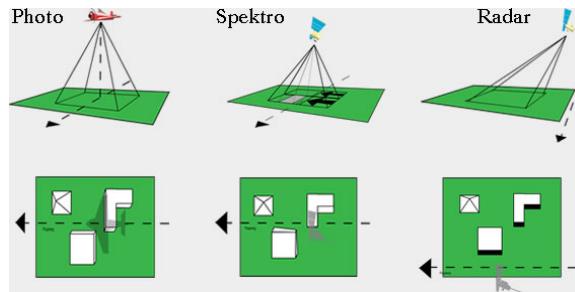
# Geometric correction

# Geometric correction

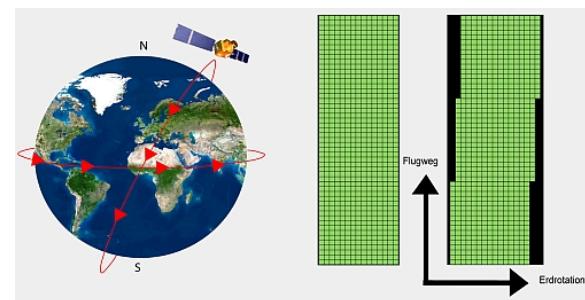
We have seen in GIS that a satellite image is given a coordinate reference system.

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)

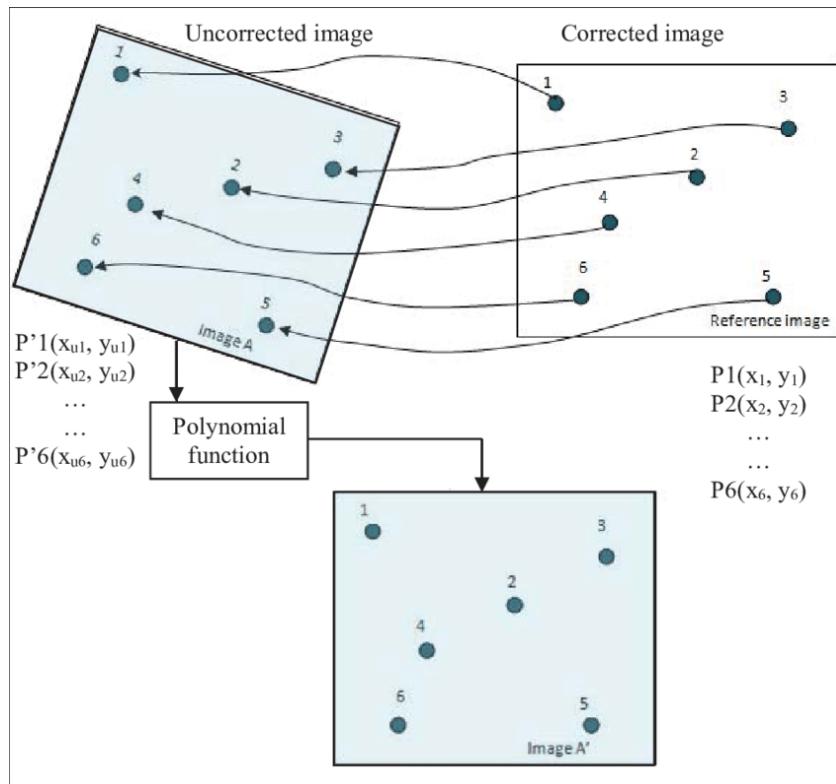


Geometric distortion from sensor view angles. Source:[Remote Sensing in Schools](#)



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
- We then plot these and try to minimise the RMSE - 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 2...

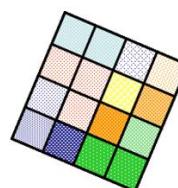
RMSE

- $(\text{observed} - \text{predicted} (\text{the residual}))^2$
- 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

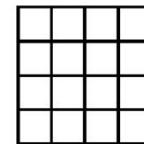
When we do this we also might shift the data slightly ...so we must re-sample the final raster:

Resample methods

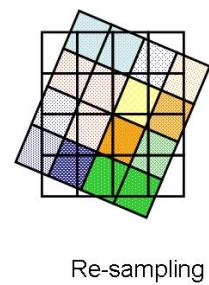
- Nearest Neighbor
- Linear
- Cubic
- Cubic spline



Input Grid



Output Grid

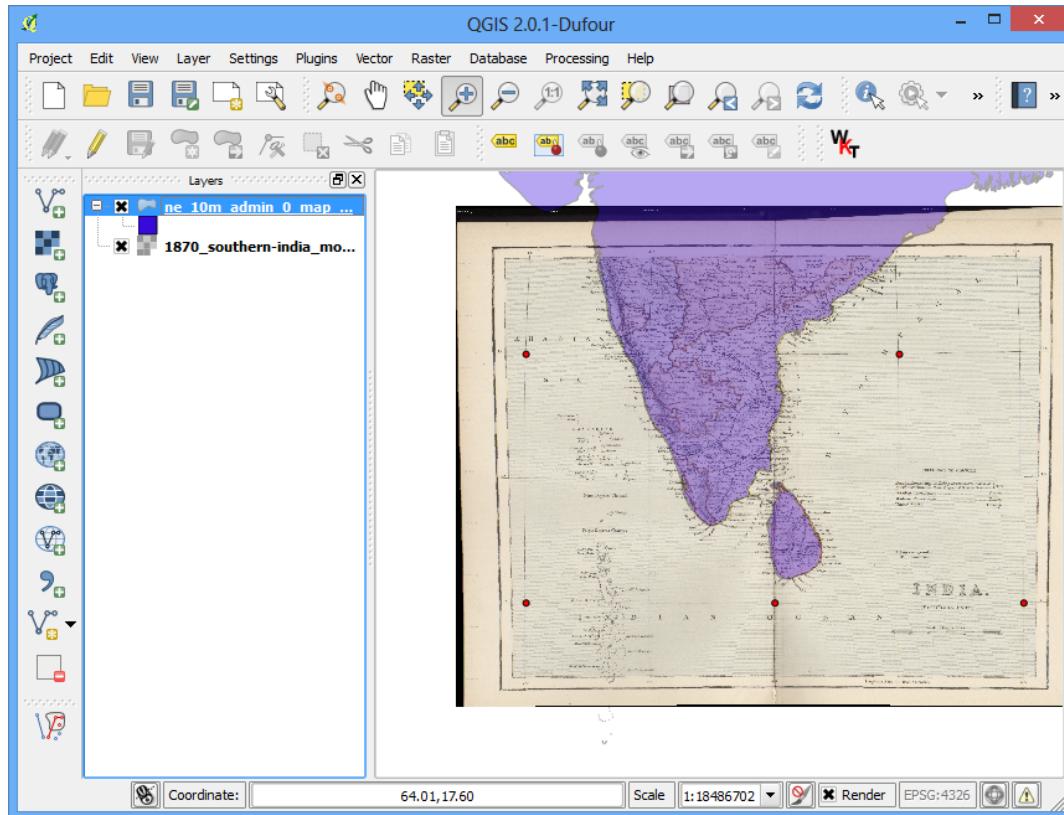


Re-sampling

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.

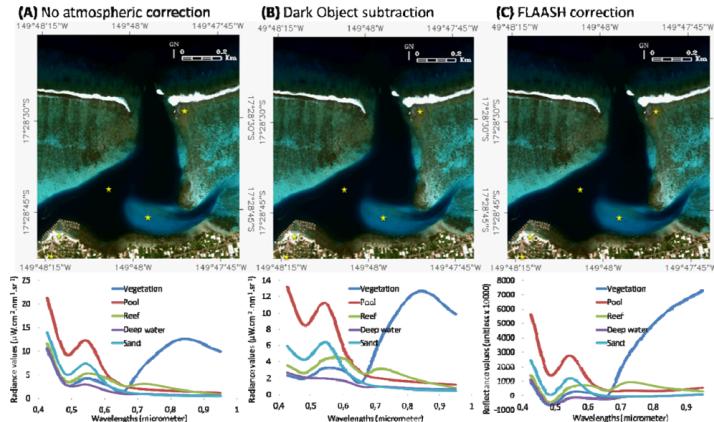
Source:[Newcastle University](#)

# 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 y 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](#)

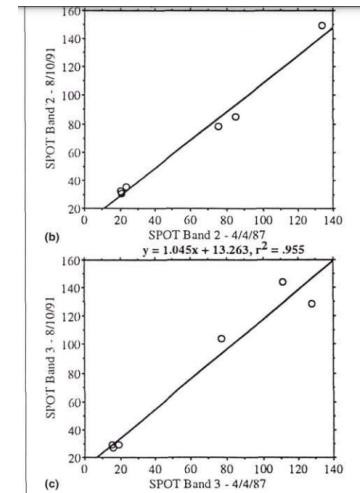


Figure 2. (a) Relationship between the same wet and dry regions found in both the 4 April 1987 and 10 August 1991 SPOT band 1 (green) dataset. The equation was used to normalize the 4 April 1987 data to the 10 August 1991 SPOT data as per methods described in Eckhardt *et al.* (1990). (b) Relationship 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 atmopsherc 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 atmospheric model (summer, tropical) - usually you can select from the tool
- Local atmospheric visibility - from a weather station, like airports
- Image altitude

## Absolute Tools \$\$\$

- ACORN - Atmospheric CORrection Now
- FLAASH - Fast Line of-sight Atmospheric Analysis
- QUAC - Quick Atmospheric 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

$$BV_k = p_\lambda A_k + B_k$$

$BV_k$  is the Digital number for band K

$p_\lambda$  is the surface reflectance from the field survey

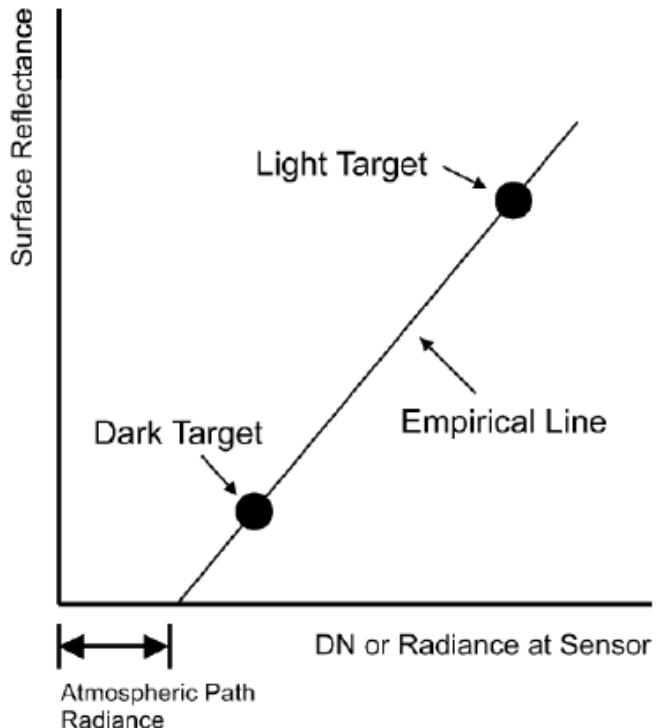
$B_k$  is the additive term, depicting the atmospheric path radiance component (scattering) across different paths of reflectance...see next slides

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

$$\text{Reflectance}(\text{fieldspectrum}) = \text{gain} * \text{radiance}(\text{inputdata}) + \text{offset}$$

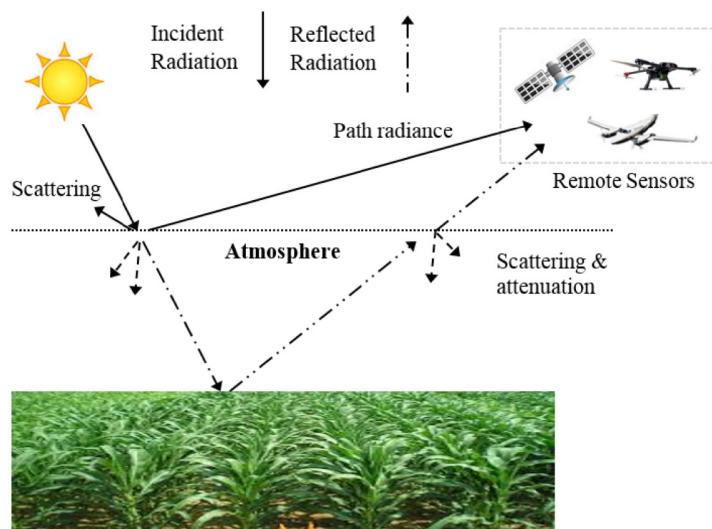


Source: David P. Groeneveld

# Empirical Line Correction 3

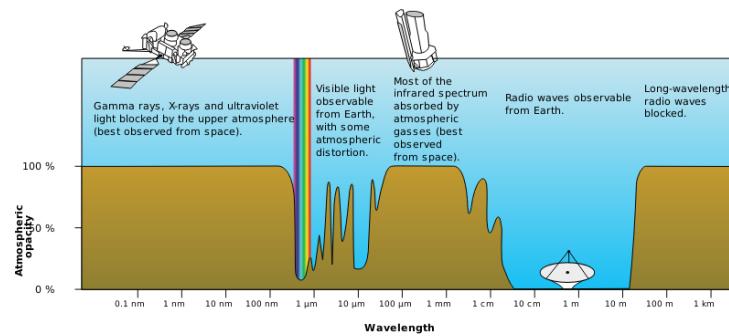
Path radiance and atmospheric attenuation

## Path radiance



Atmospheric effect on radiation measured by remote sensors

## Atmospheric attenuation



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

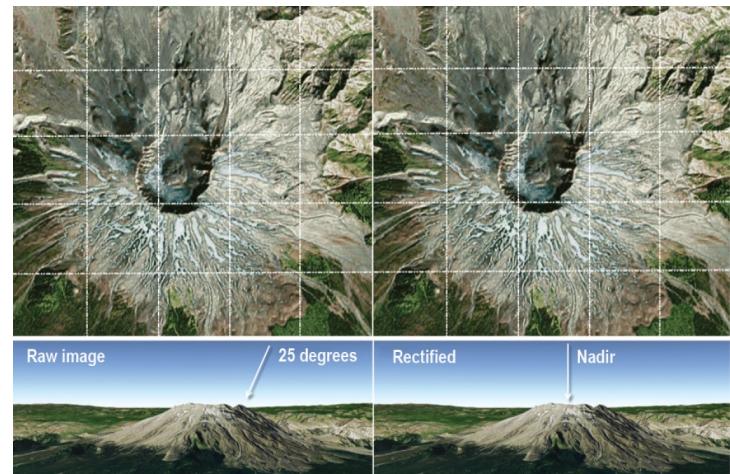
# Orthorectification correction

A subset of georectification

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

Requires:

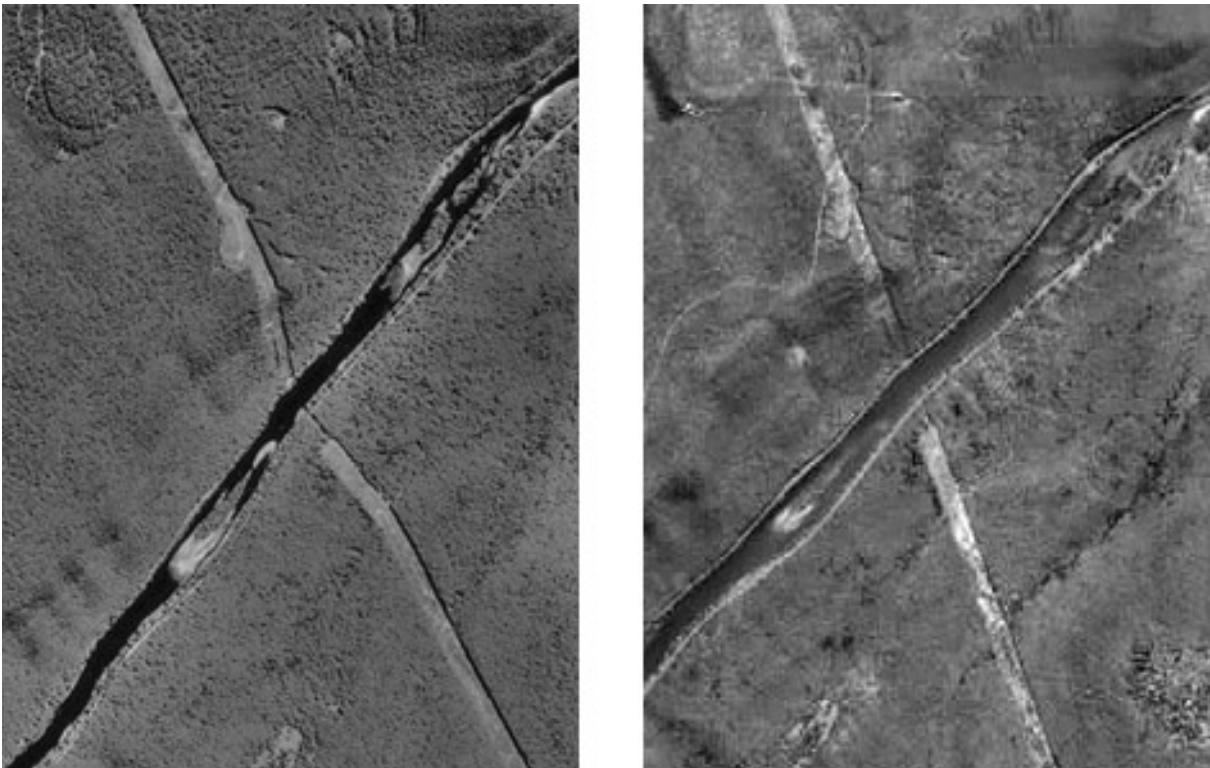
- Sensor geometry
- An elevation model



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

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

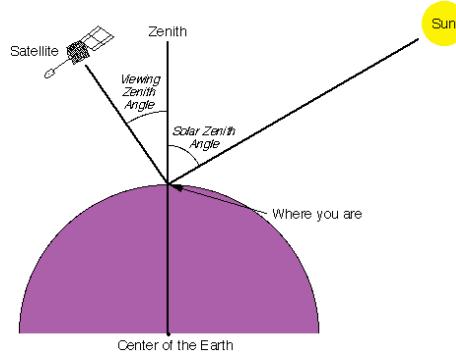
Where

- $L_T$  = radiance (DN to TOA) from sloped terrain
- $\theta_O$  = Sun's zenith angle
- $i$  = Sun's incidence angle - cosine of the angle between the solar zenith and the normal line of the slope
- 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  $\cos_i$

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

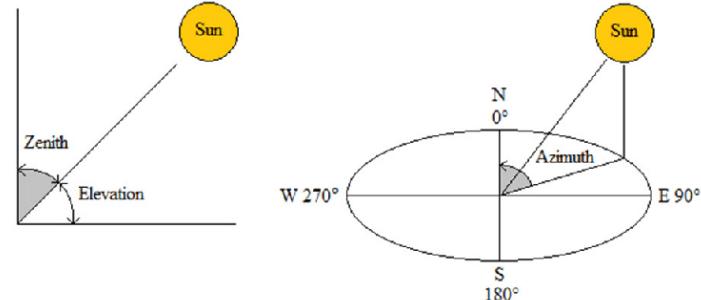
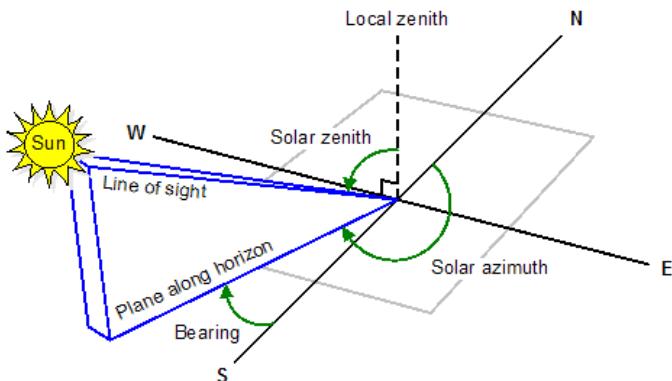
Where:

$\theta_p$  = slope angle (from DEM)  $\theta_z$  = solar zenith  $\phi_a$  = slope aspect (orientation of the slope from DEM)  $\phi_o$  = solar azimuth

# Orthorectification correction 5

solar azimuth = compass angle of the sun ( $N = 0^\circ$ )  $90^\circ$  (E) at sunrise and  $270^\circ$  (W) at sunset. See [Azimuth Angle animation](#)

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



Solar azimuth and zenith angles Source:[Khurum Nazir Junejo](#)

Solar zenith and solar azimuth Source:[catalyst.earth](#)

# 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 or light here), per metre squared (surface within FOV) per steradian (angle of the view) per nanometre (wavelength) =  $W m^{-2} sr^{-1} \mu m^{-1}$
- DN to **spectral radiance** = radiometric calibration
- Sensor calibration = the relationship between

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

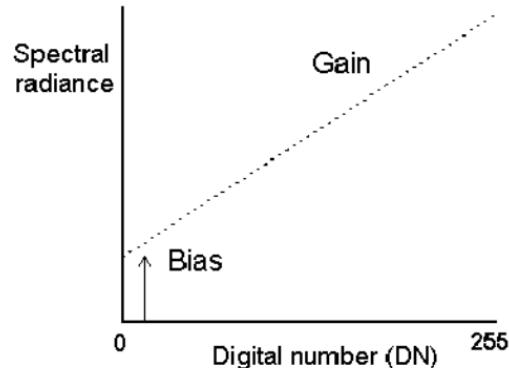
*Gain* and *Bias* are usually provided but we can calculate them.

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,  $L_\lambda$ :

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

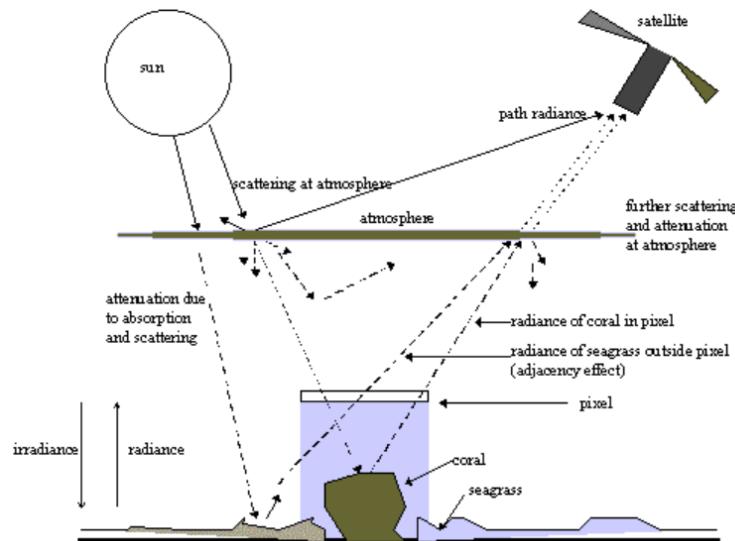
units:  $\text{mW cm}^{-2} \text{ ster}^{-1} \mu\text{m}^{-1}$  (for Landsat)

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 University

# 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 (Landsat 5) = 8 bit or 0 - 65536 Landsat 8 (12 bit)

# Remote sensing jargon 2

To clarify...

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

- Might also be called Top of Atmosphere (TOA) radiance
- How much light the instrument sees in meaningful units but still have effects of:
  - **Light source**, atmosphere and surface material

We can remove the effects of the light source to generate Top of Atmosphere reflectance but usually this is combined within the radiance to reflectance step.

# Remote sensing jargon 2

To clarify...

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

Reflectance is a property of a material (e.g. reflectance of grass is a property of grass)

- A ratio of the amount of light leaving a target to the amount of light striking it
- Performed on radiance corrected data

Typically this comes as surface reflectance (Bottom of Atmosphere) but can also be Top of Atmosphere reflectance....

# Remote sensing jargon 2

To clarify...

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

The issue with radiance is that it contains physical properties AND is dependent on the light source

## TOA reflectance

We can convert TOA radiance to TOA reflectance

- Measure radiation going down and up in a ring, divide one by the other
- Remove effects of light source

## Surface reflectance

- Remove effects of light source **and atmosphere...**

Calculations of TOA radiance and TOA reflectance. Source:[Open Library](#)

# Remote sensing jargon 2

To clarify...

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

If/ But

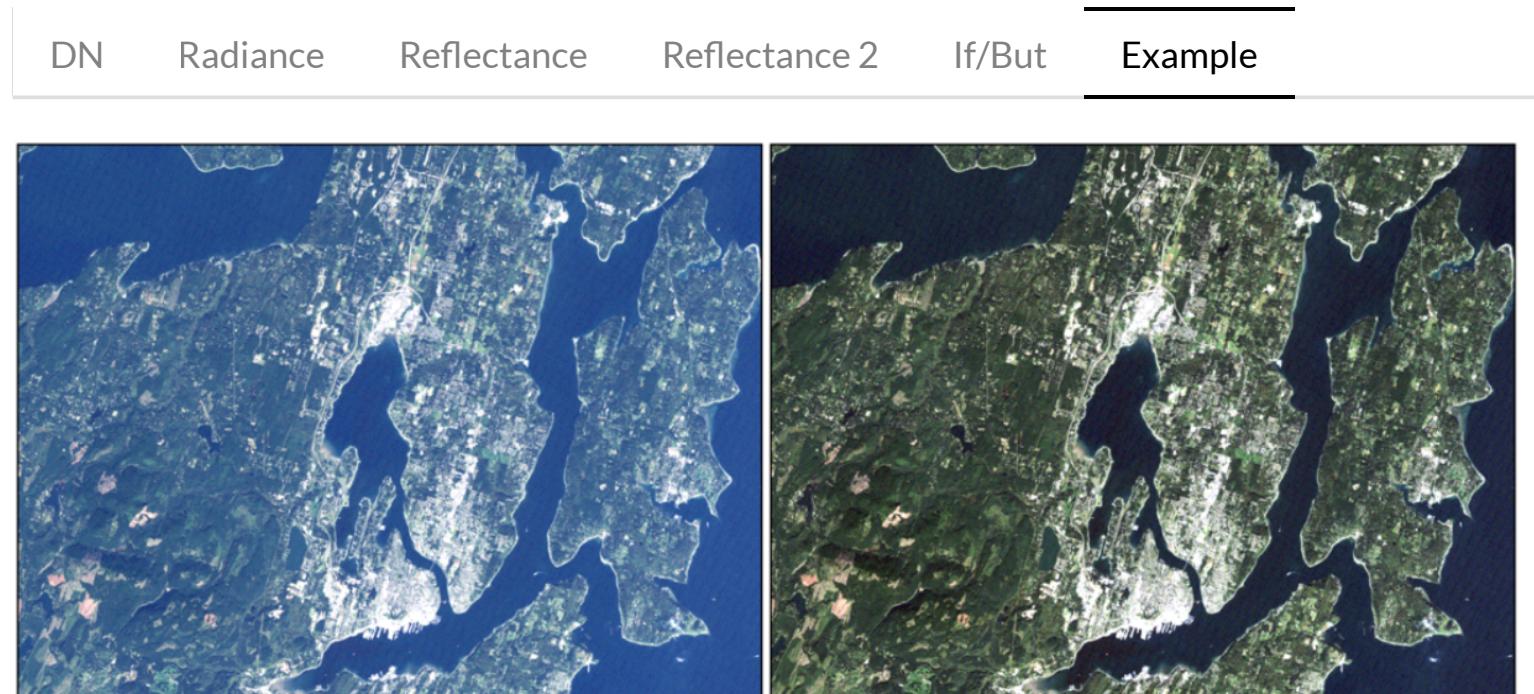
- All of the light leaving the surface goes straight to the sensor (nothing is intercepted or at an angle) = **hemispherical reflectance**
- We need to account for atmospheric and illumination effects to create reflectance. BUT this typically doesn't deal with shadows and directional effects (e.g. viewing angles) = **apparent reflectance** However, this is often called **reflectance**

Landsat Collection 2 Surface Reflectance. Source:[USGS](#)

Radiance vs. Reflectance. Source:[I3harrisgeospatial](#)

# Remote sensing jargon 2

To clarify...



Left TOA, right Surface Reflectance. Source:[USGS](#)

## 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 algorithms 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)

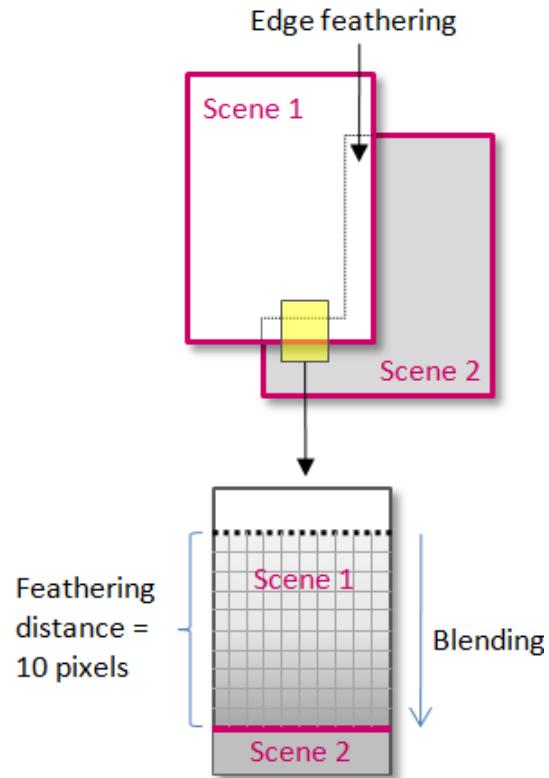
Just because someone gives you data doesn't mean you don't need to know how they created it.

## 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:Harris Geospatial

# Joining data sets 3

The base and second image overlap - 20 to 30%

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

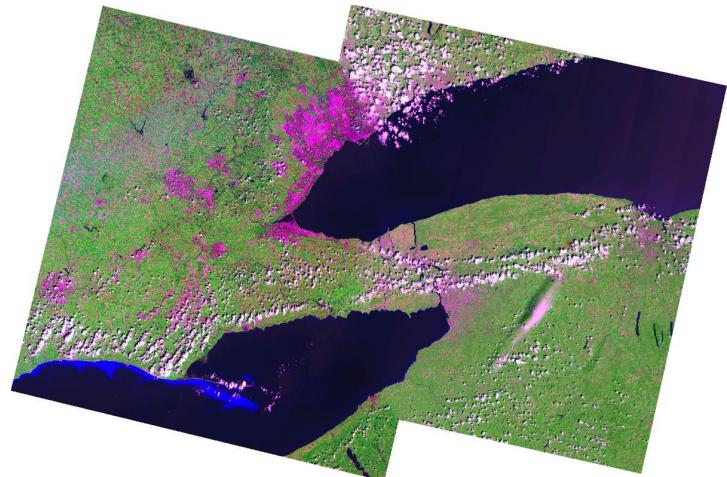
According to Jensen

- 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

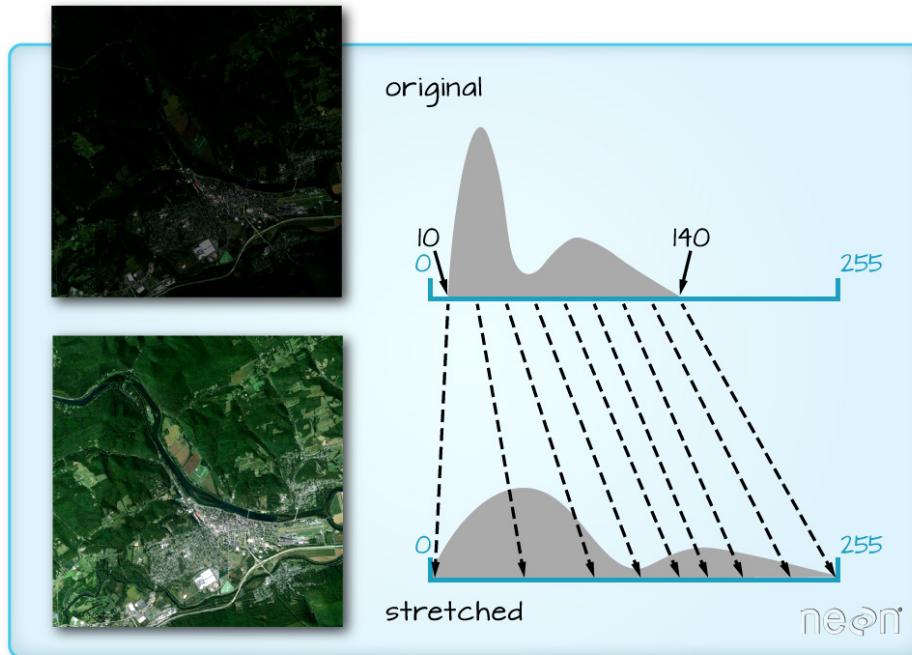
## Contrast Enhancement

- 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

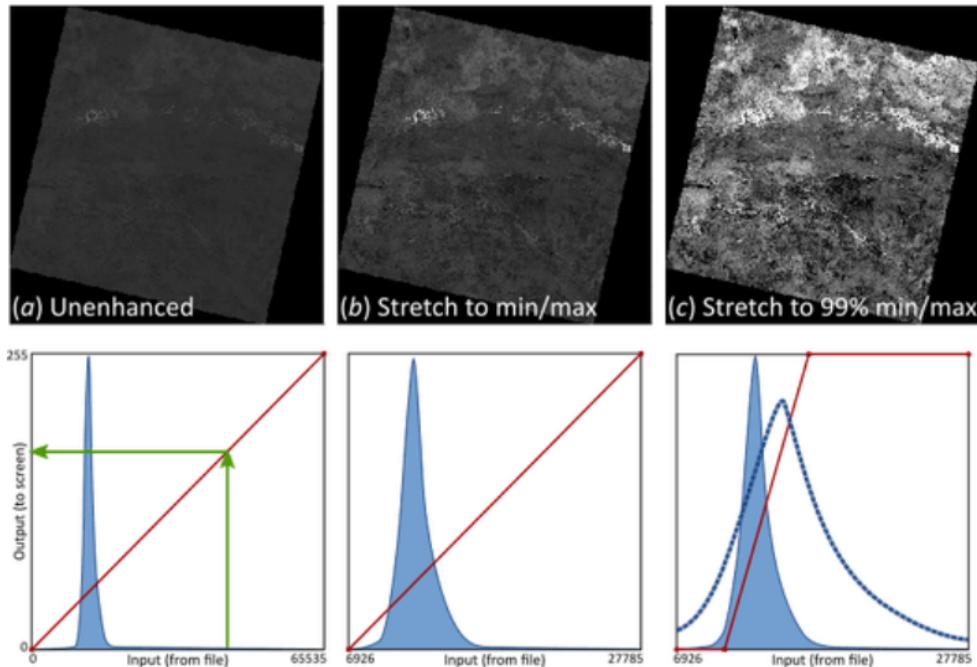
## Image Stretch



Source:EarthLab

# Image Enhancement 3

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



Source: Atilio 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 tasseled cap is also really.

See Jensen, Chapter 8, page 291 for 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)

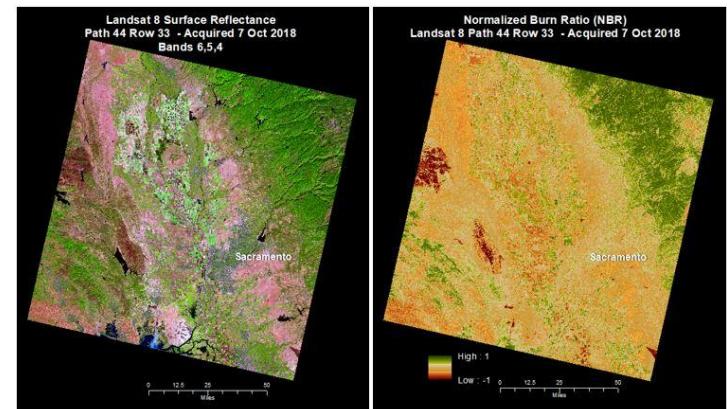
Ratio      Ratio 2      Filtering      Filtering 2      Filtering 3

Example: Normalized Burn Ratio

$$(\text{NIR} - \text{SWIR}) / (\text{NIR} + \text{SWIR})$$

In Landsat 4-7, NBR =  $(\text{Band 4} - \text{Band 7}) / (\text{Band 4} + \text{Band 7})$ .

In Landsat 8-9, NBR =  $(\text{Band 5} - \text{Band 7}) / (\text{Band 5} + \text{Band 7})$ .



Source: [USGS](#)

# Other enhancements

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Ratio	Ratio 2	Filtering	Filtering 2	Filtering 3
-------	---------	-----------	-------------	-------------

- Low pass or low frequency (averages the surrounding pixels)
- High pass or high frequency - enhance local variations
  - e.g. subtract the low pass filter from twice the value of the original central pixel

# 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
-------	---------	-----------	-------------	-------------

- Edge enhancement
  - What is an edge? - change in pixel values
  - Make edges appear in a shaded relief - like likes.
  - Change the coefficients applied to image (Jensen p.299)
  - This is termed **embossing**

Embossing has a direction...e.g. the filter for East is

0 0 0  
1 0 -1  
0 0 0

Other filters aren't direction specific e.g.  
Laplacian 4:

0 -1 0  
-1 4 -1  
0 -1 0

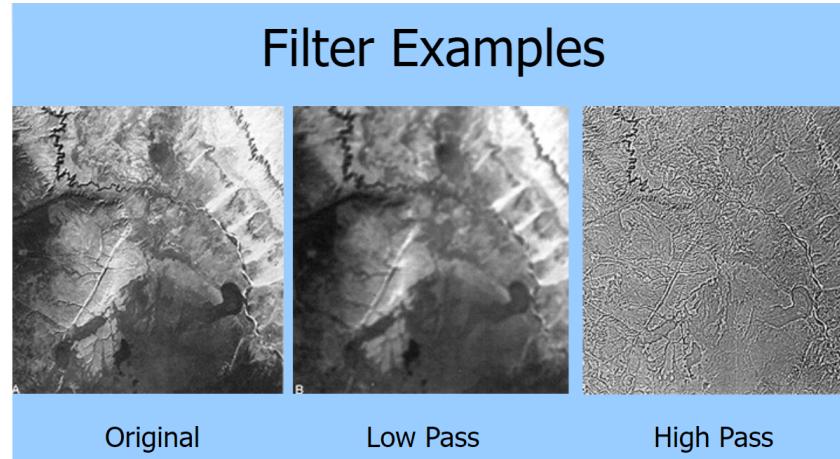
# Other enhancements

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

Example: Filtering



Source:Dwain Casey

# 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 `rasterPCA()` from the RStoolbox package

For PCA explained watch [Josh Starmer's video](#) or consult the lecture slides for GEOG 4110

# Other enhancements 2

PCA

**PCA 2**

Texture

Texture 2nd

Texture 3

Fusion

PCA example, multi-date PCA - bands from both time points are combined into one image, then PCA

**Figure 4.** Example of PCA-enhanced land use change information from cropland and water to urban land in the third principal component (PC3), 2003–2006. (a) RGB composition image of SPOT-5 (2003); (b) (RGB) composition image of SPOT-5 (2006); (c) the third principal component; (d) field survey photo (2006).

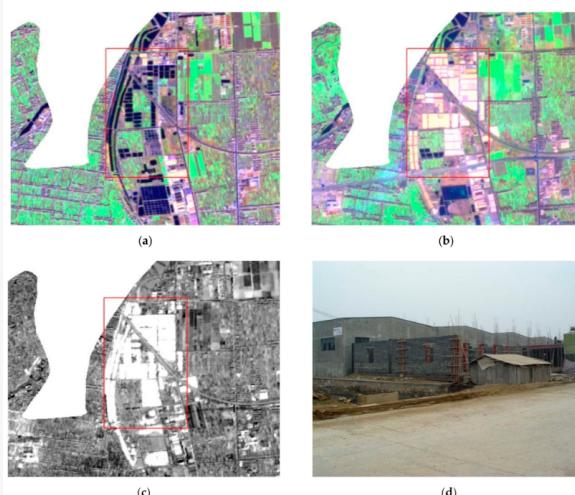


Figure 4. Example of PCA-enhanced land use change information from cropland and water to urban land in the third principal component (PC3), 2003–2006. (a) RGB composition image of SPOT-5 (2003); (b) (RGB) composition image of SPOT-5 (2006); (c) the third principal component; (d) field survey photo (2006). Source: Demg et al. 2019

# Other enhancements 2

PCA

PCA 2

**Texture**

Texture 2nd

Texture 3

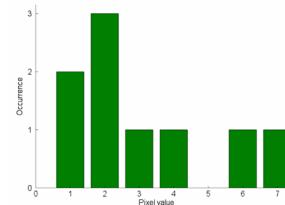
Fusion

- Images just use tonal (spectral) data not texture
- Texture = spatial variation of gray values
  - Calculate metrics (e.g. mean)
  - Create occurrence values - number of times they occur
  - Divide by the kernel (3x3) so 9 to make probabilities  $P(i)$
  - Sum all probability values in kernel
  - Multiply the pixel value by the probability from the kernel (e.g. mean)

First order (occurrence) = use counts or occurrences

6	5	2	6	5
4	<b>1</b>	2	7	6
2	<b>3</b>	2	6	4
4	<b>4</b>	2	1	5
2	5	3	6	3

2. ENVI computes a histogram that determines the frequency of occurrence of the quantized values within the kernel.



3. It creates a vector (1D array) of the occurrence values.

[8, 2, 3, 1, 1, 8, 3, 1]

4. It normalizes the occurrence values by dividing them by the number of values in the kernel (9 in this example). These are called probabilities.

$P(i)$  [0.000, 0.222, 0.333, 0.111, 0.111, 0.000, 0.111, 0.111]

5. It computes the texture metric by summing the normalized occurrence values and applying the relevant equation.

Source: [Harris](#)

# Other enhancements 2

PCA      PCA 2

Texture

**Texture 2nd**

Texture 3

Fusion

Second order(co-occurrence) = relationship between pixel pairs "a function of both the angular relationship and distance between two [or kernel] neighboring pixels"

6	5	2	6	5
4	4	3	5	6
2	3	5	6	4
4	6	4	3	5
2	5	3	6	3

6	5	2	6	5
4	4	3	5	6
2	3	5	6	4
4	6	4	3	5
2	5	3	6	3

The co-occurrence matrix in this example would be as follows:

	3	4	5	6
3	0	0	3	0
4	2	0	0	0
5	0	0	0	2
6	0	2	0	0

ENVI computes the following **second**-order co-occurrence metrics using the equations from Haralick, Shanmugan, and Dinstein (1973).

- Difference of pixel (origin) then to right
- Matrix of changes or co-occurrence (see left, rows are reference)
- Work out probability (value/ sum all values)
- Plug into to calculation...e.g.mean...
- Original value  $i$  \* probability of  $i$  to  $j$  based on matrix
- See [Haralick video](#)

Source:Harris

# Other enhancements 2

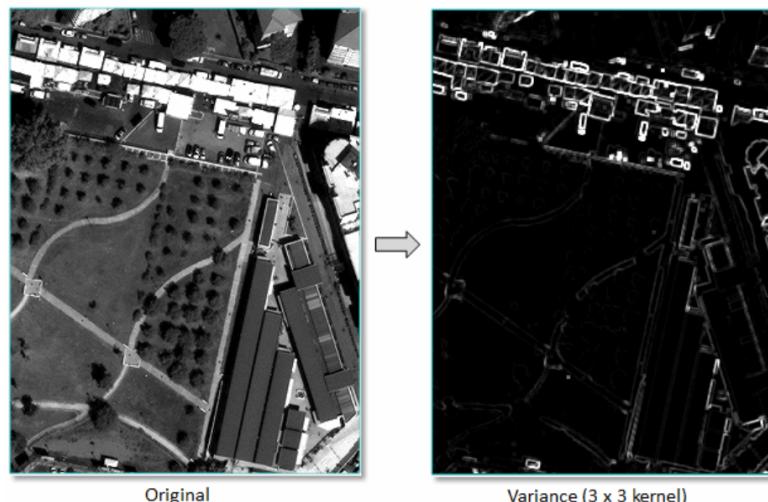
[PCA](#)
[PCA 2](#)
[Texture](#)
[Texture 2nd](#)
[\*\*Texture 3\*\*](#)
[Fusion](#)

## Texture example: first order variance

### Variance

This is a measure of the dispersion of the values around the mean.

$$\text{Variance} = \sum_{i=0}^{N_g-1} (i - M)^2 P(i)$$



Source:Harris

# Other enhancements 2

PCA

PCA 2

Texture

Texture 2nd

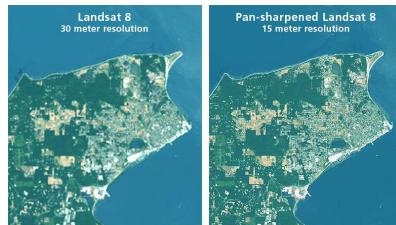
Texture 3

Fusion

- Image fusion is where data from multiple sensors / sources is **fused** together

## Pan sharpen

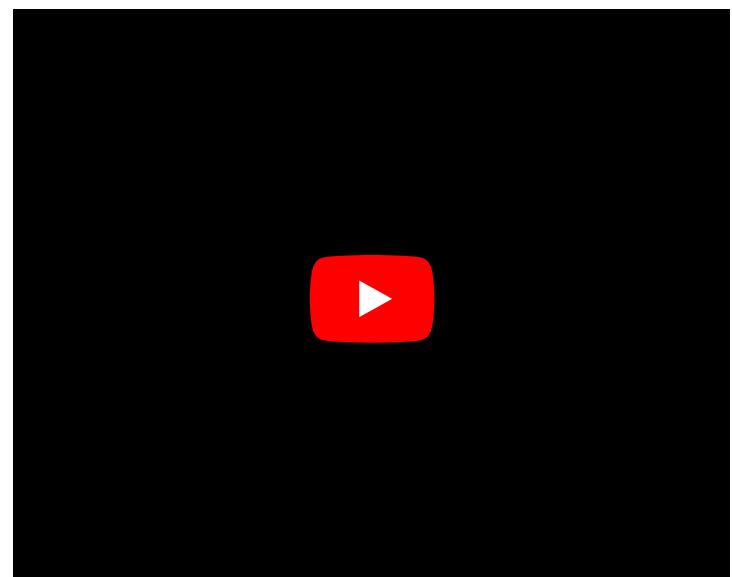
- In Landsat the multi-spectral data (30m) can be sharpened with the panchromatic band (15m)
- Usually this is **just the visible bands**, although the Gram-Schmidt algorithm also computes NIR



Source:shadedrelief

## Data Fusion

Better together by **Schulte and Pettorelli, 2017**



## 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?

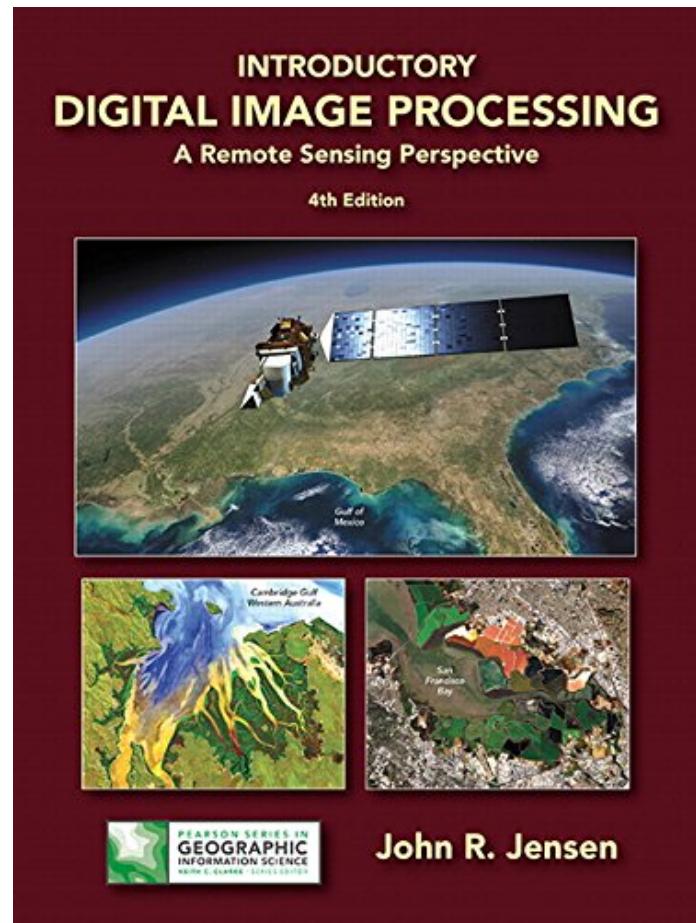
# Task

For the task this week select one concept from the lecture to explore in greater detail (e.g. texture analysis to remotely sensed images).

Write 2-3 paragraphs supporting your responses with plots and literature:

- Explain the concept (e.g. what texture analysis is)
- Detail how it has been applied in 2 studies
- Reflect on the applicability / usefulness

# Reading



UCL library book