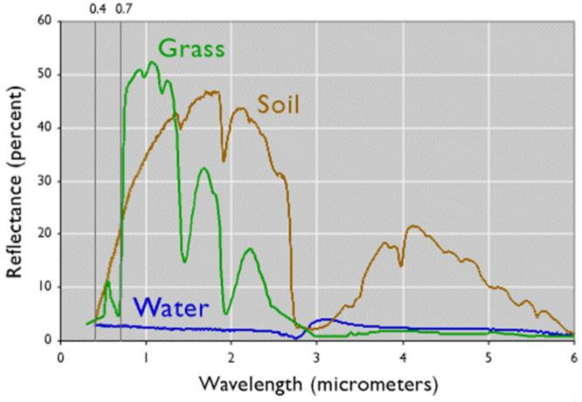
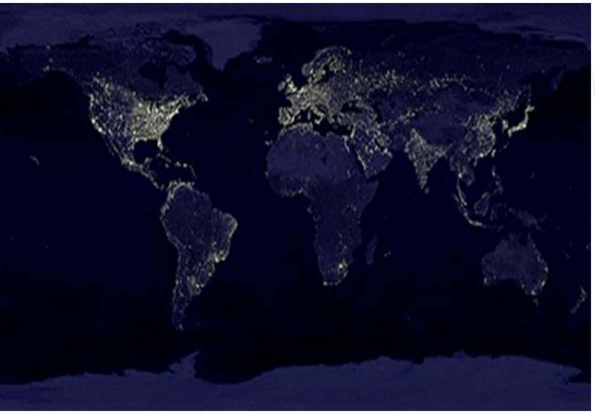
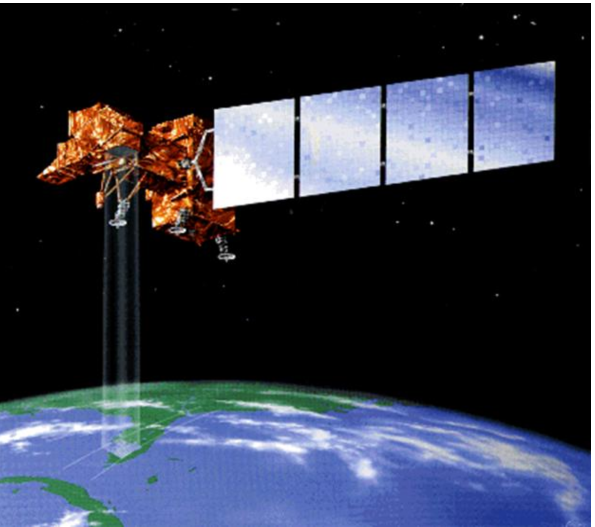
Application of GIS to Fast Track Planning and Monitoring of Development Agenda

Radiometric, Atmospheric & Geometric Pre-processing of Optical Remote Sensing

13 – 17 June 2018

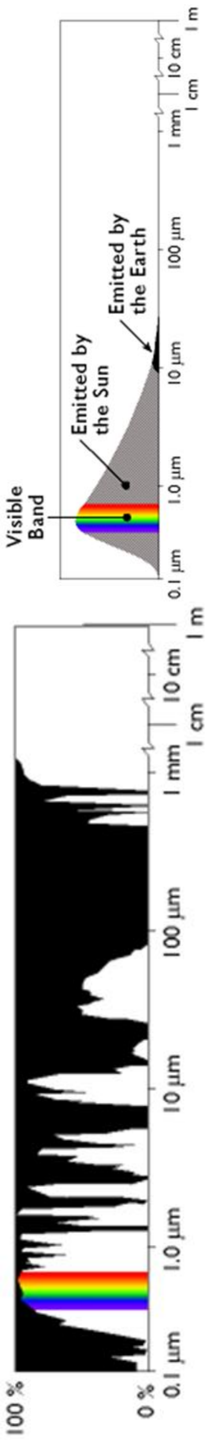






Outline

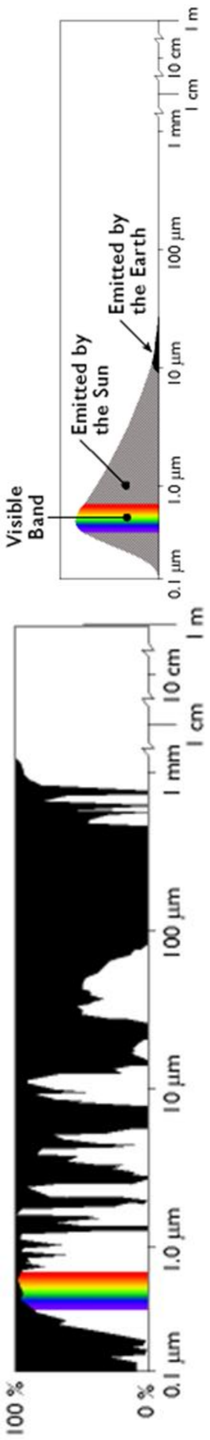
1. Why pre-process remotely sensed optical images.
2. Radiometric calibration.
3. Atmospheric correction approaches.
4. Geometric correction and image registration.
5. Result of pre-processed LANDSAT 8 image
6. An example of LANDSAT 8 data product
7. Summary and pre-processing tips.
8. Further reading list



Why pre-process remotely sensed digital images?

The nature of remotely sensed image data:

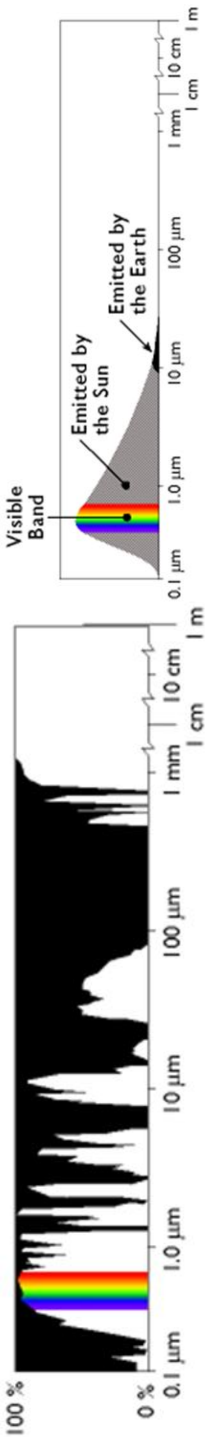
- emitted radiance from the Earth surface travels through the atmosphere before it is intercepted by the remote sensing instrument.
- this process can both attenuate (reduced in strength) and add to the at-sensor radiance recorded.
- therefore, it is important to separate the atmosphere's contribution to the measurements made by the instrument from the contribution of the underlying surface



Why pre-process remotely sensed digital images?

- correct for geometric distortions that result from the instrument flight-line orientation or orbit characteristics
  - RS imagery provided by a supplier may exhibit undesirable geometric distortions , depending on the supplier's pre-processing level.
  - further processing may be required before the images can be used for various applications, for example:

Why pre-process remotely sensed digital images?

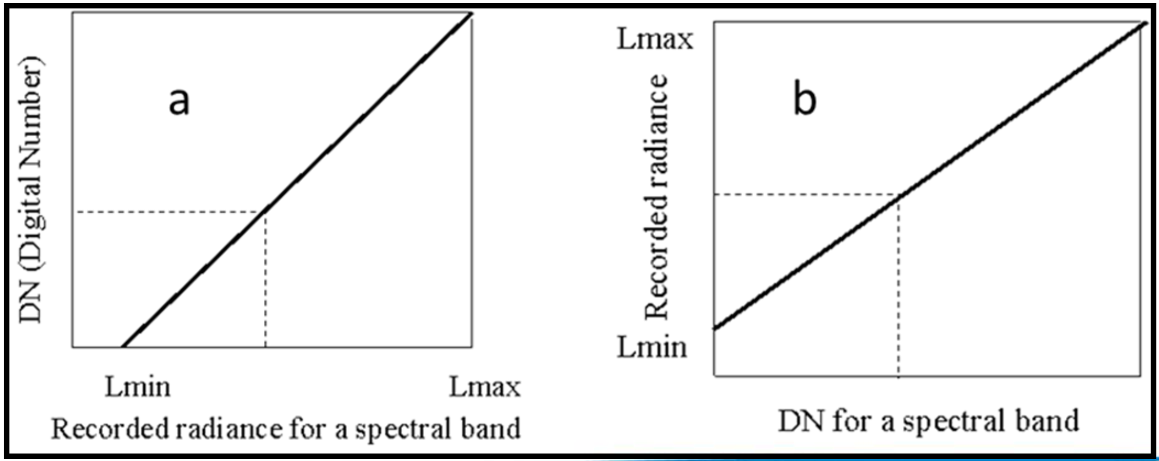


- When conducting quantitative image analysis in a single scene (**see example later**) or comparing between images acquired on different dates or by different sensors to estimate cover types.
- When the purpose is to derive Earth's surface properties that can only be estimated from their reflectance features (e.g. compensation of hyperspectral data for atmospheric effects)

Radiometric calibration

- recorded radiance measurements in each spectral band is converted into quantized, calibrated scaled digital number (DN) – stored for each ground sampling area (pixels).

- pixel DN is a linearly transformed representation of at-sensor radiance for a discrete ground sampling location (see panel **a** & **b**).

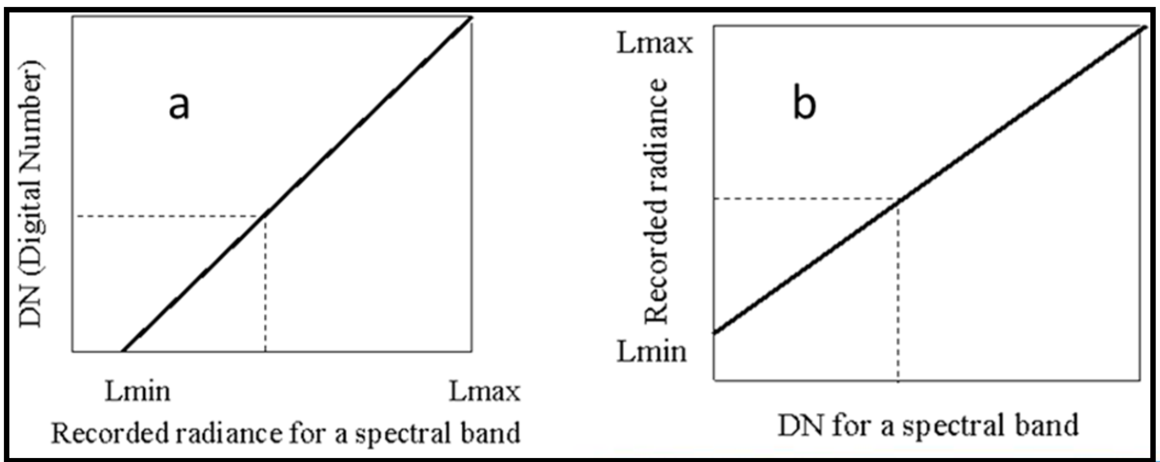


Panel a: DN-to-radiance;

Panel b: Radiance-to-DN

Relationship between radiance (L) and pixel DN

- The slope and offset of the linear transformation is specific for each spectral band, so that the sensor's initial calibration values can be used to calculate radiance (L) and inversely used to calculate pixel DN.



$$DN = \frac{DN_{max}}{L_{max} - L_{min}}(L - L_{min})$$

So

$$L = \frac{L_{max} - L_{min}}{DN_{max}} \times DN + L_{min}$$

that is

$$L = gain \times DN + offset$$

which can be thought of as

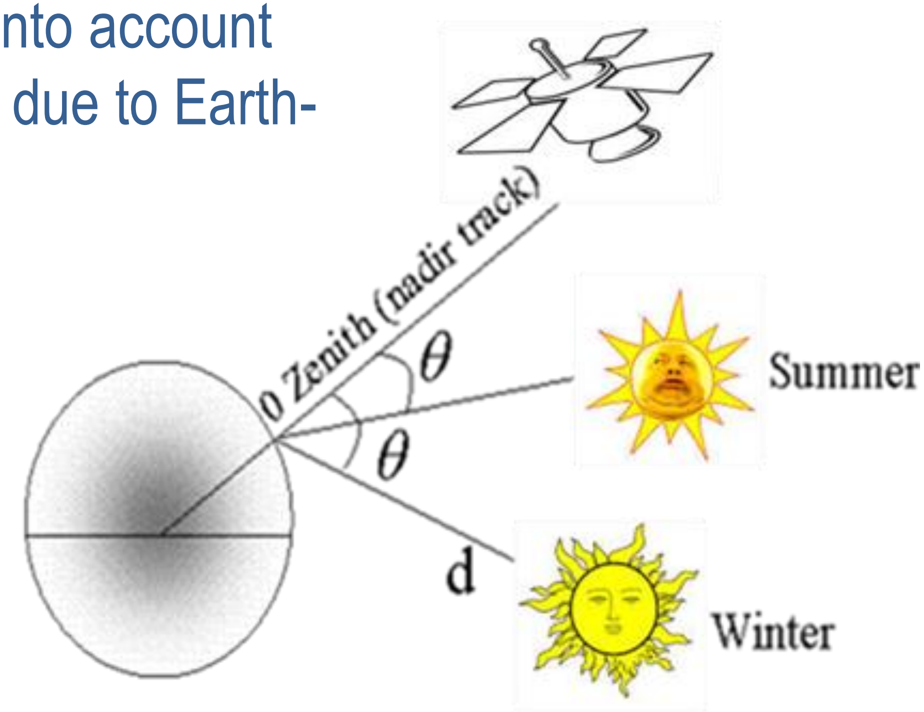
$$L = slope \times DN + intercept$$

mesured in

$$W - m^{-2} - sr^{-1} - \mu m^{-1}$$

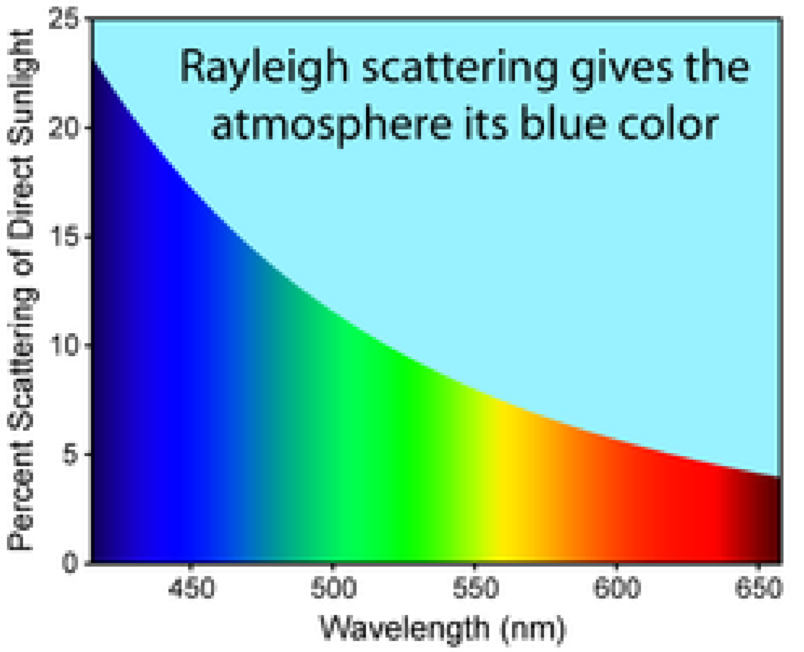
Conversion to Top-of-Atmosphere (ToA) spectral radiance

- Conversion of at-sensor radiance to apparent at-sensor spectral reflectance is required before applying atmospheric correction:
- At sensor-reflectance involves taking into account temporal changes in solar illumination due to Earth-Sun geometry



Atmospheric correction

- Several atmospheric phenomena were known to affect at-sensor reflectance's : e.g. Rayleigh scatter, ozone, water vapor, and aerosols….

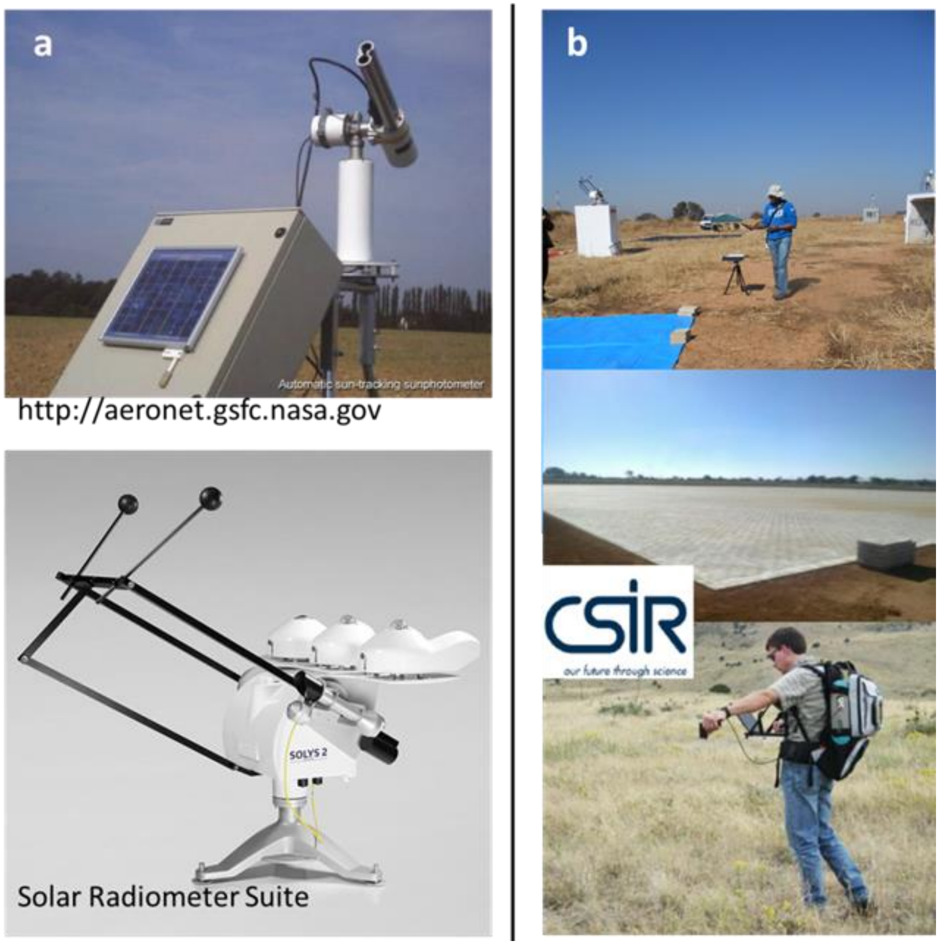


- atmospheric effects may have to be removed to derive a good bottom of the atmosphere (BoA) reflectance or estimate of the true at-ground upwelling radiance.

Atmospheric correction approaches

1. physical-based environmental models:

- based on a mathematical understanding of atmospheric radiation transfer theory and atmospheric scattering
- requires detailed estimates of the state of atmospheric optical thickness and atmospheric aerosols
- models are complex and data intensive, requiring field data, validation and they are computationally intensive



Atmospheric correction approaches

2. Semi-empirical modelling approach:

- uses complex models but for a significantly reduced set of input parameters compared to the physical models
- correction can be based on an estimate of atmospheric visibility and standard atmospheric constants for latitude/longitude/date
- results may not be as accurate as the one that can be obtained for same targets using the physical-based models
- Results obtained using semi-empirical modelling can be significantly affected by atmospheric visibility.

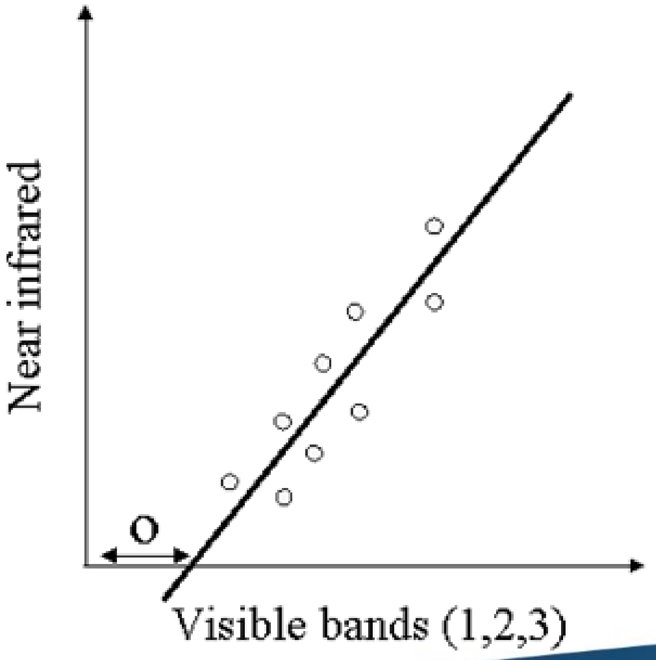
Atmospheric correction approaches

3. Empirical estimation approach

- uses only the image data to remove atmospheric effects
- only corrects for atmospheric path radiance which is at-sensor radiance contributed by atmospheric scattering
- only account for Rayleigh atmospheric scattering

The correction procedure requires that:

- The image must have pixels of expected zero reflectance in the visible and NIR.
- Preform linear regression of each visible band against the NIR band for each pixel.
- The X-axis offset is considered to be an expression of path radiance.
- Subtract the X-axis offset from the visible band



Geometric correction and image registration

- geometric distortions in digital image data consist of:
  - systematic error caused by Earth's eastward spinning motion and curvature (more evident from space than at lower altitudes aerial platform).
  - random geometric distortions result from relief displacement, variations in the satellite altitude and attitude, payload instrument anomalies.

relief displacement caused by variations in terrain elevation is more evident from unrectified aerial imagery

- well defined orbital geometry correction parameters can be achieved using predefined transformations which model the aspect, skew and rotational distortions of a sensor.

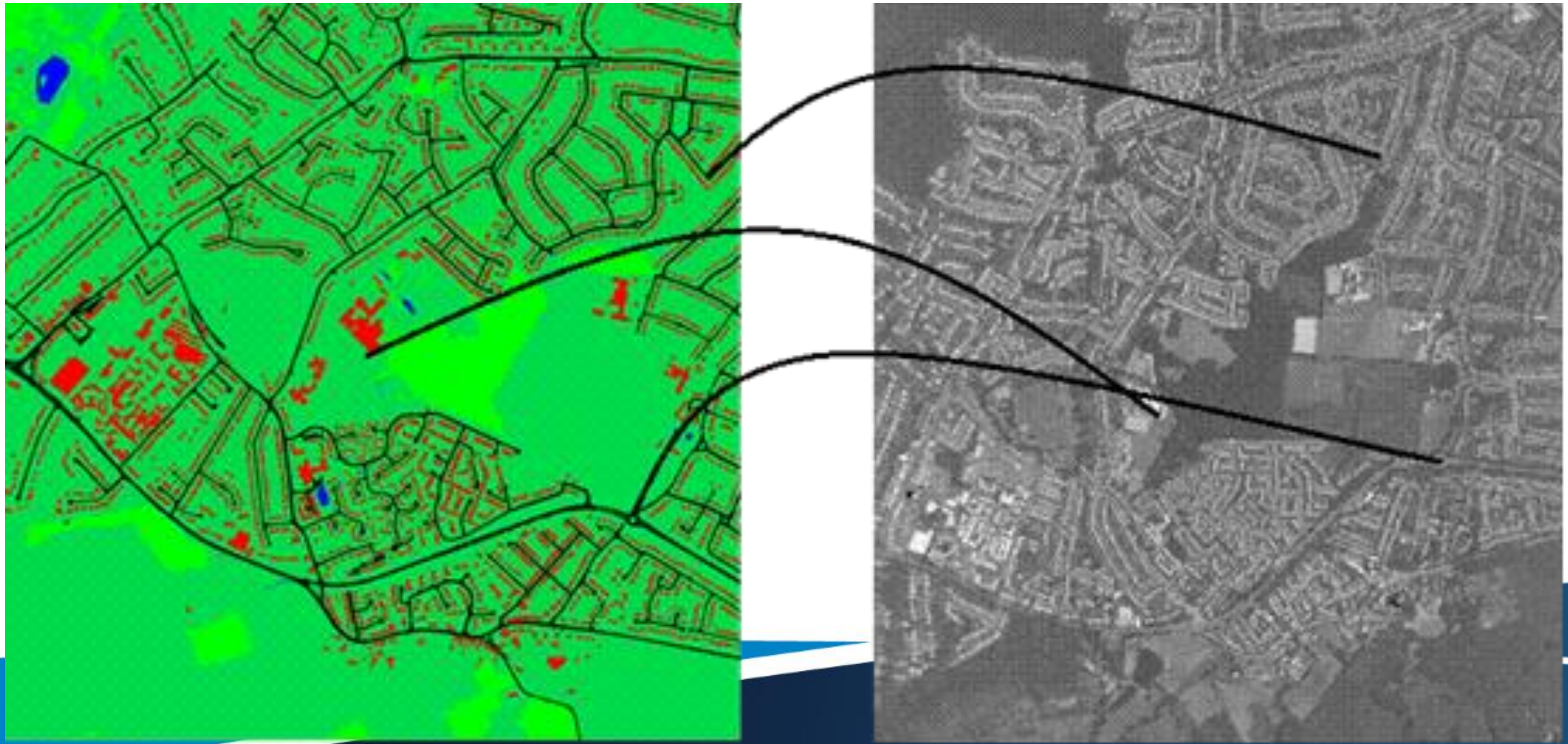
Geometric correction and image registration

- random geometric errors can be corrected through a multi-step process known as **rubber sheeting**:
  - involves stretching and warping an image to georegister control points shown in the image to that of other reference map datasets or known ground control point (GCP) locations on the ground;

- GCP locations are used to calculate the transformation between the image and the reference map,
- transformation to the new coordinate system for each pixel is done to generate a new image,
- the actual DN is assigned to each pixel in the new image,
- estimation of the procedure is performed.

Correction using GCPs:

- GCPs should:
  - be distinct features in both the map and image.
  - should have clear boundaries and regular geometry.
    - good GCPs would be house corners, road intersections, field corners etc.
    - bad GCPs would be water bodies, natural vegetation, oval or circular features.



How many GCPs should you use?

- the minimum is the number required to estimate the transformation coefficients.
- General rule of thumb is that, the more the better.
- Try to avoid excessive clustering and leaving unsampled areas.
- Always ensure that you have GCPs close to the image boundary.
- Sample more intensively in areas (e.g. mountainous landscape) where you think there may be considerable distortion of high spatial frequency.

Least Squares Approximation

- Given a set of ground control of known map (Easting, Northings) and related image (column, row) we need to estimate the transformation between the two co-ordinate sets:

Eastings we have

$$e = \begin{bmatrix} e_1 \\ . \\ e_n \end{bmatrix} \qquad p = \begin{bmatrix} 1 & c_1 & r_1 \\ 1 & . & . \\ 1 & c_n & r_n \end{bmatrix} \qquad a = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}$$

A single estimation of an Easting from c & r is

$$e_i = a_0 + a_1 c_i + a_2 r_i$$

In matrix form this can be represented as

$$e = Pa$$

But we want a so that we can use the above for unknown e so

$$a = (P'P)^{-1} P'e$$

Least squares estimation summarized in matrix notation.

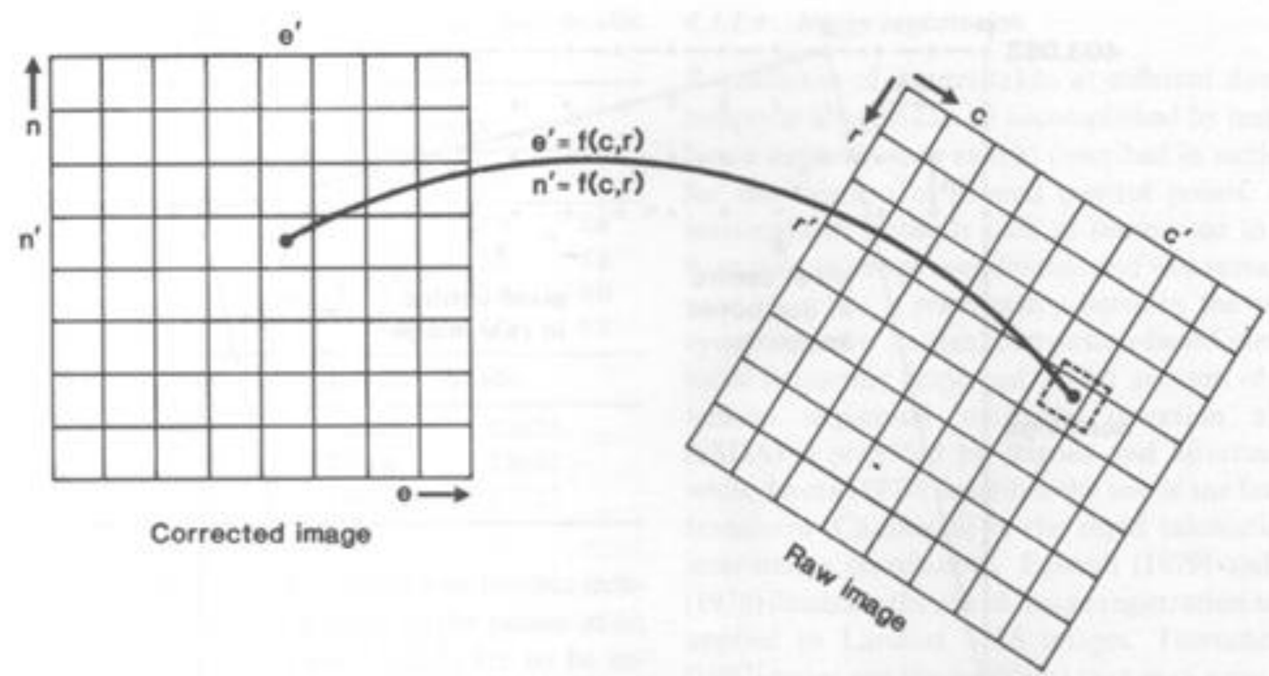
Assessing Geometric Accuracy

- the coordinates resulting from a transformation are an estimate and therefore need to be assessed.
- accuracy is normally expressed for each control point and overall root mean square error (RMSE).
- high RMSE values (> 1 pixel) indicate the level of inaccurate transformation.
- if the chosen GCPs were adequate the registration process can be repeated with additional/different GCPs in order to decrease the point and total error.

Point	Error X	Error Y	Point Error
1	-1.542023	1.346588	2.047226
2	-0.960491	1.837280	2.073196
RMSE = 1.909580 (pixel)			

Resampling

- Once the least squares coefficients have been derived and the (x,y) calculated for a pixel, a DN must be assigned to it by a reverse least squares estimation.
- the resulting col/row of an X/Y is likely not to be an integer as the corrected pixel lies across two or more pixels in the raw image (see illustration below)



Resampling

1. **Nearest neighbour**
   - a pixel is selected that is nearest to the estimated col/row of the reverse least squares:
   - – retains the original image histogram (distribution) – advantage,
   - – visually the resulting images can be "blocky" – disadvantage .

2. **Bilinear**
   - uses the four surrounding neighbours with equal weighting
   - Assumes that the pixel value lies on a planar surface
   - – modifies the original histogram and can give a blurred image

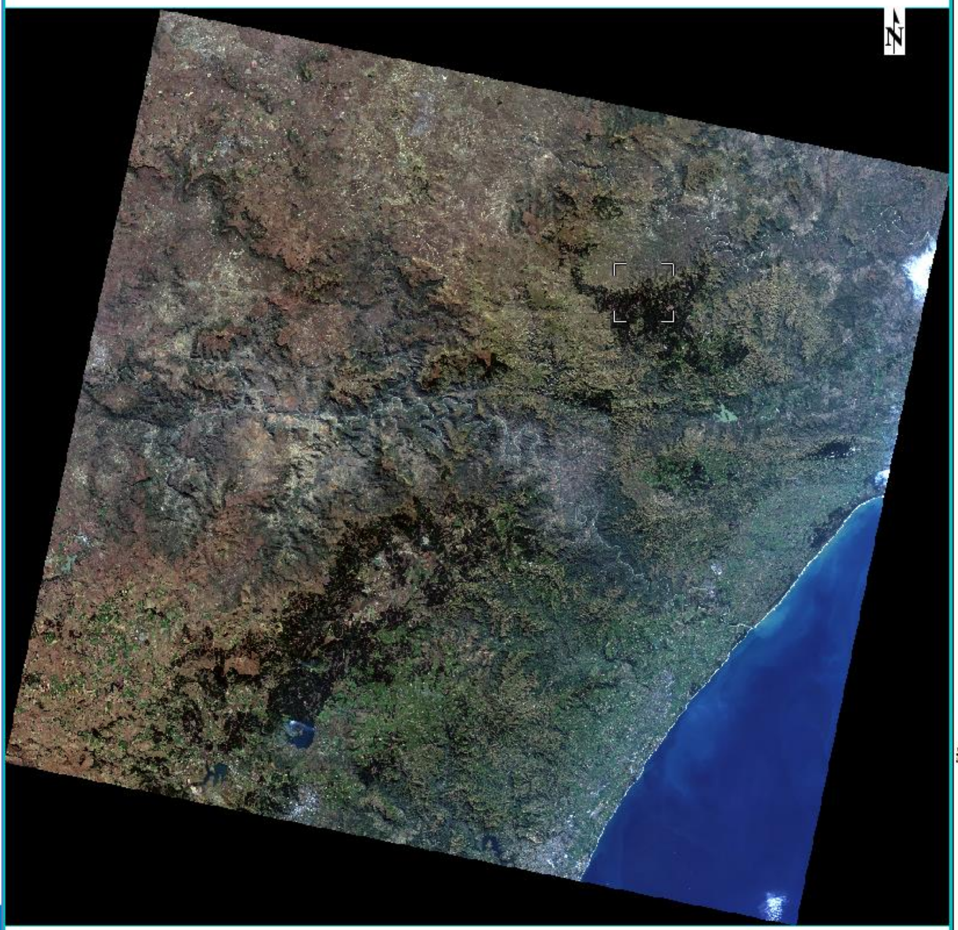
Resampling

3. **Bicubic**

- uses the 16 nearest pixels to estimated col/row (unequal weighting)
- computationally intensive
- Despite considerable modification of the original image histogram, it produces the best visual results

The Result of pre-processed LANDSAT 8 image

Radiometrically, and geometrically corrected LANDSAT 8 scene

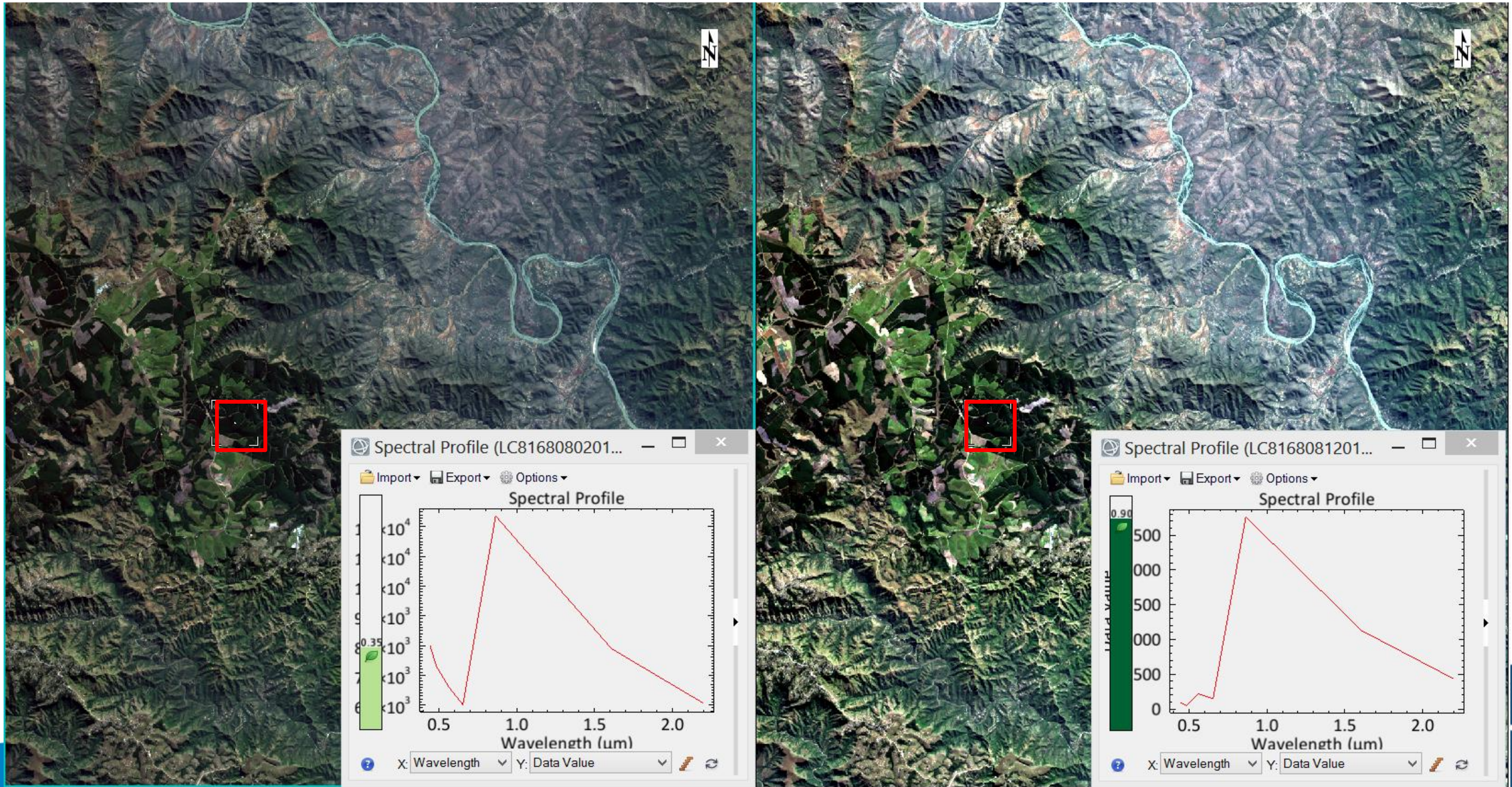


Atmospherically corrected LANDSAT 8 scene

The Result of processed LANDSAT 8 image

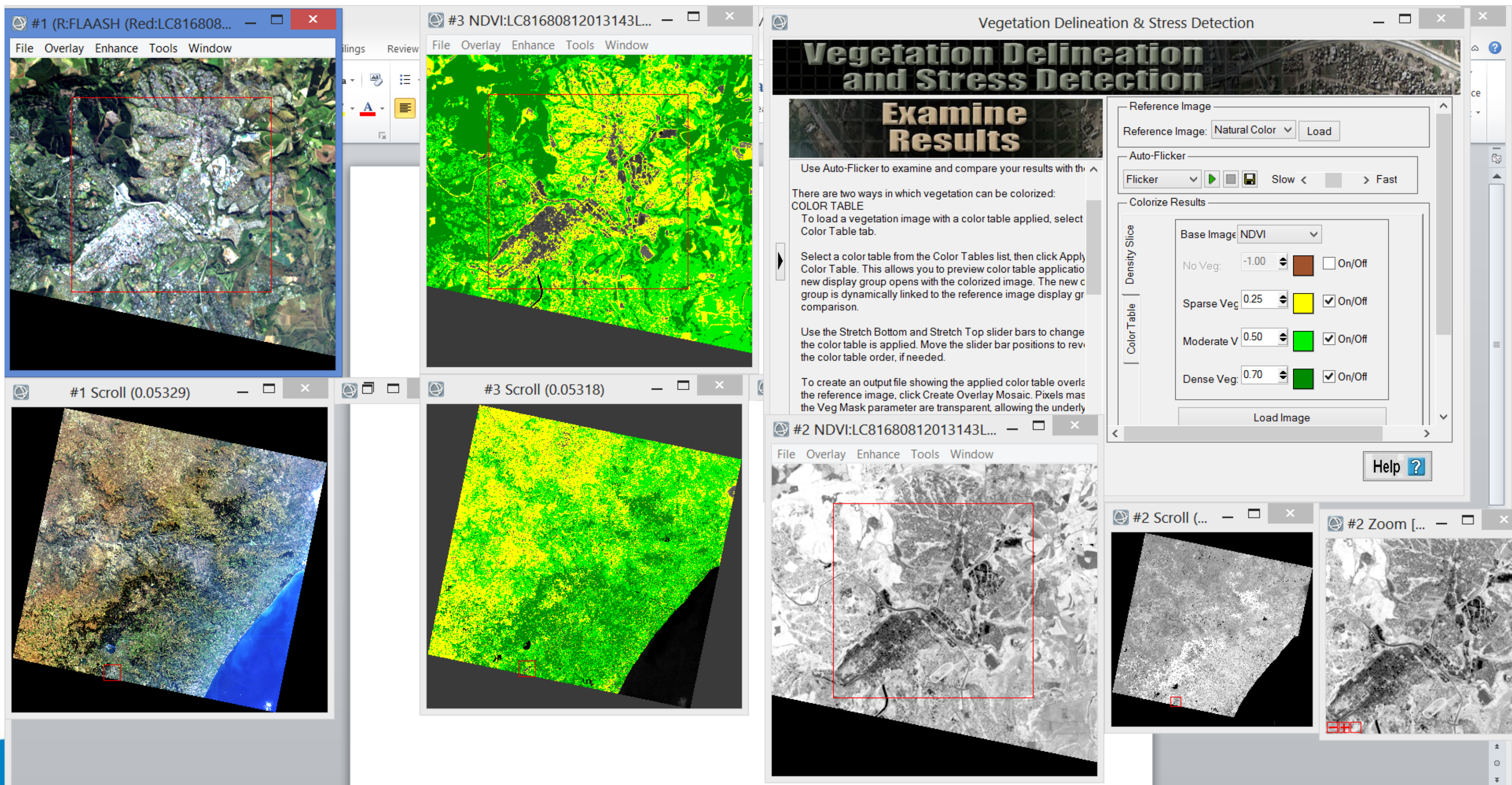
Corrected LANDSAT 8 image for quantitation analysis

$$NDVI = (NIR - R) / (NIR + R)$$



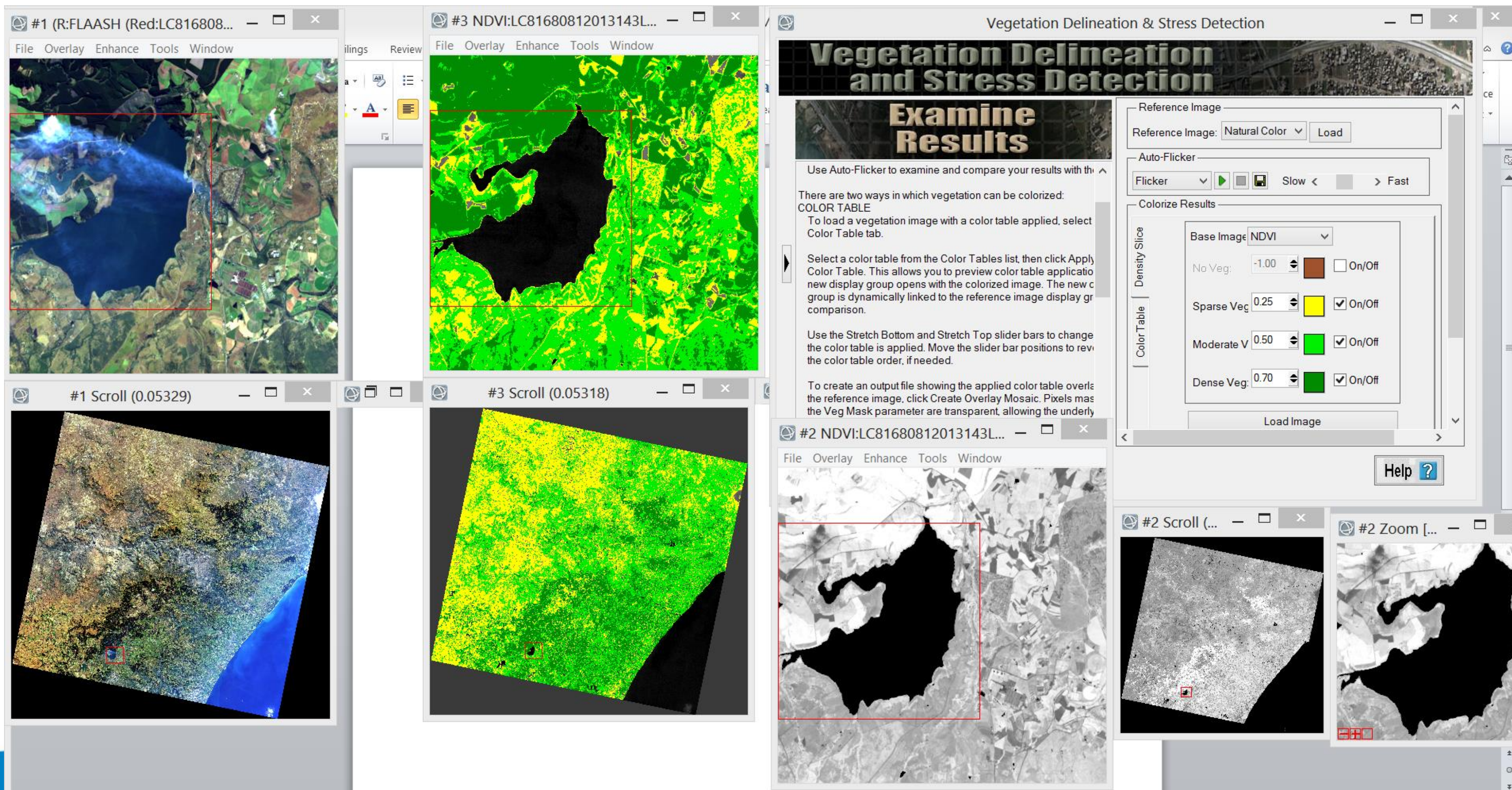
The Result of processed LANDSAT 8 image

Deriving data products from corrected LANDSAT 8 scene: e.g. NDVI layer



The Result of processed LANDSAT 8 image

Deriving data products from corrected LANDSAT 8 scene: e.g. NDVI layer



Summary

- Remotely sensed satellite data are derived from measurements of electromagnetic radiation.
- Digital sensing systems enables users to map phenomena that are otherwise invisible.
- Several atmospheric phenomena, including Rayleigh scattering, ozone, water vapor, and aerosols, are known to affect reflectance's measured by sensors.
- Image correction algorithms yield corrections to compensate for some of these.

Pre-processing top-tips

At the start of a project always:

- obtain as much information from the supplier on what processing has been done on the image supplied to you.
- carefully assess the image header and all files supplied with it.
- Visually check the image for visual atmospheric effects e.g., visible haze can occur in the blue spectral-band.

Evaluate your needs:

- If not performing change detection or ratios you may not need to perform atmospheric correction.
- bicubic resampling is often used if producing an image for visual overlay with map data - but not for quantitative analysis.

Know your algorithms:

- Be aware of the implications, assumptions and limitations of a particular approach

Further reading list

Campbell, J.B. 1996-2007. Introduction to Remote Sensing. New York: Guilford. (eds. 1-4) (1987, 1996, 2002, 2007).

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