Remote sensing introduction; Color theory; The basics of image processing

Week #1: 30 August 2023

I. Class Information

- all the detailed class information, notes, schedule, etc. are found on the class webpage:

  http://ivis.eps.pitt.edu/courses/geol1460/

- this page is online and I will also post the link to it on the Canvas page for the class
- the class is 3 hours every Wednesday evening either for the lecture (Thaw Hall room 11) **_or _** for the lab (SRCC 207)
  - it is to your benefit to attend the lectures and ask questions
  - this is a rigorous class and simply reading the online notes each week will not serve you well for the exam

- I will not be recording the lectures nor streaming them live
  - if you are unable to attend a lecture, you have the notes, but please come talk to me in office hours if you have questions
  - the same policy stands for the lab meetings, run by Poushalee Banerjee

- there will be more details given at the start of lecture

II. What is remote sensing??

- it is the collection and interpretation of information about a target without being in physical contact with it
  - mostly using electromagnetic (EM) radiation
  - can also be acoustic (sonar)
  - <u>examples:</u> human eye, camera, aerial photographs, satellite and airborne scanners (like, Landsat, ASTER, weather satellites)

  - measuring changes in the intensity with wavelength
    - interpreting the physical properties of the material
    - spatial (area) variations
    - temporal (time) variations
    - physics of remote sensing and the derived information varies strongly with wavelength

  - *minimal definition* (more appropriate for what we do here)
    - remote sensing is *the non-contact recording of information from the electromagnetic spectrum by means of instruments on platforms such as*

spacecraft, and the analysis of the acquired information by means of visual and digital image processing
    - will vary depending on the wavelengths, sensor types, platforms, and analysis

- is it an art or science (or a tool for each)??
    - the text lists remote sensing, GIS, and cartography as scientific sub-disciplines or advanced techniques that support and integrate with traditional sciences
        - physical sciences, biological sciences, social sciences

    - however, the growth of remote sensing in the past 50 years (and GIS in the past 3 decades) indicates that these fields are on their way to becoming full scientific disciplines in time

- advantages of remote sensing
    - unobtrusive (passive)
    - unbiased data collection
    - non single-point data
    - data collected in-situ
    - others?
- disadvantages of remote sensing
    - not a panacea for everything!
    - human-introduced errors
    - emit EM radiation (active)
    - uncalibrated data over time
    - $$

- what can Remote Sensing measure?
    - x, y geographic location
    - z topographic location
    - vegetation health
        - chlorophyll content, water, % biomass, phytoplankton

    - surface/sea temperature
    - surface roughness
    - soil moisture & evaporation
    - atmosphere
        - chemistry, temperature, water %, wind speed, precipitation, clouds

    - others
        - snow/ice, volcanoes, earthquakes, wildfires, land use, ocean health, etc.

- two types of remote sensing systems:
    - <u>passive:</u> detection of energy from natural illumination or emission
        - <u>example:</u> camera, visible/near infrared sensors, thermal infrared sensors

    - <u>active:</u> detection of energy reflected back to the sensor after providing the illumination
        - <u>example:</u> camera with a flash, flashlight and your eye, radar, lasers (lidar)

III. EM Principles:

- **detection:** general principles here *(more details later in the semester)*

- energy interactions:
  - remote sensing is only useful because we are able to detect some property about the surface
  - the only way that this is possible is if the surface alters the energy in some way upon interaction
  - this "alteration" is what we detect

  - five types of energy/matter interaction that can take place:

    i. reflected
      - energy returned from surface with an angle of reflection equal and opposite to angle of incidence
      - caused by surfaces "smooth" relative to the incident wavelength

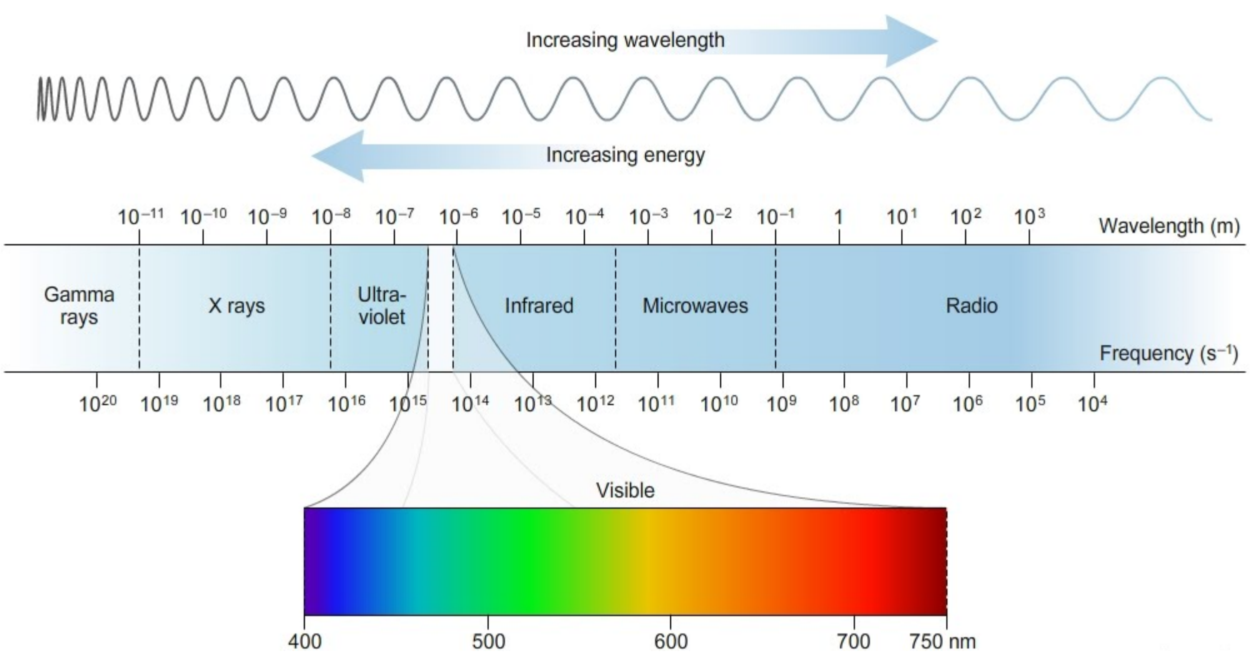
    ii. scattered
      - deflection of energy in multiple directions
      - caused by surfaces "rough" relative to the incident wavelength

    iii. transmitted *(refracted)*
      - energy passes through the material
      - a change in density (index of refraction) between two materials causes the velocity of the incident wave to change

    iv. absorbed
      - energy is transformed (usually to longer wavelength heating)

    v. emitted
      - release of energy from the material (it is now the source)

- EM spectrum and EM waves



- waves have a constant velocity in a vacuum
- but vary in wavelength and frequency by the following equation:

$$\mathbf{v = c / \lambda}$$

- where, **c** = speed of light = 2.99×10^{8} m/sec; **v** = frequency (Hz or cycles/sec)
  - EM radiation is quantized into discrete packets called photons

- allows for the frequency (v) to be related to the energy of the wave

$$\mathbf{E = h\ v}$$

  - where, **h** = Planck constant = 6.626×10^{-34} Joule seconds
  - because v is inversely proportional to wavelength, **smaller wavelengths (higher frequencies) have higher energy**
  - <u>example:</u> X-Rays penetrate deeper (more damaging) to your body than energy from radio waves
  - <u>example:</u> UV-A rays penetrate deeper into your skin than UV-B, but UV-B is more harmful *(higher energy)*

- EM wavelength regions
  - varies from gamma rays (short wavelength) to radio waves (long wavelength)
    1. gamma rays (≤ 0.0001 microns) *(1,000,000 microns in 1 meter)*
       - produced by change in the energy state of the neutrons/protons
       - best for measuring variations in light elemental compositions

    2. X-rays (≤ 0.01 microns)
       - photons absorbed by the inner shell of electrons

    3. ultra violet [UV] (≤ 0.4 microns)
       - photons emitted/absorbed by the outer shell of electrons
       - information on transition metals (Fe^{2+}, Fe^{3+}, Cu^{2+}) and chlorophyll

    4. visible [VIS] (≤ 0.67 microns)
       - similar to UV

    5. near infrared [NIR] (≤ 1.5 microns)
       - similar to UV

    6. short-wave infrared [SWIR] (≤ 3.0 microns)
       - vibrational structure of certain minerals (OH^{-}, $CaCO_3$)

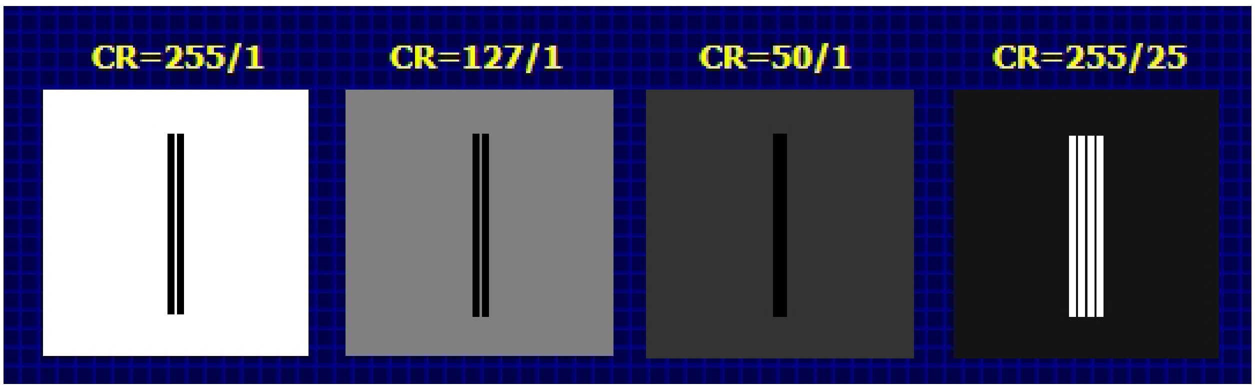
    7. thermal infrared [TIR] (≤ 100 microns)
       - information on the molecules and bond strength
       - excellent for surface mineralogy
       - information on surface temperatures

viii. microwave [radar] (0.1 cm - 10 m)
- includes TV and radio bands
- radar wavelengths (discrete bands between 3-60 cm) good for remote sensing
- little information on composition, but a lot about the particle size and surface roughness

IV. Information Interpretation

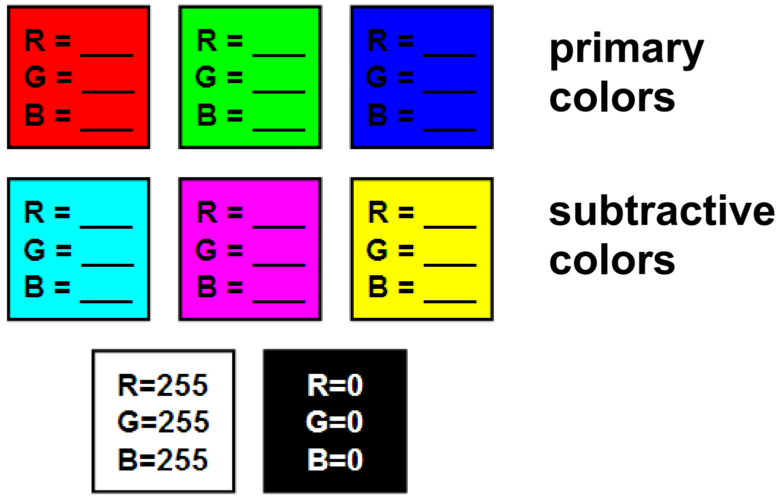
- Color Theory
  - **important point!**
    - where applied to image visualization, color display and mixing is *different* than common assumptions (like mixing paint)
    - *critical to understand the difference and how a particular color is created from the three primary colors and what that eventually tells you about the physical properties of the surface*
    - please make sure you understand this
    - will make the rest of the course very hard if you do not

- *first,* contrast ratio (CR): tells you how easily you can separate gray-scale values
  - human eye can only distinguish ~30 shades of gray



- *second,* primary colors *(aka, additive colors)*
  - red, green, blue (RGB)
  - R+B+G = white, -R-B-G = black
  - all other colors are formed from some percentage of these three
    - a "true color" image - RGB corresponds to the actual RGB wavelengths that your eye sees
    - "false color" image - RGB is used to display other wavelength regions (example: infrared images)

- *next,* secondary colors *(aka, subtractive colors)*
  - three secondary colors formed by the subtraction of one color from white
  - or, looking at it another way, 2 primary colors added together
    - - R (or, B+G) = cyan
    - - G (or, R+B) = magenta
    - - B (or, G+R) = yellow



- *finally,* color mixing
  - because digital data commonly varies from 0 to 255, a "pure" color would be represented by a 255 value, with the other two colors having values of 0
  - *with that, try to fill in the blanks in the above figure before class*

  - one pixel in three wavelength regions may have 3 different DN values
  - each wavelength placed in a RGB will combine to form a color
  - examples *(try to fill in these colors before class)*:

RED	**GREEN**	**BLUE**	**FINAL COLOR?**
155	17	219	____________
219	155	17	____________

- color mixing *(real example)*
  - vegetation color changes in autumn
  - typical spectra of vegetation *(more on spectral features in the next few weeks)*
  - vegetation composed of six primary constituents
    1. water
    2. cellulose (carbohydrate polymer)
    3. lignin (woody plants)
    4. nitrogen
    5. chlorophyll (two types, A & B)
    6. anthocyanin
       - ➢ pigment that is responsible for the coloration of flowers and autumn leaves

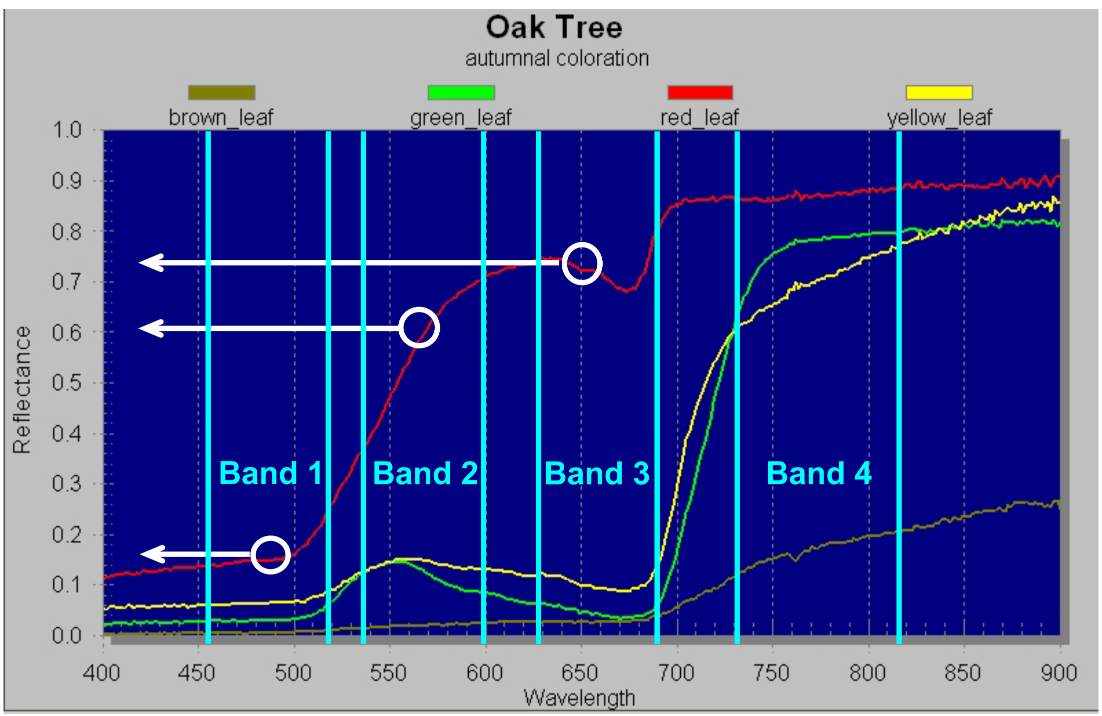
  - vegetation health *(drying out in autumn)*
    - lower water and chlorophyll, increased anthocyanin
    - results in increase in brightness in the VIS red
    - decrease in brightness in the NIR
    - fairly constant in the green

- from reflection spectrum to satellite image
  - *key point to understand!*
  - *how do you translate something happening at the scale of a leaf to the scale of a satellite image pixel??*

  - the chemical constituents of that leaf (or a rock, or a lake, or your skin) interact with the incoming light
    - the light is altered and reflected back as a continuous spectrum at all wavelengths
    - that spectrum (plus all the other spectra from all the other leaves in that pixel) are averaged together and captured by the satellite sensor
      - ➢ that pixel has a dimension determined by the spatial resolution of the sensor *(more on this later in the lecture)*

    - but the sensor does not capture all those wavelengths (maybe only a few)
      - ➢ this is known as the spectral resolution of the sensor

    - putting those image pixels into the computer software produces color



  - energy returned (percent reflectance) in the red leaf spectrum
    - function of the wavelength region
    - may be different for the human eye (white circles) than a multispectral instrument like ASTER
      - ➢ for example, in the above plot, the red leaf spectrum if imaged by a sensor with 4 bands would result in values of: 0.18 (Band 1), 0.62 (Band 2), and 0.75 (Band 3)
      - ➢ if, instead of measuring in reflectance from 0 to 1, we measured in DN from 0 to 255, the values would be: 46, 158, and 191
      - ➢ so, in R,G,B color space these DN values would produce __________?

V. Basics of digital image processing

- surface interaction with EM waves yields information
    - both a function of the sensor doing the detection and the surface material

    - function of the sensor:
        - the spatial resolution
            - depends on the altitude and the instrument characteristics

        - the sensitivity of the detector
        - the number of wavelength bands *(spectral resolution)*

    - *function of the composition/texture and wavelength*
        - *example: chemical composition, surface roughness, temperature, distance from the sensor*
        - *will look more at this next week*

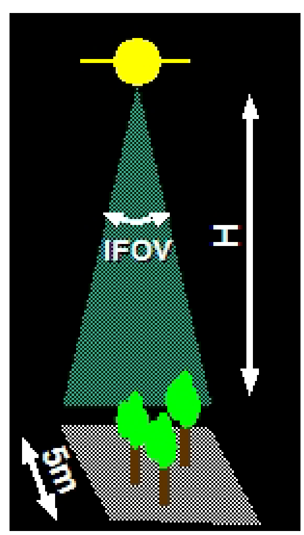
- imaging characteristics
    - pixel = "picture element"
        - the quantized spatial resolution of the image
        - displayed as a square as image is zoomed in

        - value is recorded as DNs (digital numbers)
            - for 8-bit (28) data this number ranges from 0-255 (gray-scale)
            - for 16-bit (216) data this number ranges from 0-65,535
            - the value chosen depends on the what type of physical parameter you are trying to store
            - integer values typically need 8-bit DN values, however decimal values may need 16-bit

    - image display
        - able to display only 1, 8-bit image in each of three primary colors (red, green, blue)
            - would be shown on a 24-bit monitor
            - the mixing of these three values produce all other colors *(color theory)*

    - what is ***spatial*** resolution?
        - the size of the spatial resolution cell (pixel)
        - determined by two parameters:
            - height of the sensor above the ground
            - instantaneous field of view (IFOV) of the sensor
            - **pixel size = H x IFOV**
            - *where, H = meters, and IFOV = radians*

            - <u>airborne example:</u> H = 2km, IFOV = 2.5mrad; pixel = **5m**
            - <u>orbital example:</u> H = 500km, pixel = 12.5 m, IFOV = ________ mrad



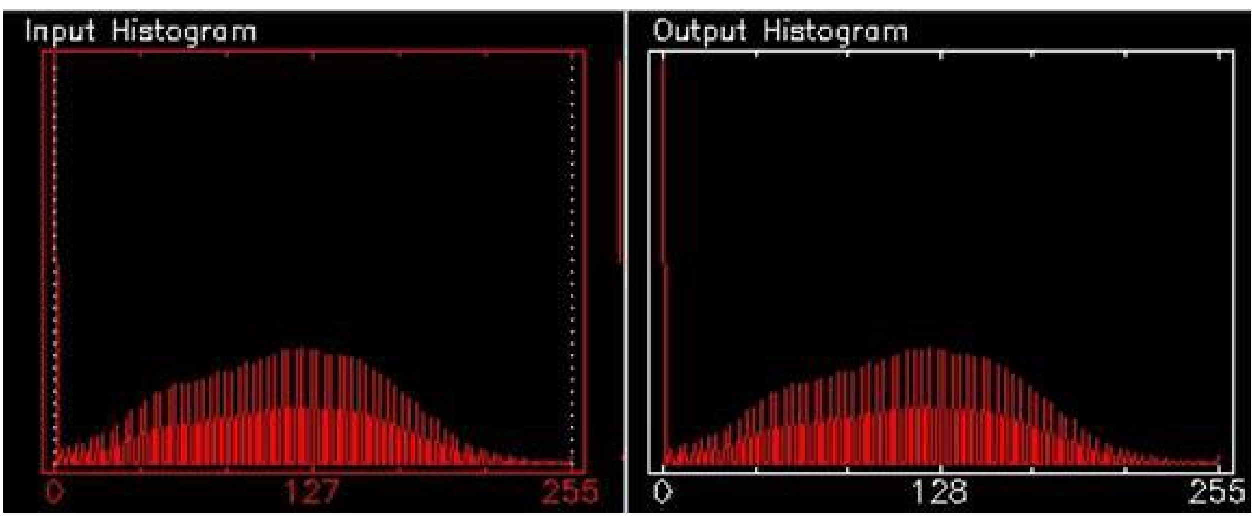
- so far, we have looked at basic image theory
  - color, pixels, image formation, etc.

- now, want to look at altering the image in some way
  - <u>data enhancement:</u> stretching, HSI-transforms, density slice
  - <u>data extraction:</u> PC-transforms, band ratios, classifications
  - <u>data restoration:</u> errors, noise, geometric distortions, filters

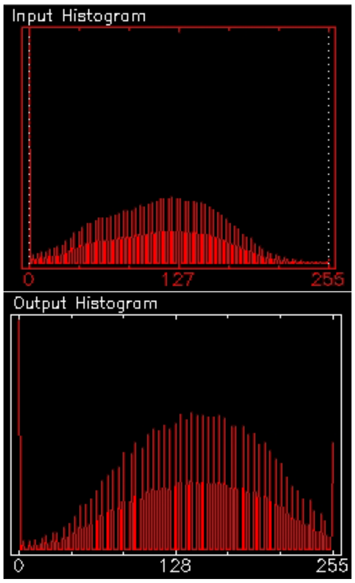
- generally, one would follow these in order
  - “fix-up” the data, remove errors, calibrate
  - then extract quantitative information

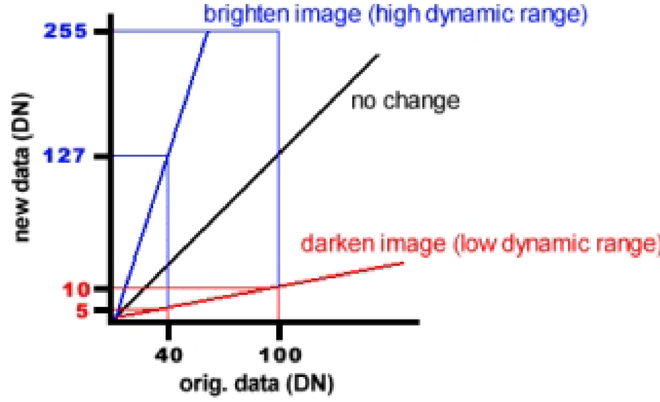
- data enhancement *(density slice)*
  - a visualization tool to add color to a gray-scale image
  - DN range is divided into groups and assigned a color

- histogram or contrast stretches
  - what is a histogram?
    - distribution of all the DN values for an image, single band, or subset thereof
    - for an image with a large variation of DN values, the corresponding histogram is generally normally-distributed with a mean (x) at some DN value



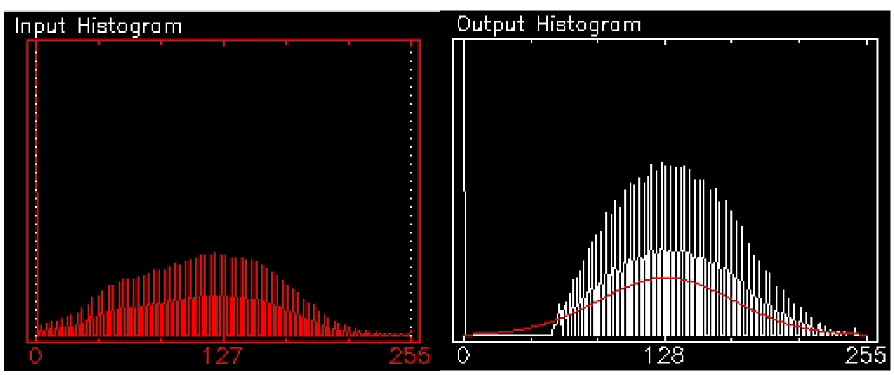
  - linear stretch
    - application of a linear equation to the data
      - map input DN to an expanded range of output DN
      - mapping some percentage of the histogram "tails" to 0 and 255
      - causes a loss of data in those regions, while expanding the majority of the DN
      - input DN ranged from 40 to 100, linear stretched from 127 to 255 and 5 to 10





- DN distribution can have a low dynamic range
- stretching or separating the data to cover most/all of the available dynamic range (0-255) is known as a stretch

- gaussian stretch
  - fit of the histogram to a gaussian distribution
    - the "tightness" of the curve is determined by the value of gamma



- other stretch types
  - examples: piecewise linear, square root, histogram normalization
  - all designed to enhance the dynamic range of the input histogram in a linear or non-linear way
  - all stretches are purely for image visualization
  - because they alter the DN values, they can never be used to extract quantitative information from the image!

- data extraction *(Band Ratios)*
  - very basic methodology to extract information in multispectral images
  - division of the pixel values for two or more wavelength bands
    - highlight subtle spectral and/or temporal variations
    - typically done after atmospheric correction and conversion to surface units (e.g., reflectance, emissivity, temperature)

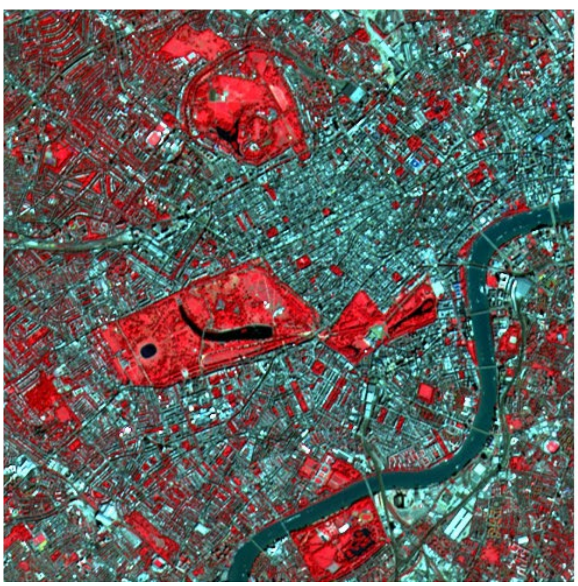
- reduce topographic and albedo effects (may be good or bad)
- “classic” ratios for Landsat TM bands which highlight mineral identification and vegetation health

- Normalized Difference Vegetation Index (NDVI) is probably the most famous:

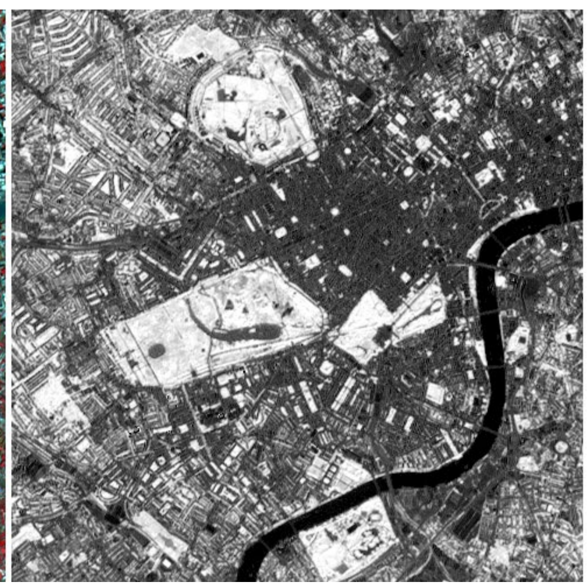
$$\mathbf{NDVI = (TM4 - TM3) / (TM4 + TM3)}$$

  - however, for another sensor like ASTER these band numbers will be different: (AST3 - AST2) / (AST3 + AST2)
  - produces values from 0 - 1.0, with a higher NDVI value implying “healthier” vegetation
  - *WHY (hint, look at the Oak Tree spectra again on page 6)??*
    - vegetation health (example: drying out in autumn)
    - lower water and chlorophyll, increased color pigments
    - results in increase in brightness in the VIS red
    - decrease in brightness in the NIR
    - fairly constant in the green

  - *example, London, England (ASTER data):*



(false color)



NDVI

  - note: in other (less rigorous) Remote Sensing classes taught elsewhere, NDVI is the culmination of the class
    - I describe it in the first lecture (and we will revisit it)
    - however, it is just a simple band ratio
    - I want you to come away with the theory behind these concepts and not just the idea of, *“if I click the NDVI button in the software, that makes an image of plant health”*