Introduction to Remote Sensing

- A **Primer** on Electromagnetic Radiation
- **Digital, Multi-Spectral** Imagery
- The **4 Resolutions**
- **Displaying** Images
- **Corrections** and **Enhancements**
- **Passive vs. Active** Sensors
  - **Radar** Remote Sensing

What is Remote Sensing?

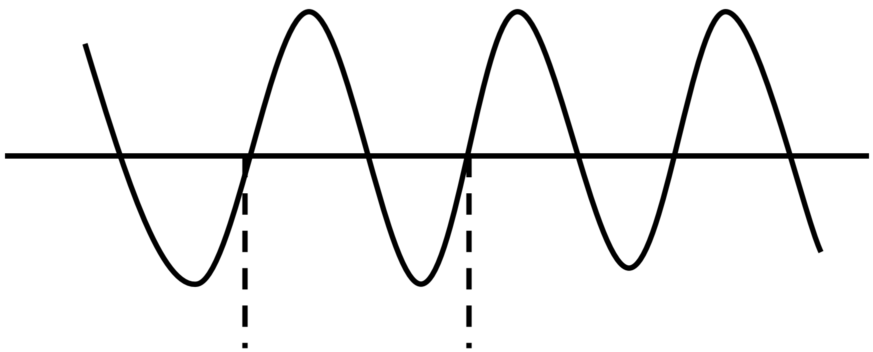
- Remote sensing is the **science and art** of obtaining information about a target, through the analysis of data acquired by a device that is **not in contact** with the target under investigation
- We routinely use remote sensing when we **see** things:
  - Our eyes can see thing around us, and sometimes even far away from us
  - We can identify what we see as objects (e.g. blackboard, door, desks, etc.)
- Why can we see? Because of the sunlight (or light from light bulbs) **reflected** off objects to the nerve cells in our retinae. However, our eyes can only see a narrow range of solar radiation within a large spectrum

Two Types of Remote Sensing

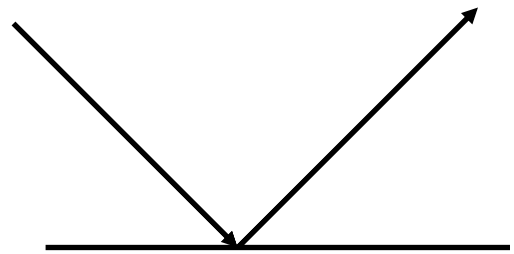
- In remote sensing, the medium that usually carries the information is **electromagnetic radiation**. Using various sensors, we can collect the electromagnetic radiation in **any portion of the spectrum**. Based on the source of the energy, remote sensing can be broken into two categories:
- **Passive remote sensing**: The source of energy collected by sensors is either **reflected solar radiation** (e.g. cameras) or **emitted by the targets** (thermal imaging).
- **Active remote sensing**: The source of energy collected by sensors is actively **generated by a man-made device**. Examples include radar (which uses microwave energy) and LIDAR (LIght Detection Imagery And Ranging, which uses a laser).

Solar Radiation

Electromagnetic radiation energy: **Wave-particle duality**



Wavelength (λ)



particle

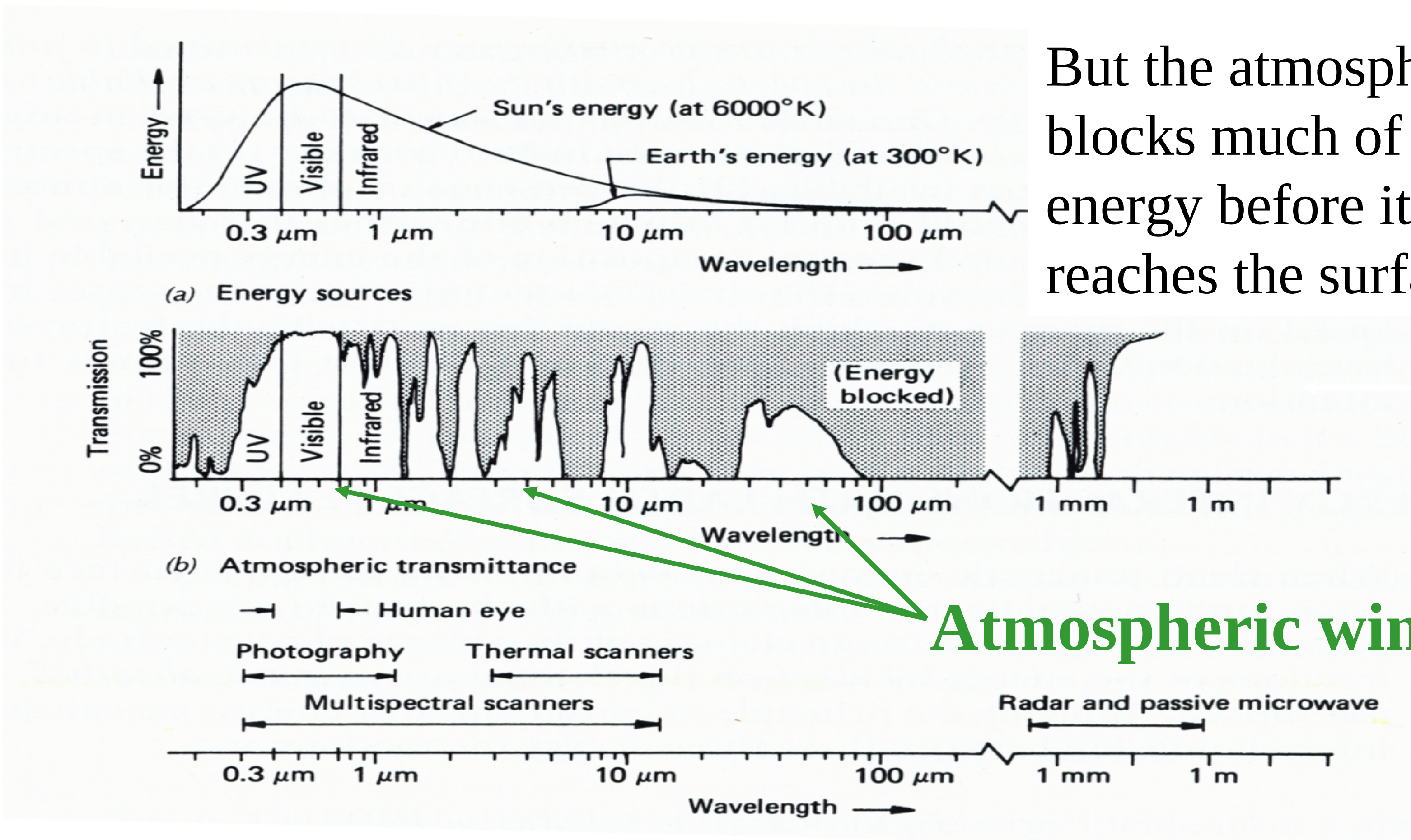
- EMR energy moves at the **speed of light (c)**: $c = f\lambda$
- ***f*** **= frequency**: The number of waves passing through a point within a unit time (usually expressed per second)
- **Energy** carried by a photon: $\varepsilon = h f$ [h=Planck constant (6.626×10^{-34} Js)]
- The shorter the wavelength, the higher the frequency, and the **more energy** a photon carries. Therefore, short wave ultraviolet solar radiation is very destructive (sunburns)

Light and Color

- Our visual system not only allows us to identify objects; we also **see things in color**; this provides us additional information about the objects we see
    - For example: We can distinguish between a **banana** that is green (not ripe nor ready to eat) from a **banana** that is yellow (that is ripe and ready to eat)
- The natural light we see can be described using seven colors, which can be remembered using the acronym **ROYGBIV**: R = Red, O = Orange, Y = Yellow, G = Green, B = Blue, I = Indigo, V = Violet
- These colors were identified by **Sir Isaac Newton** with a prism in 1672: His research helped launch the era of modern optics

Solar Electromagnetic Radiation

- The sun emits EMR across a **broad spectrum** of wavelengths:



But the atmosphere blocks much of the energy before it reaches the surface

Atmospheric windows

Digital Remote Sensing

- The advent of **digital remote sensing** for geographic information purposes has a great deal in common with the availability of **digital cameras for consumers**, that provide the following advantages:

  1. You can take as many pictures as you'd like
  2. You can process the images with computers to produce special effects
  3. The color information will not fade with time
  4. You can make as many copies as you'd like to give to your friends

What is Digital Remote Sensing?

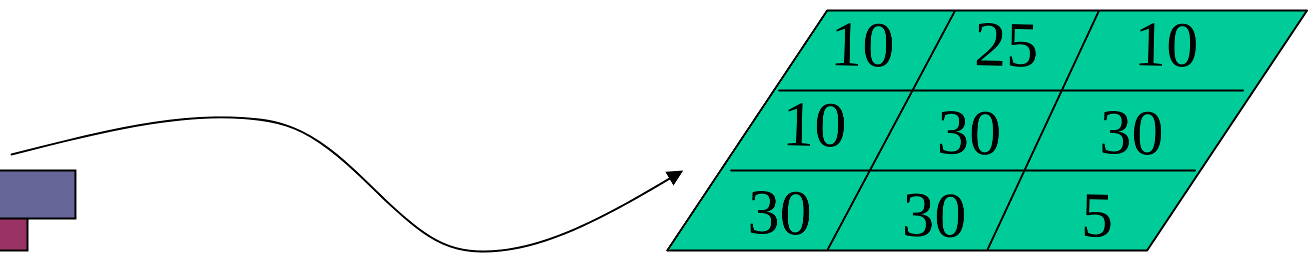
•Digital remote sensing literally means that the remotely sensed information is **stored as digits or numbers** rather than on film

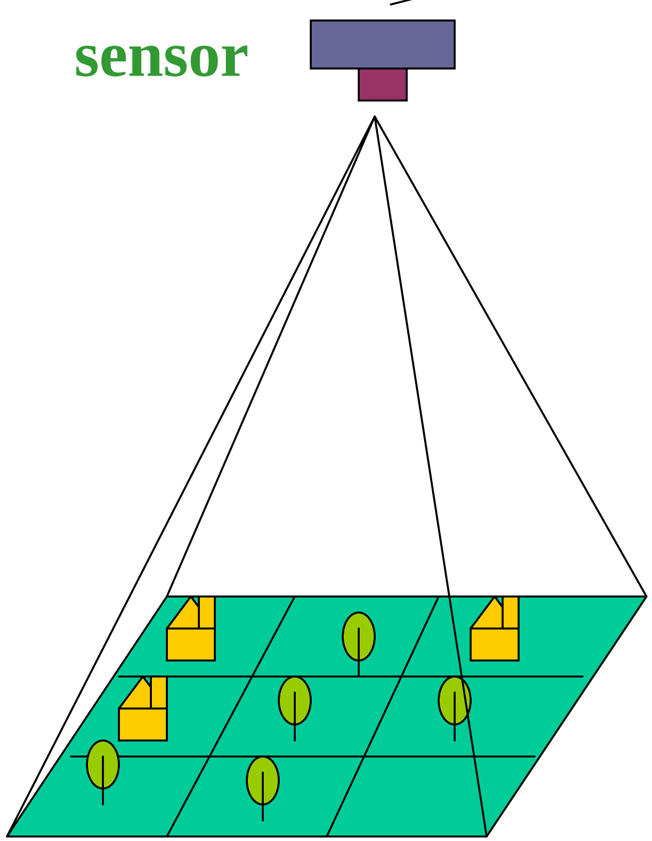
•Information recorded on film (in a satellite photograph) is essentially the **amount of sunlight reflected back into space** from the Earth's surface. Different ground object reflect different amounts of energy in certain wavelengths, leading to a different extents of exposure on the film. The developed photo is a printed representation of the sunlight reflected from the target. The interpreter has to extract information from a print based on the shape, size, tone, and texture to identify target objects

Analog-to-Digital Conversion

- As long as we can record the amount of **energy** (in a certain wavelength range) received from the ground surface, we **do not have to record it on film**
- Later technology has replaced the film with a **device that generates electric current when exposed to sunlight**. The level of voltage is linearly related to the amount of sunlight received (these are not really very different from the charge coupled devices [CCD] that you'd find in a consumer digital camera)
- Through a analog-to-digital converter, **digital remote sensing produces numbers** 1, 2, 3, … instead of the exposure of negatives. Each of the numbers indicates the intensity of sunlight received for a certain target area

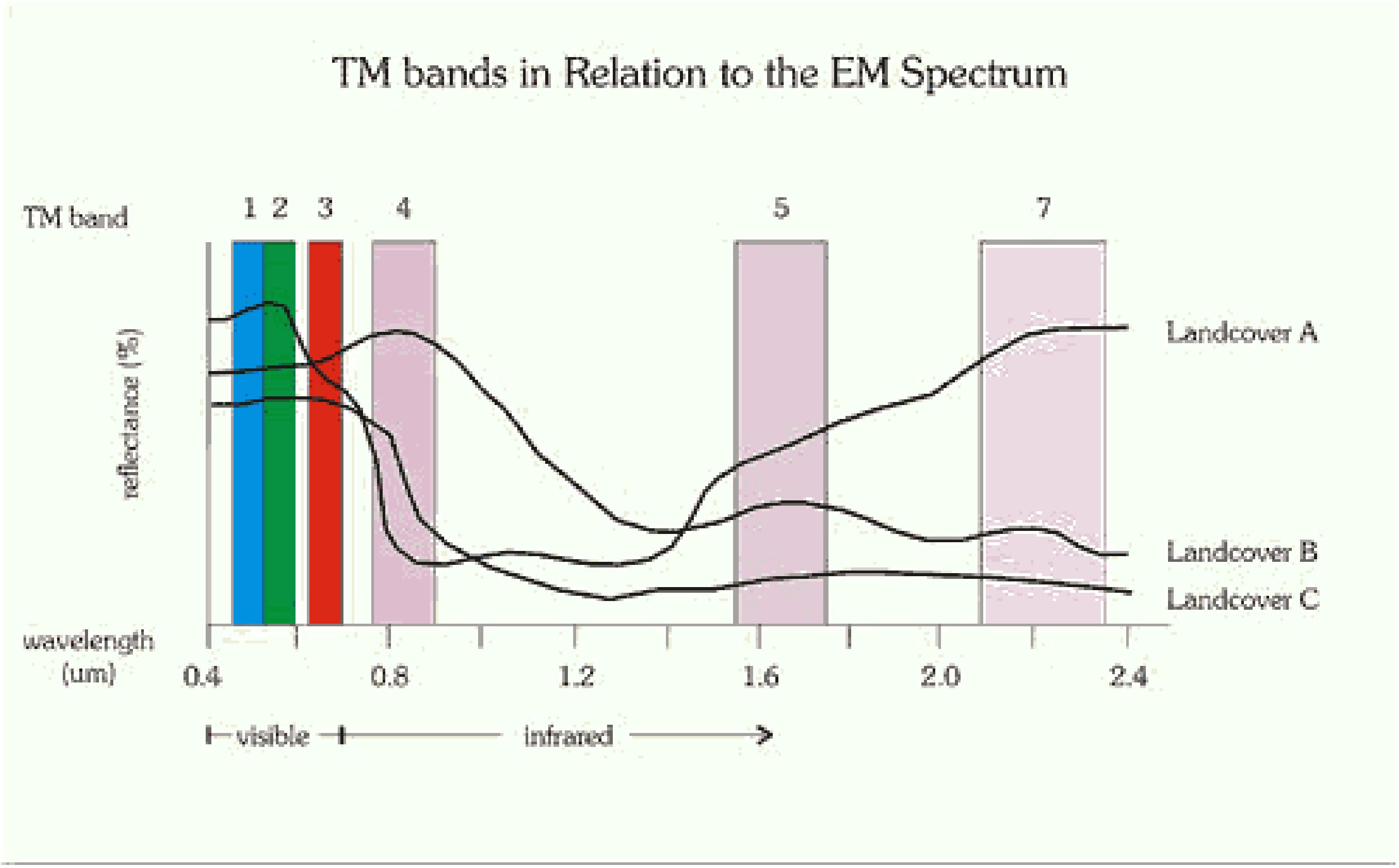
Digital Images





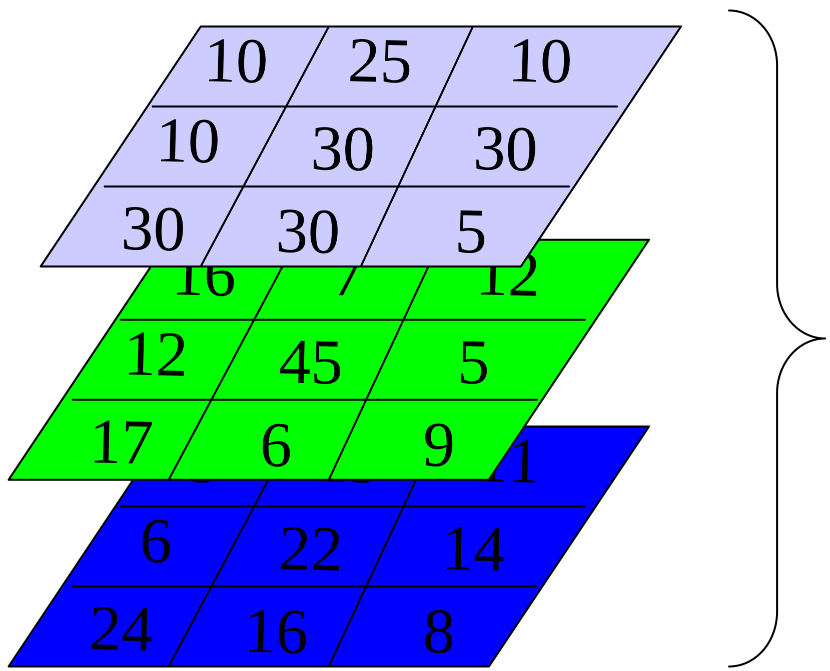
1. The area is covered with a **grid** of cells
2. Each cell has a **digital number** indicating the amount of energy received from the cell (in a certain wavelength range)
3. The cell is called a **pixel** (a picture element)
4. The size of the pixel is the **spatial resolution**

Multispectral Remote Sensing



Spectral Bands of Landsat Thematic Mapper Sensors
http://www.satelliteimpressions.com/landsat.html

Multispectral Remote Sensing



Multispectral remotely sensed data

Each **band** will generate a **layer** of remotely sensed data, usually with the same cell (pixel) size. For Landsat satellites, we will have 6 layers of data corresponding to the 6 bands

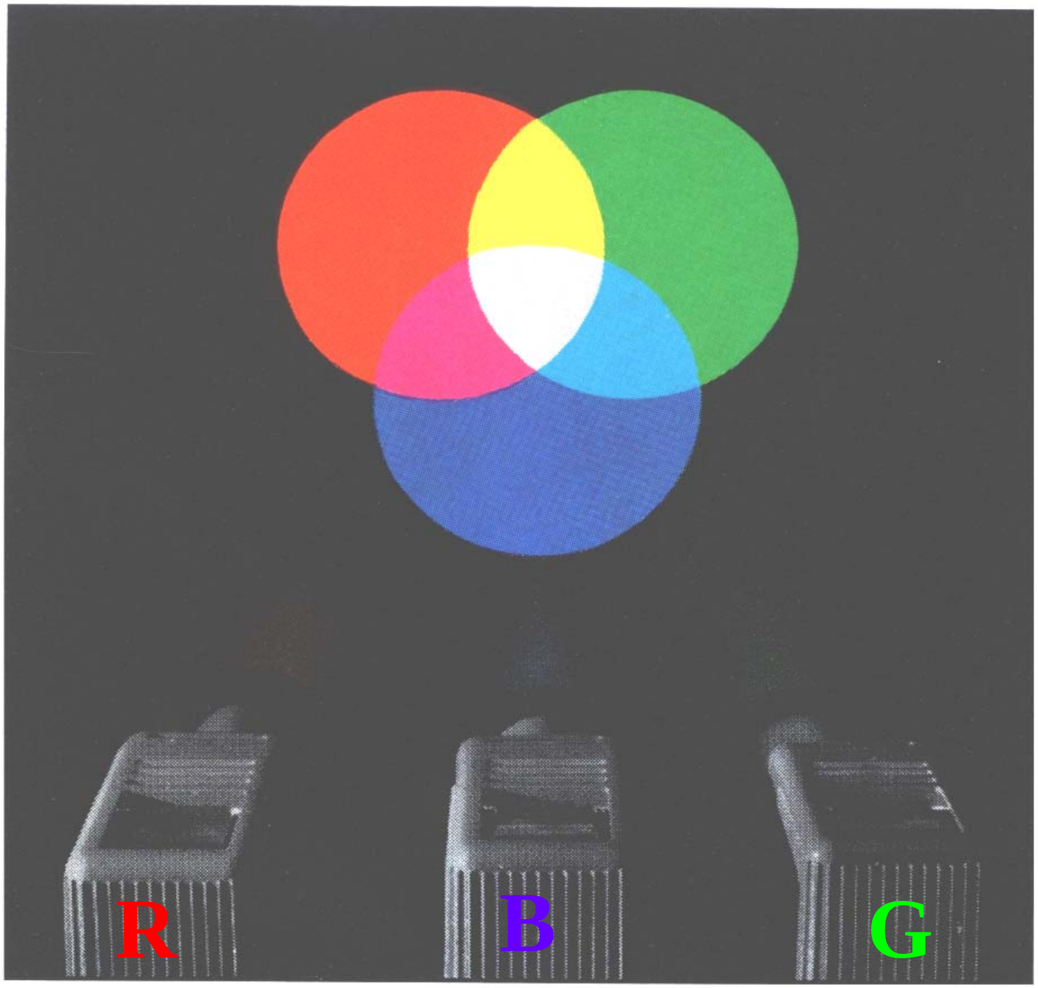
How Do We Display Multispectral Image Data?

1. We put the **digital numbers** into the color guns of computer display so that the **level of intensity** for the color corresponds to the **size of the number** (i.e. brightness values are equal)

2. If we put the **same digital numbers** into all three color guns on a computer, we will get a **black and white** picture. We call this an image

3. If we put the digital number for red light in red gun, and the digital numbers for blue light in blue gun, and the digital numbers for green light in green gun, we will have a **true color image**. Otherwise mappings we call **false color images**

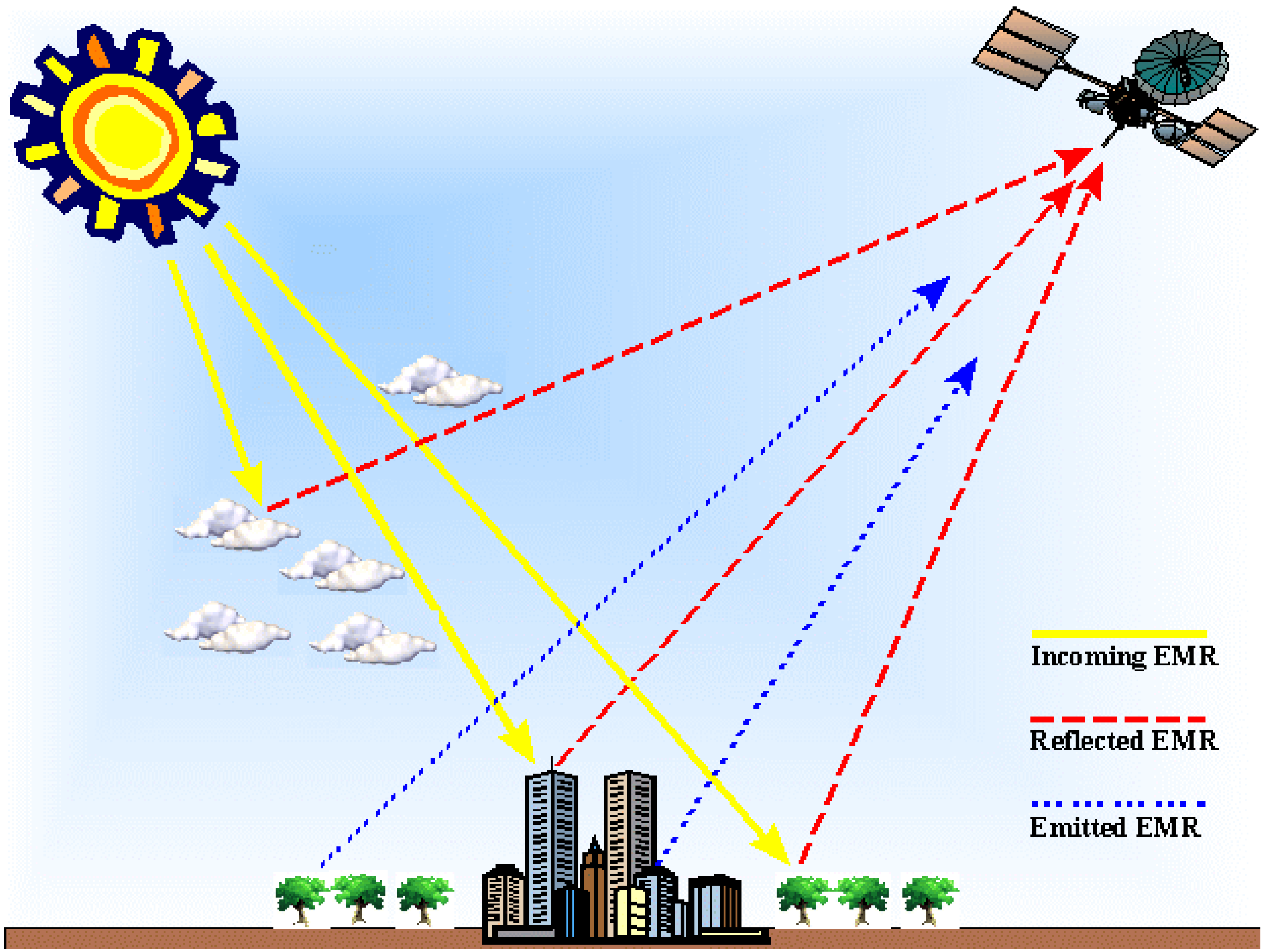
Color Arithmetic



red + green = yellow
green + blue = cyan
red + blue = magenta

Satellite Imagery - Sensing EMR

- Digital data obtained by sensors on satellite platforms

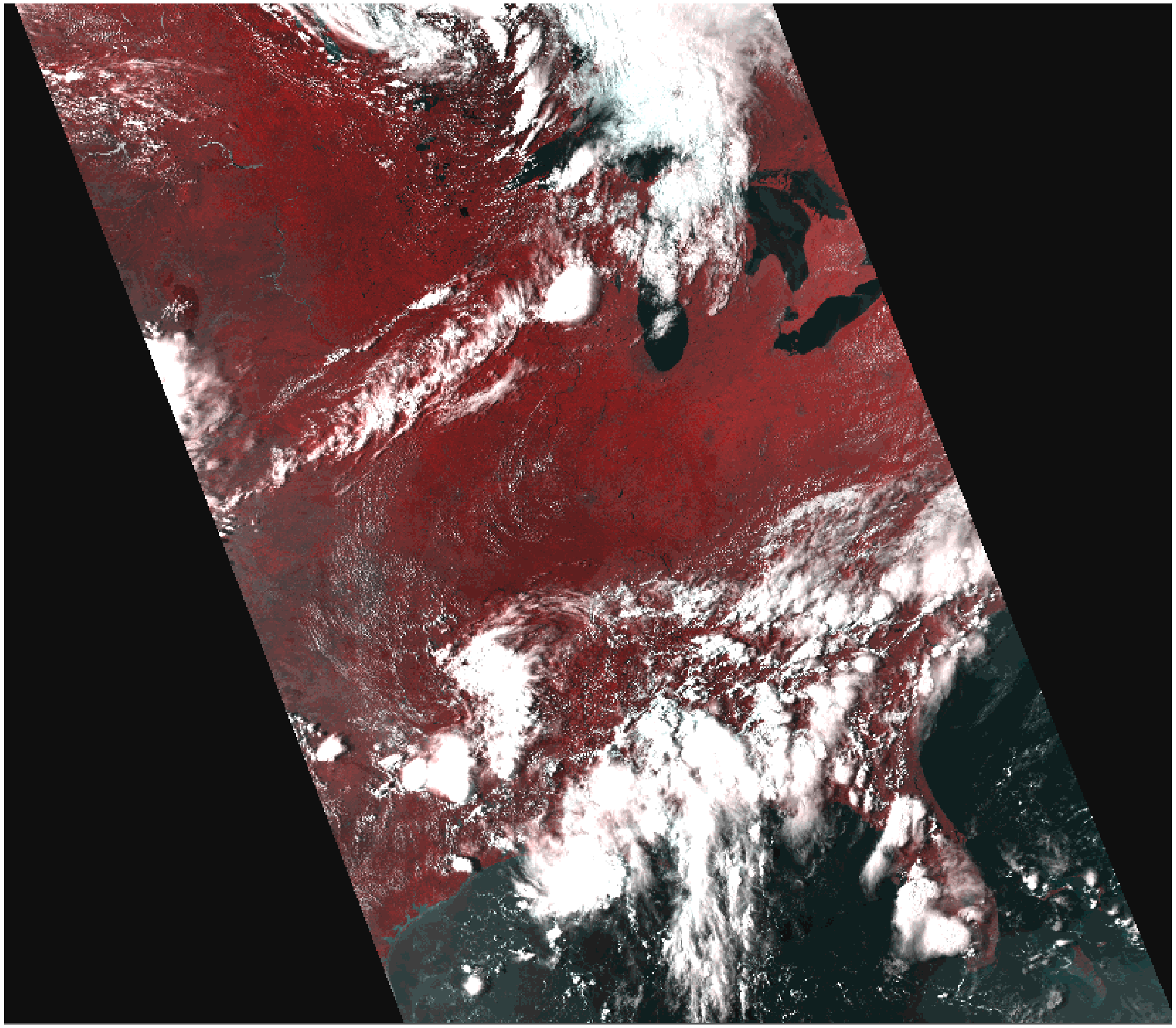


Satellite Imagery - 4 Resolutions

- Satellite imagery can be described by four resolutions:
  - **Spatial resolution**: area on ground represented by each pixel, e.g.
    - Landsat Thematic Mapper - 30m
    - Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolutions Imaging Spectrometer (MODIS) - 1km
    - SPOT - 10m panchromatic /20m multispectral
    - IKONOS - 1m panchromatic /4m multispectral
  - **Temporal resolution**: how often a satellite obtains imagery of a particular area
  - **Spectral resolution**: specific wavelength intervals in the electromagnetic spectrum captured by each sensor (bands)
  - **Radiometric Resolution**: number of possible data values reportable by each sensor (how many bits)

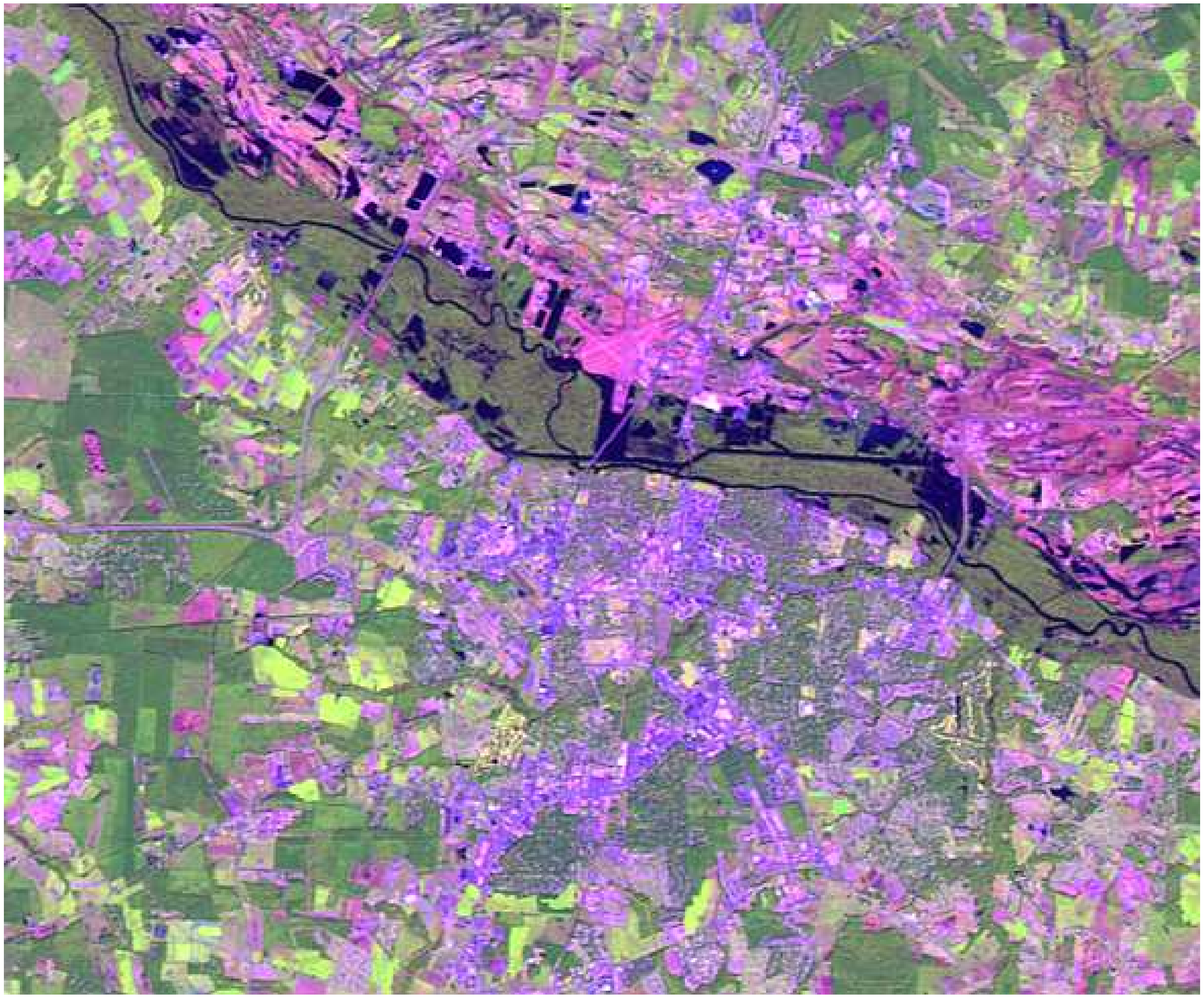
Spatial Resolution

AVHRR Image of the central and SE USA - 1 km pixels



Spatial Resolution

Landsat Image (543) of Greenville, NC - 30m pixels

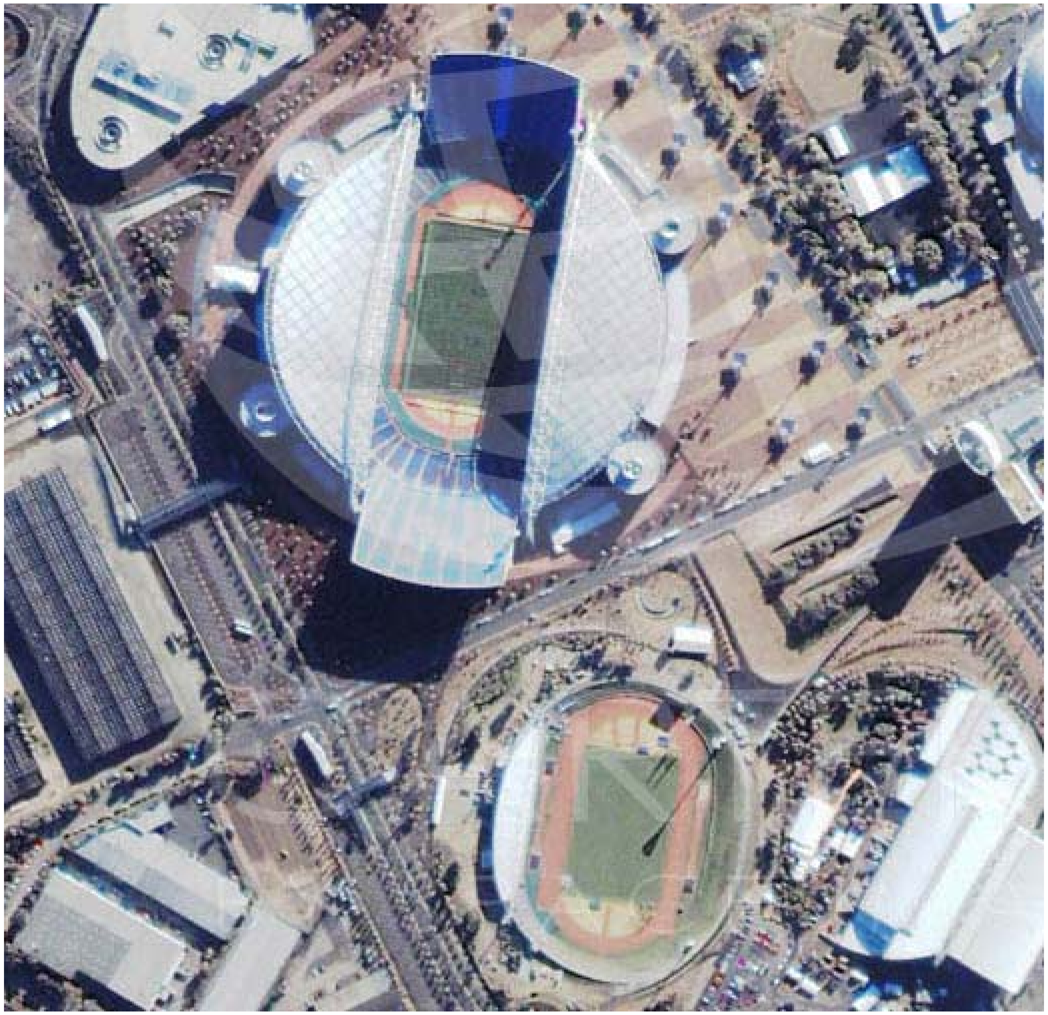


Spatial Resolution

SPOT Multispectral Image of Palm Springs, CA - 20m pixels

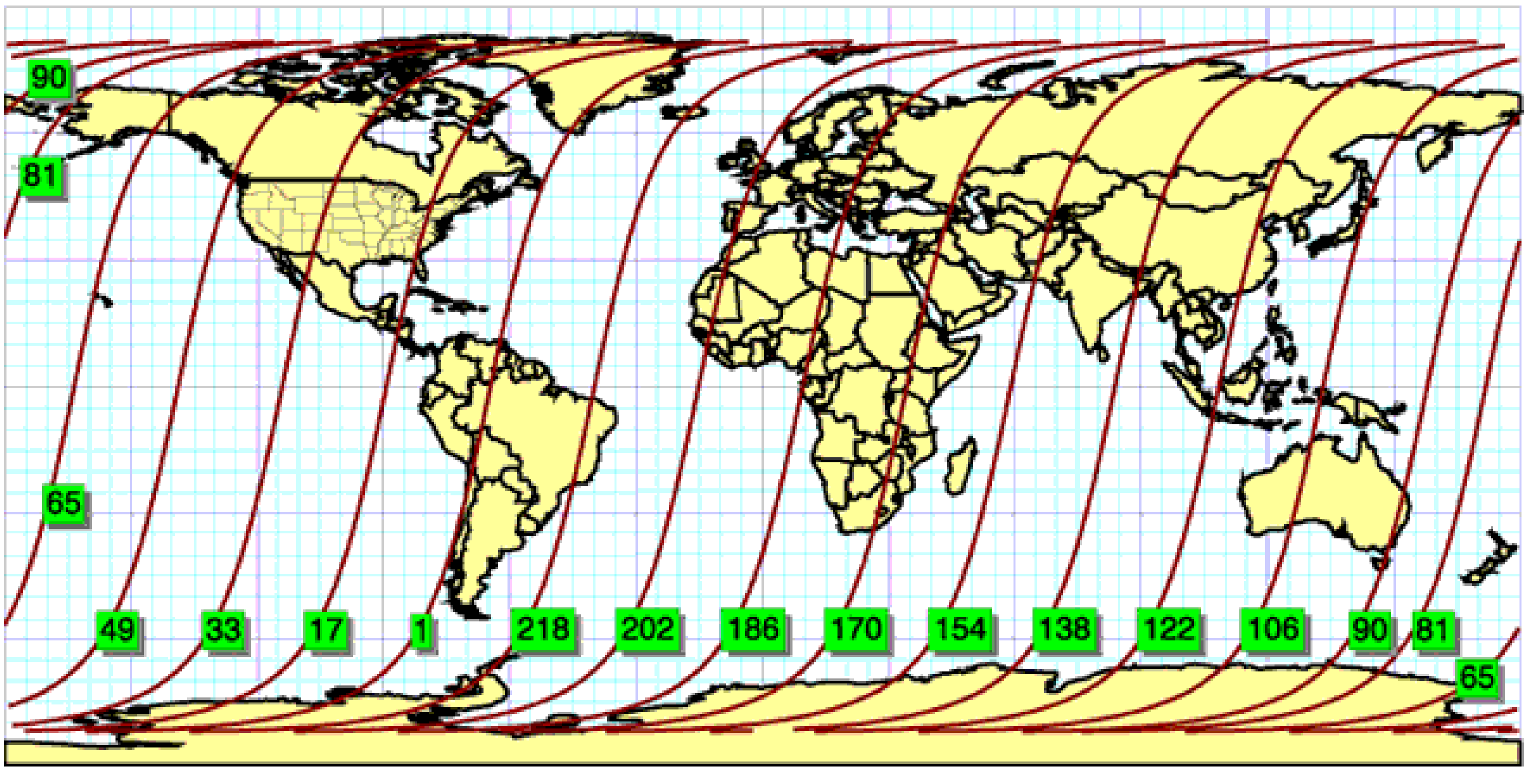
Spatial Resolution

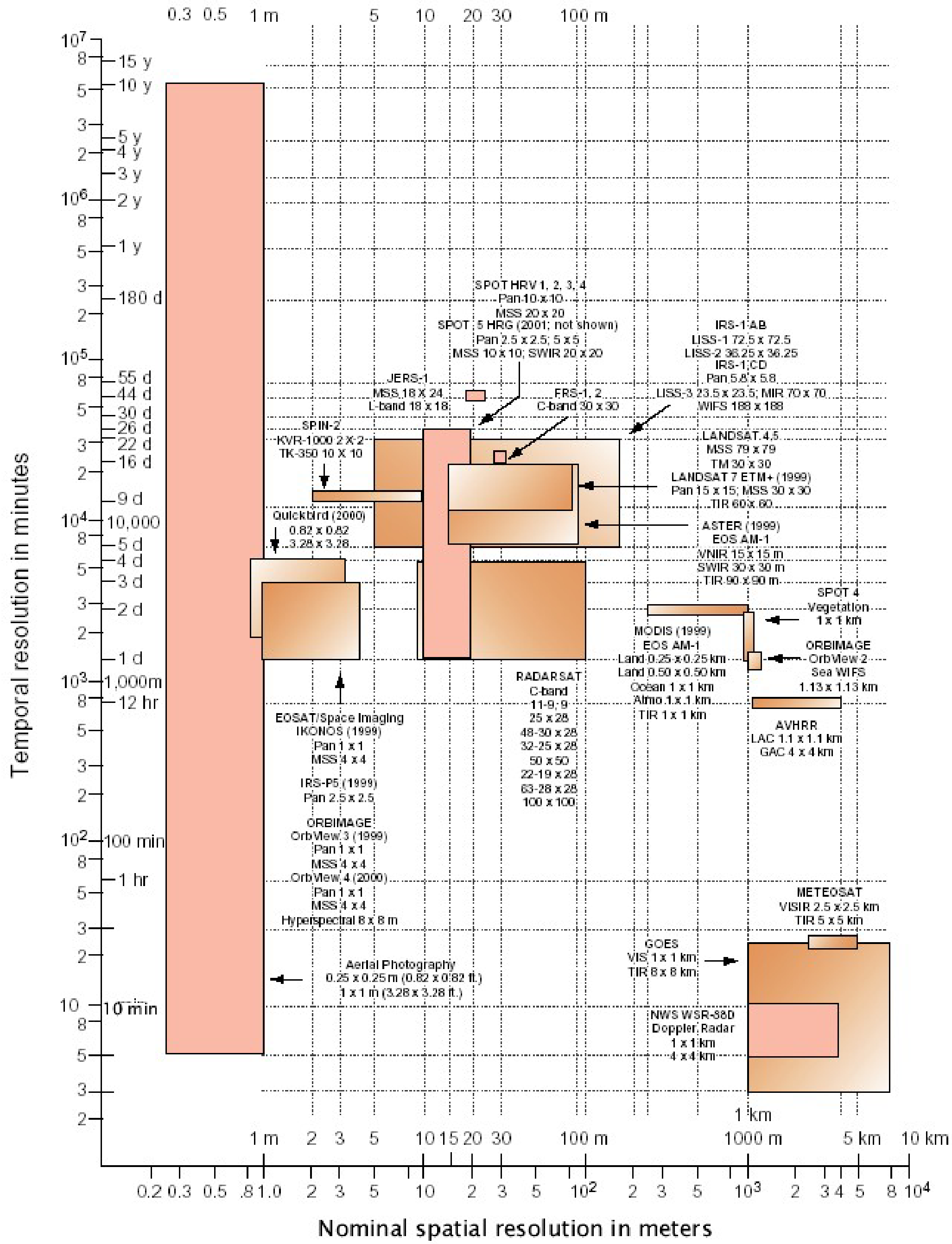
IKONOS panchromatic image of Sydney Olympic Park - 1m



Temporal Resolution

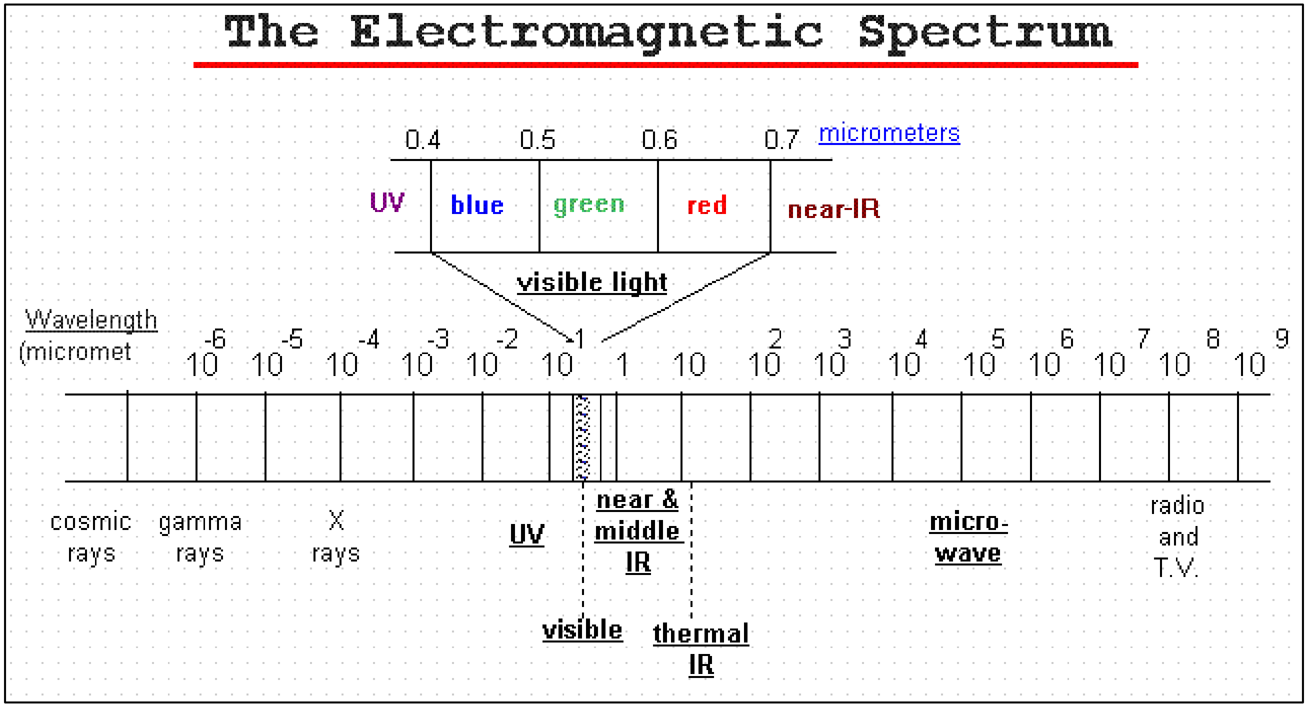
- Number of **days between overhead passes** - satellite orbit
  - – Landsat - 16 days
  - – AVHRR & MODIS - daily
  - – IKONOS - 1 to 3 days




Temporal resolution in minutes
Nominal spatial resolution in meters
SPOT HRV 1, 2, 3, 4
Pan 10 x 10
MSS 20 x 20
SPOT 5 HRG (2001; not shown)
Pan 2.5 x 2.5; 5 x 5
MSS 10 x 10; SWIR 20 x 20
JERS-1
MSS 18 X 24
L-band 18 x 18
ERS-1, 2
C-band 30 x 30
IRS-1AB
LISS-1 72.5 x 72.5
LISS-2 36.25 x 36.25
IRS-1CD
Pan 5.8 x 5.8
LISS-3 23.5 x 23.5; MIR 70 x 70
WIFS 188 x 188
SPIN-2
KVR-1000 2 X 2
TK-350 10 X 10
LANDSAT 4,5
MSS 79 x 79
TM 30 x 30
LANDSAT 7 ETM+ (1999)
Pan 15 x 15; MSS 30 x 30
TIR 60 x 60
Quickbird (2000)
0.82 x 0.82
3.28 x 3.28
ASTER (1999)
EOS AM-1
VNIR 15 x 15 m
SWIR 30 x 30 m
TIR 90 x 90 m
SPOT 4
Vegetation
1 x 1 km
MODIS (1999)
EOS AM-1
Land 0.25 x 0.25 km
Land 0.50 x 0.50 km
Ocean 1 x 1 km
Atmo 1 x 1 km
TIR 1 x 1 km
ORBIMAGE
OrbView 2
Sea WIFS
1.13 x 1.13 km
RADARSAT
C-band
11-9, 9
25 x 28
48-30 x 28
32-25 x 28
50 x 50
22-19 x 28
63-28 x 28
100 x 100
AVHRR
LAC 1.1 x 1.1 km
GAC 4 x 4 km
EOSAT/Space Imaging
IKONOS (1999)
Pan 1 x 1
MSS 4 x 4
IRS-P5 (1999)
Pan 2.5 x 2.5
ORBIMAGE
OrbView 3 (1999)
Pan 1 x 1
MSS 4 x 4
OrbView 4 (2000)
Pan 1 x 1
MSS 4 x 4
Hyperspectral 8 x 8 m
METEOSAT
VISIR 2.5 x 2.5 km
TIR 5 x 5 km
GOES
VIS 1 x 1 km
TIR 8 x 8 km
Aerial Photography
0.25 x 0.25 m (0.82 x 0.82 ft.)
1 x 1 m (3.28 x 3.28 ft.)
NWS WSR-88D
Doppler Radar
1 x 1 km
4 x 4 km
15 y
10 y
5 y
4 y
3 y
2 y
1 y
180 d
55 d
44 d
30 d
26 d
22 d
16 d
9 d
10,000
5 d
4 d
3 d
2 d
1 d
1,000m
12 hr
100 min
1 hr
10 min
1 km
1 m
2
3
5
10
15
20
30
100 m
1000 m
5 km
10 km

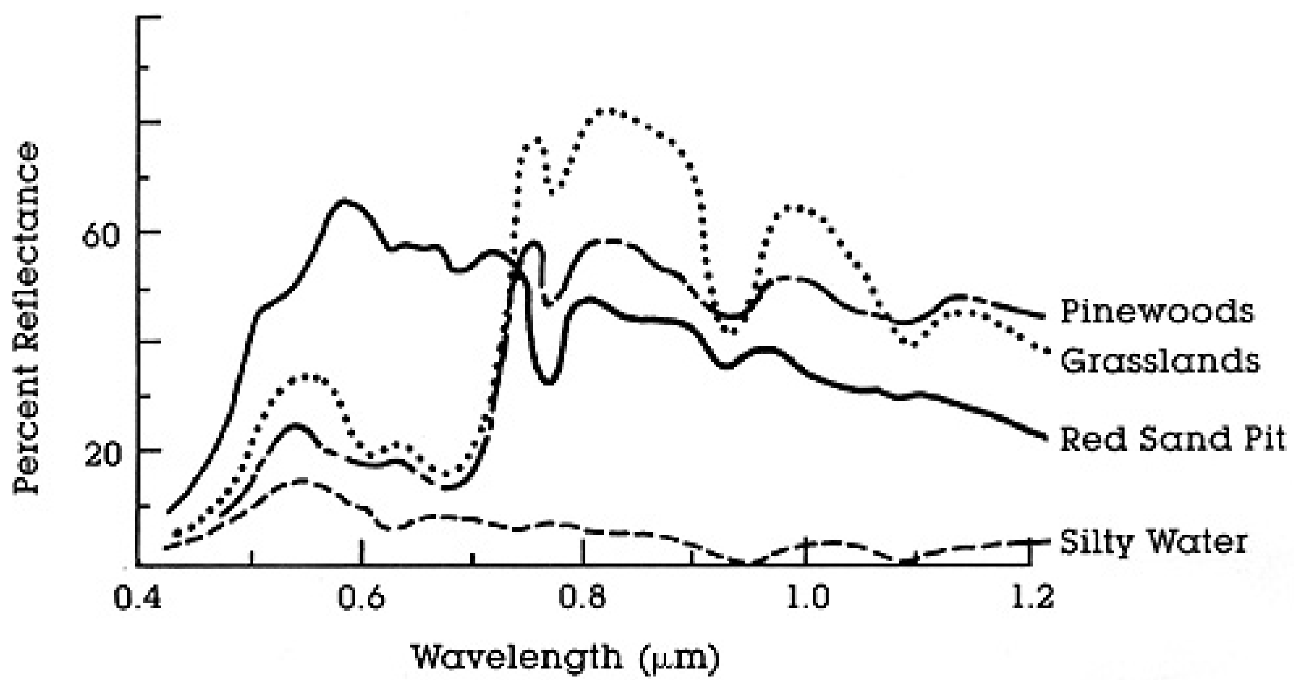
Electromagnetic Spectrum

- EMR at a **wide range** of wavelengths
- Range typically from 10^{-12}m to 10^{3}m
- In remote sensing, we mainly focus on **visible, infrared and microwave** wavelengths

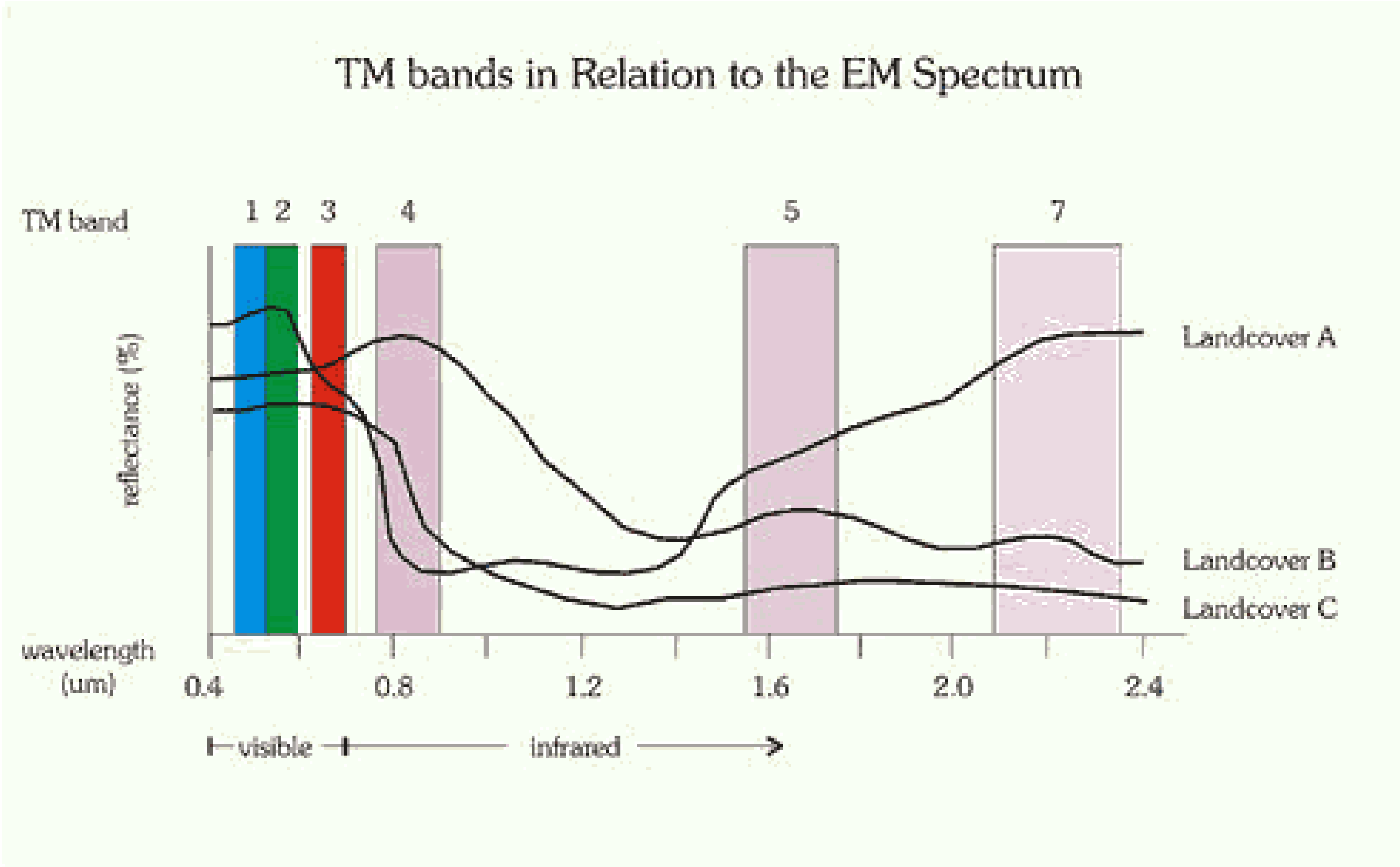


Spectral Resolution

- Number, spacing and width of sampled wavelength bands (Landsat: 7 bands, AVIRIS: 224 bands!)
- Multispectral vs. Panchromatic
- Higher resolution results in more precision in the representation of **spectral signatures**



Multispectral Remote Sensing



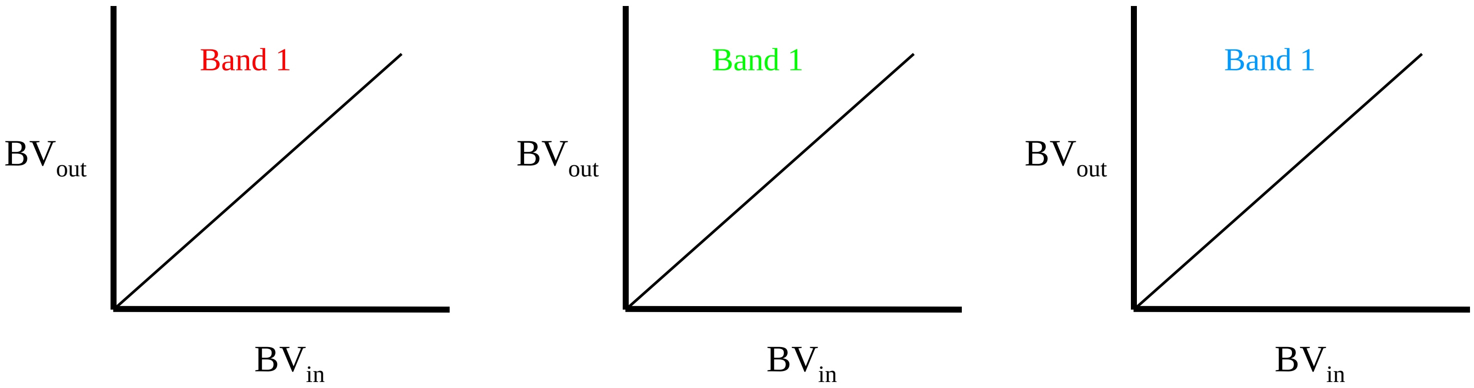
Spectral Bands of Landsat Thematic Mapper Sensors
http://www.satelliteimpressions.com/landsat.html

Radiometric Resolution

- Number of possible data values reported by the sensor, which determines **how many levels of brightness** it can distinguish
- Range is expressed as **2^n power**
  - 8-bit radiometric resolution has 2^8 values, or 256 values - range is 0-255 (e.g. Landsat TM data)
  - 16-bit resolution has 2^{16} values, or 65,536 values - range is 0-65535 (e.g. MODIS data)
- The value in each pixel is called the
  - **Digital Number (DN)**
  - **Brightness Value (BV)**

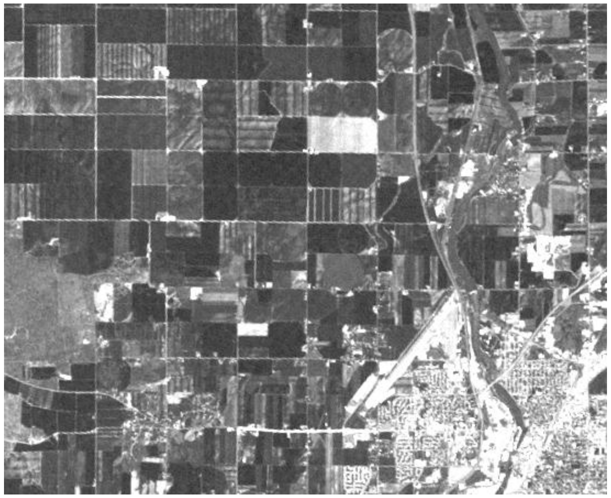
Image Display - Single Band

- Assume that the In and Out brightness values are equal
- For a single band, the resultant color will be grayscale



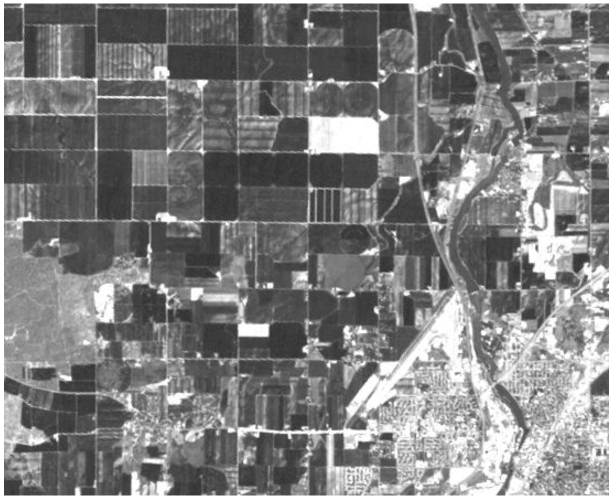
- All three colors display the same value, so the colors are shades of gray

Image Display - Single Band



Band 1 - Blue

Band 2 - Green



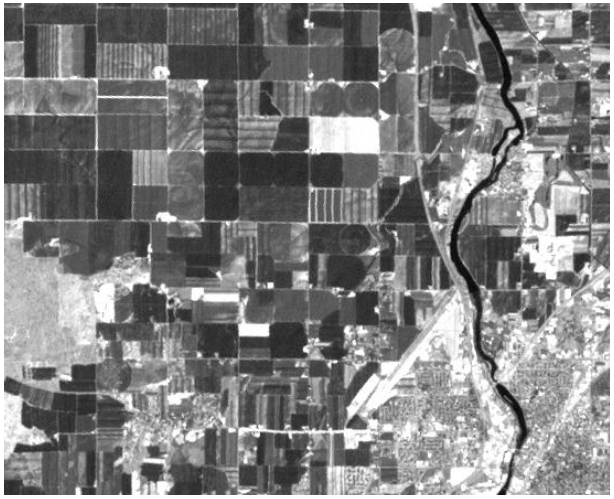
Band 3 - Red

Band 4 - NIR

Image Display - Single Band

Band 5 - IR

Band 6 - TIR



Band 7 - FIR

Image Display - Multi-Band

- For a multi-band image, the resultant color will depend on which bands are assigned to which color guns

True Color Composite

(321)

False Color Composite

(432)

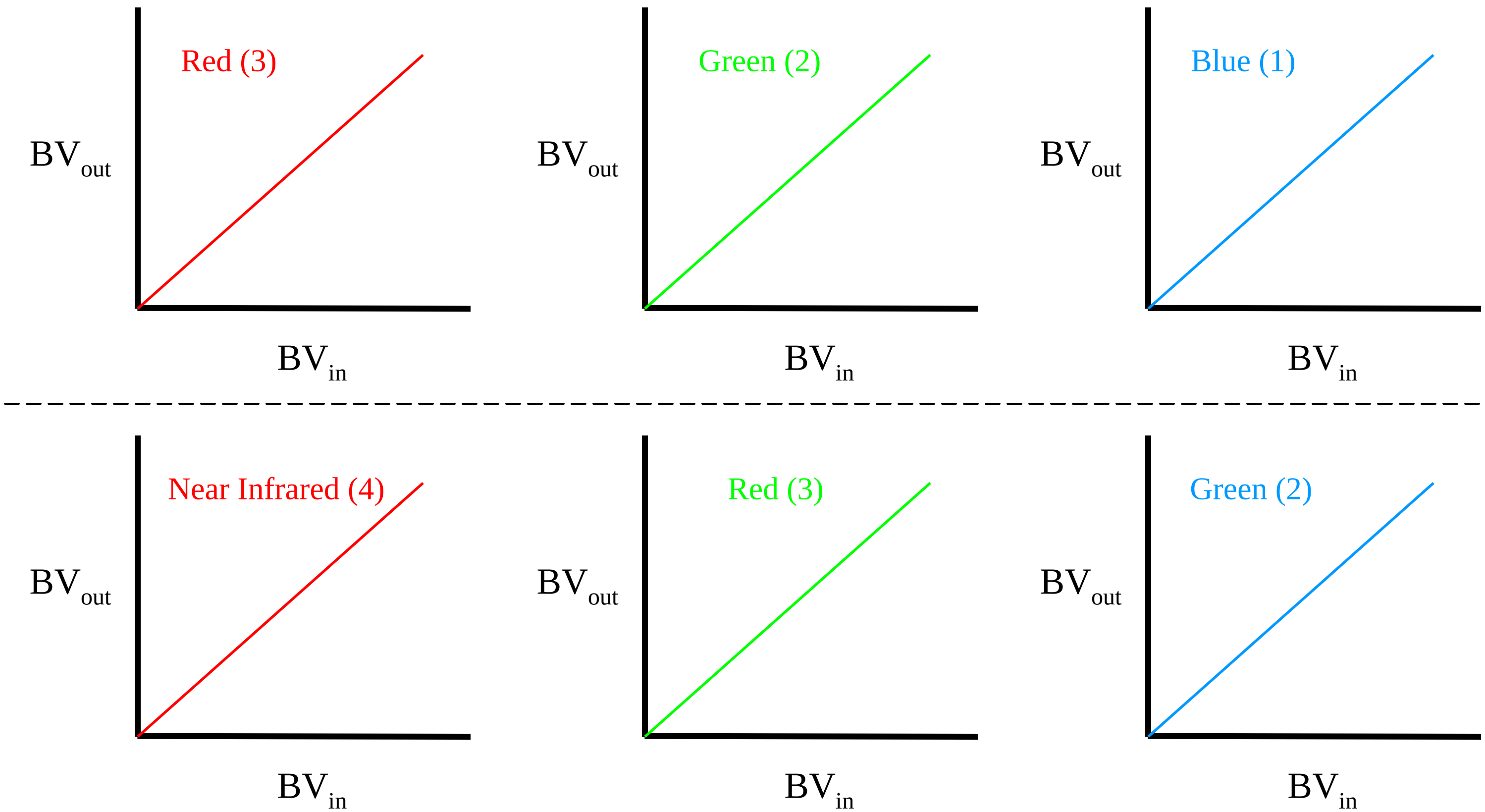
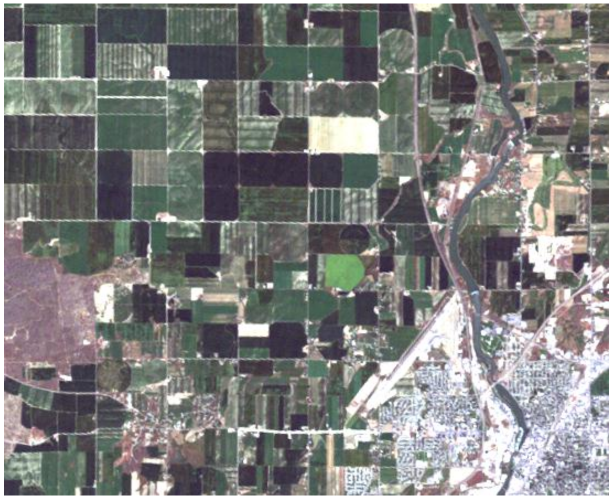
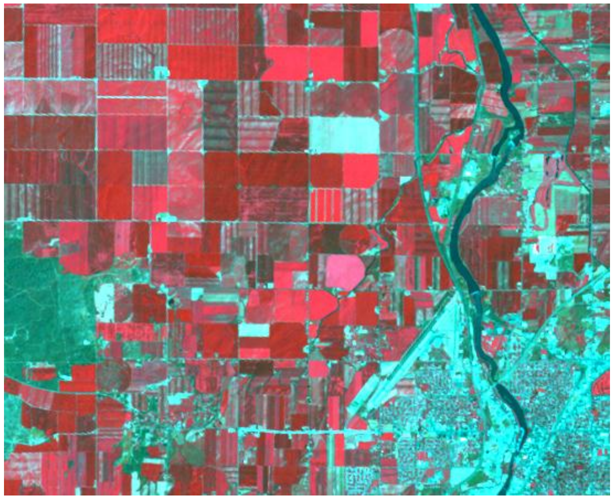


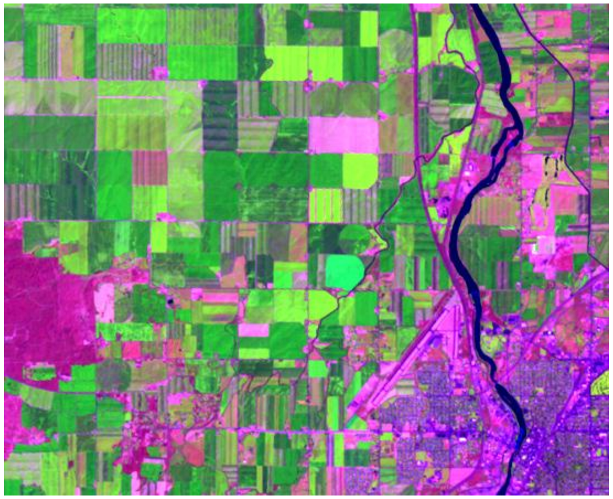
Image Display - Multi-Band



321



432



543

Image Display - Stretching

- Contrast Enhancement - **“stretching”** all or part of the input BVs from the image data to the full 0-255 screen output range for better visual performance (i.e. we **maximize** the contrast so we can see the differences better)

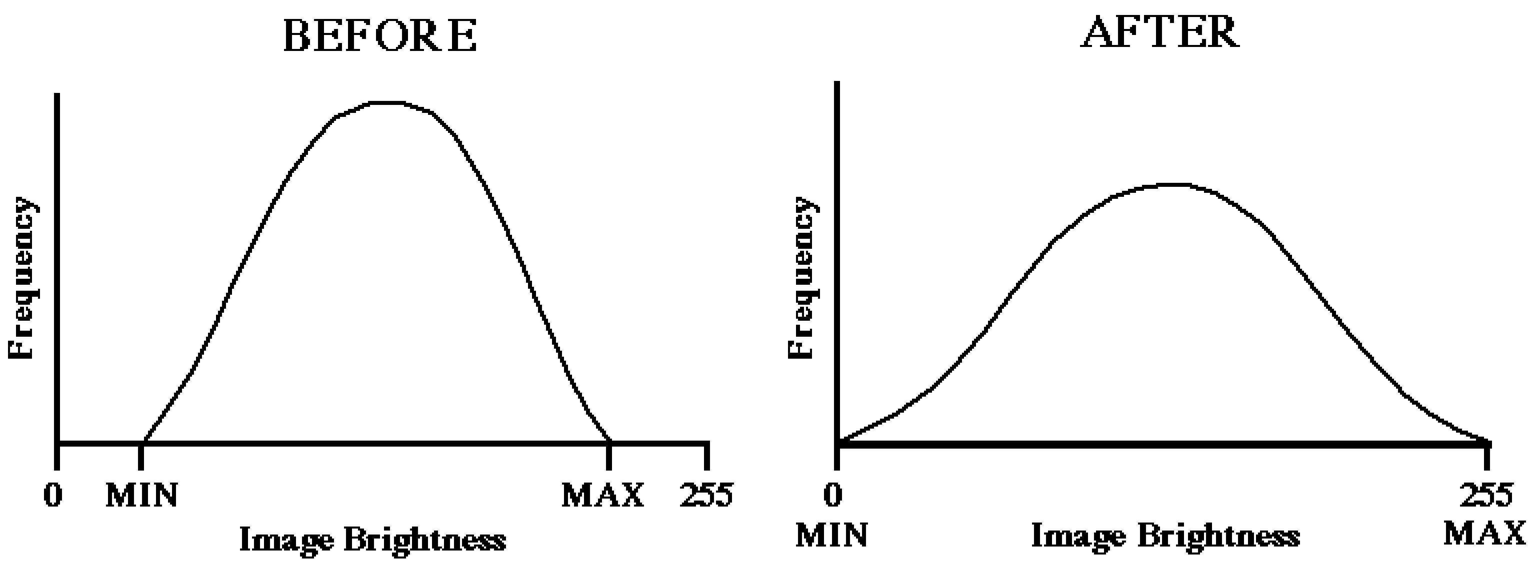


Image Display - Stretching

- A **linear stretch** is one of the most common types of contrast enhancement
- The minimum BV is remapped to 0
- The maximum BV is remapped to 255
- E.g. given a certain band histogram:

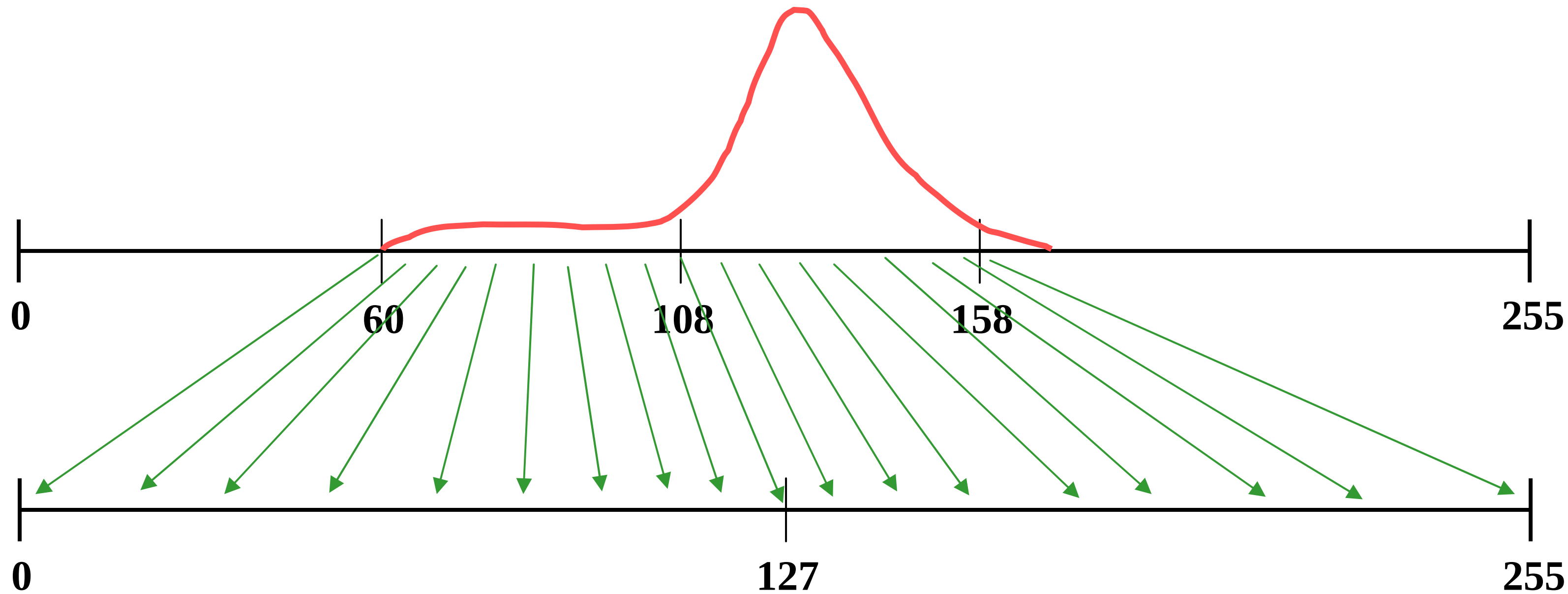
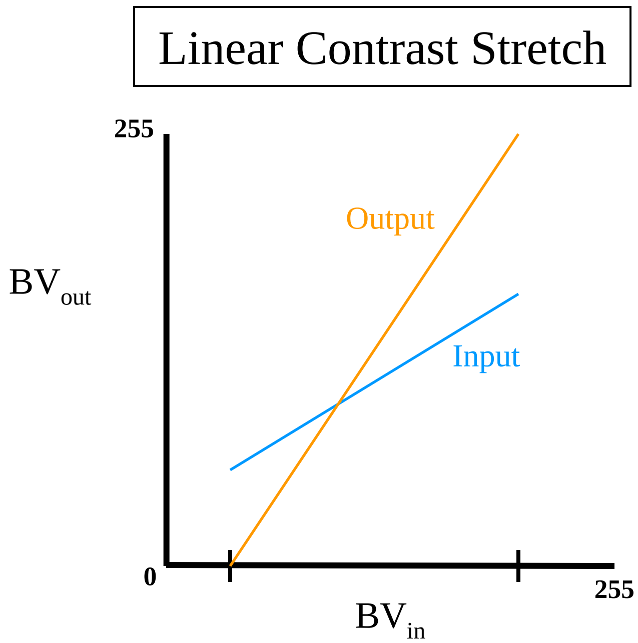
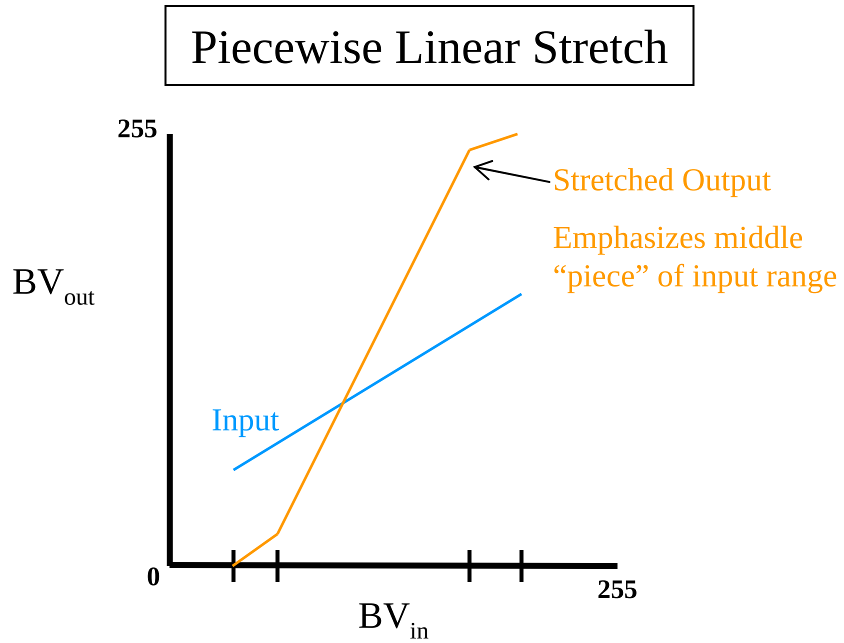
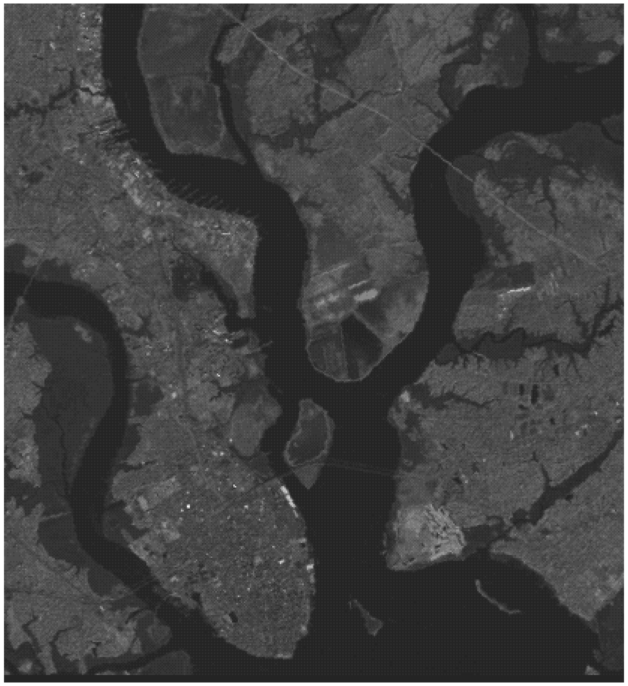


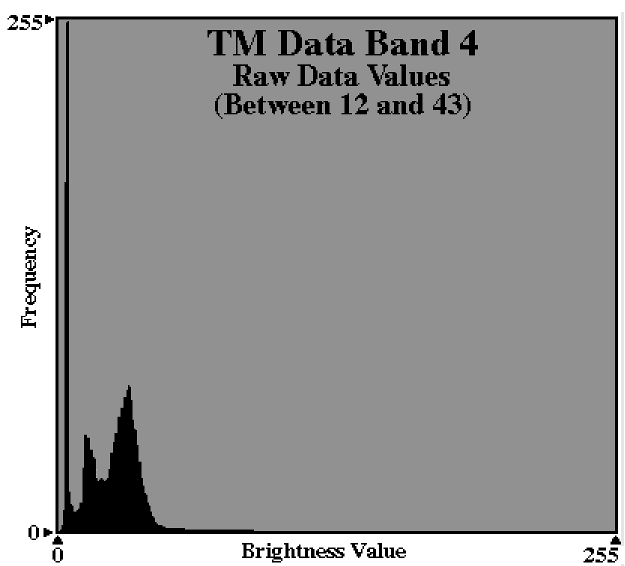
Image Display - Stretching

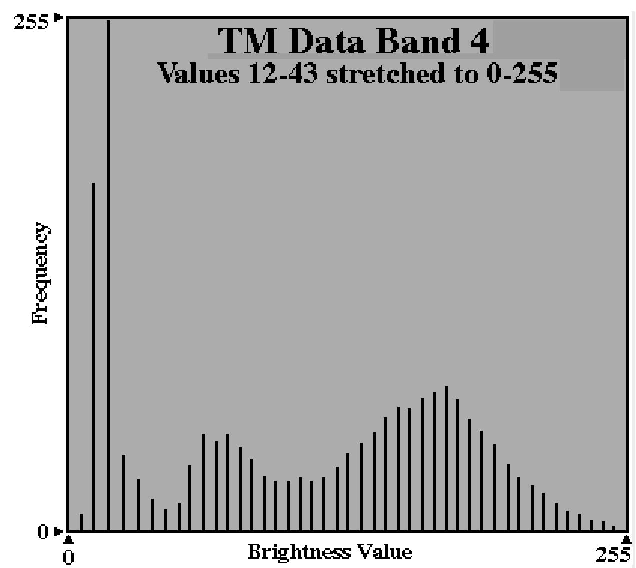
- Two types of linear stretches:
  - The basic **linear contrast** stretch
  - A **piecewise linear** stretch





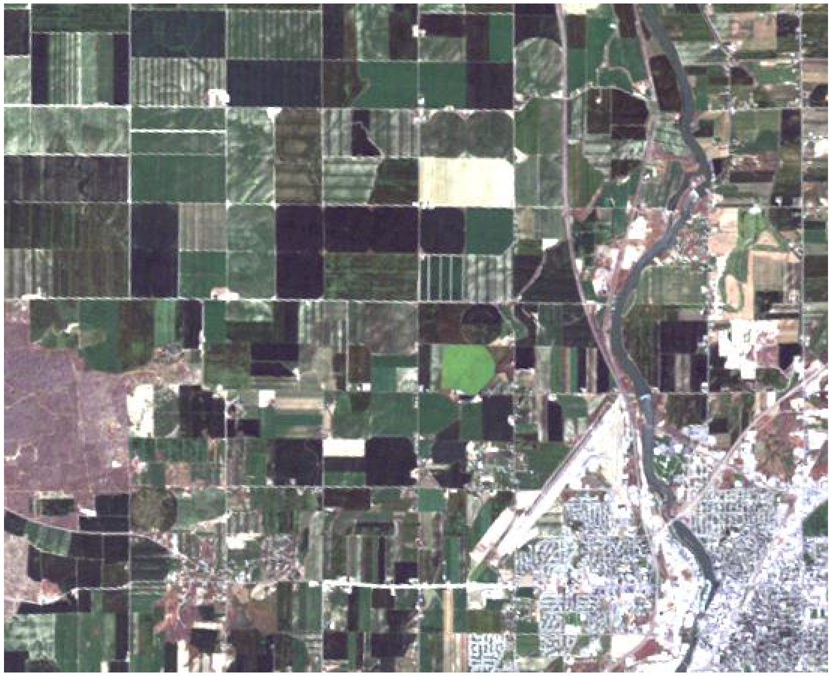



TM Data Band 4
Raw Data Values
(Between 12 and 43)
255
0
Frequency
Brightness Value
0
255


TM Data Band 4
Values 12-43 stretched to 0-255
255
0
Frequency
Brightness Value
0
255

True-Color 321 Image

No stretch applied



True-Color 321 Image

Linear Contrast Stretch

Image Pre-Processing

- Radiometric Corrections
  - changing the image data BVs to **correct for errors or distortions** from a variety of sources:
    - atmospheric effects
    - sensor errors

- Geometric Corrections
  - changing the geometric/spatial properties of the image data so that we can accurately project the image, a.k.a.
    - **image rectification**
    - **rubber sheeting**

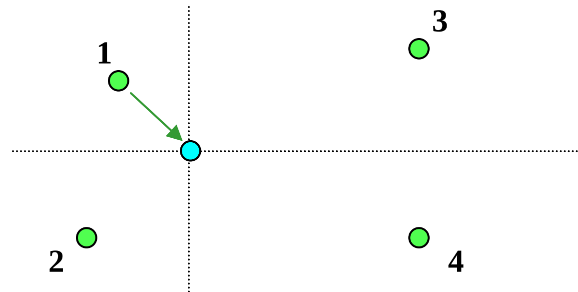
Geometric Correction

- Four Basic Steps of Rectification

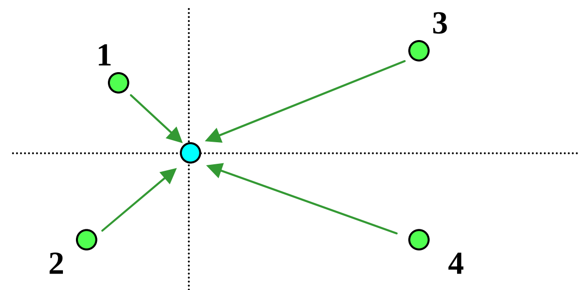
  1. Collect **ground control points (GCPs)**
     Points in the image for which you can determine real-world coordinates
  2. Create **equations** relating the image pixel coordinates at those GCPs to their real-world coordinates
  3. **Transform** the pixel coordinates based on the equations
  4. **Resample** the pixel values (BVs) from the input image to put values in the newly georeferenced image

Geometric Correction

- Three Types of Resampling
  - **Nearest Neighbor** - assign the new BV from the closest input pixel.
    This method does not change any values.



  - **Bilinear Interpolation** - distance-weighted average of the BVs from the 4 closest input pixels



  - **Cubic Convolution** - fits a polynomial equation to interpolate a "surface" based on the nearest 16 input pixels; new BV taken from surface

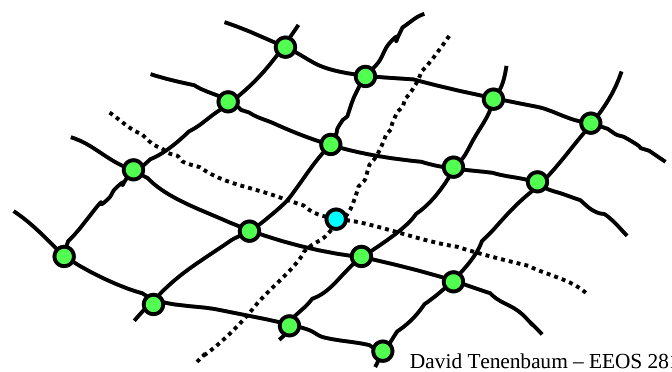


Image Enhancements

- Image enhancements are designed to improve the usefulness of image data for various applications:
  - **Contrast Enhancement** - maximizes the performance of the image for visual display
  - **Spatial Enhancements** - increases or decreases the level of spatial detail in the image
  - **Spectral Enhancements** - makes use of the spectral characteristics of different physical features to highlight specific features

Spatial Enhancements

- Filters - used to emphasize or de-emphasize spatial information
  - **Low-pass filter** - emphasize large area changes and de-emphasize local detail
  - **High-pass filter** - emphasize local detail and de-emphasize large area changes

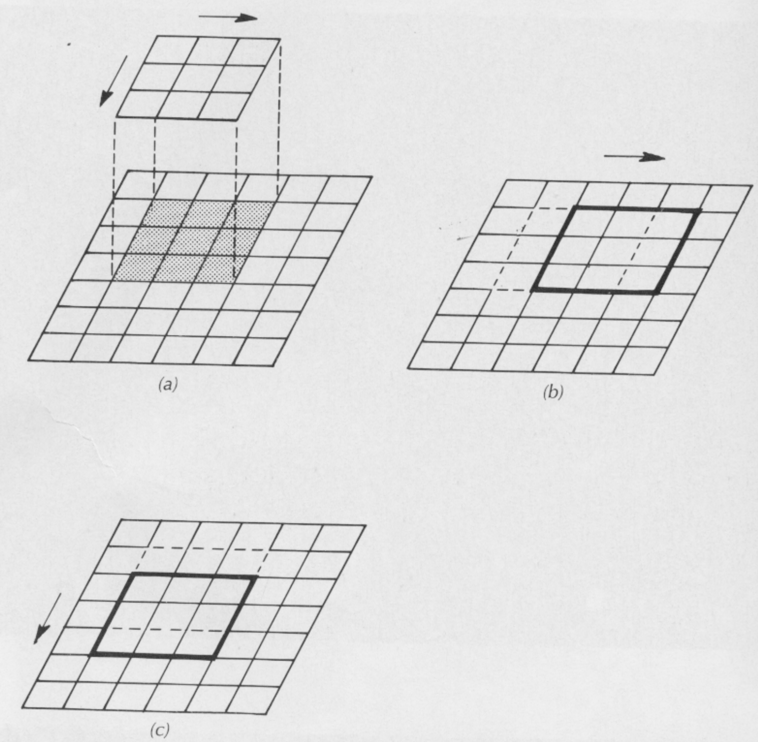
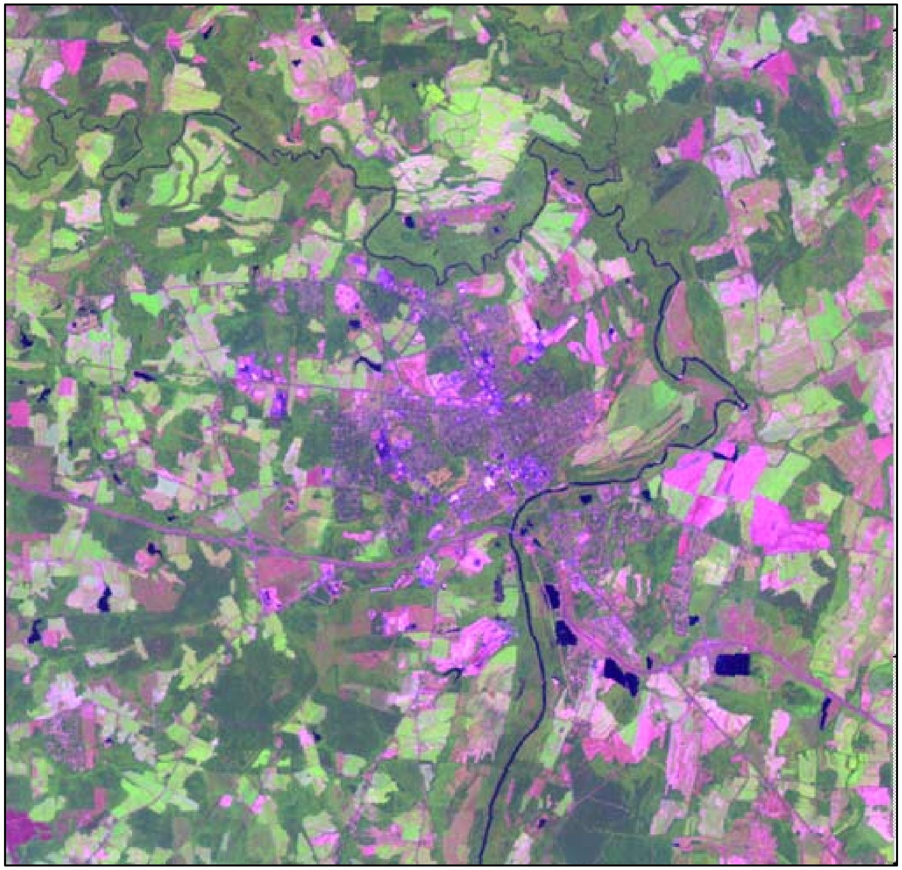


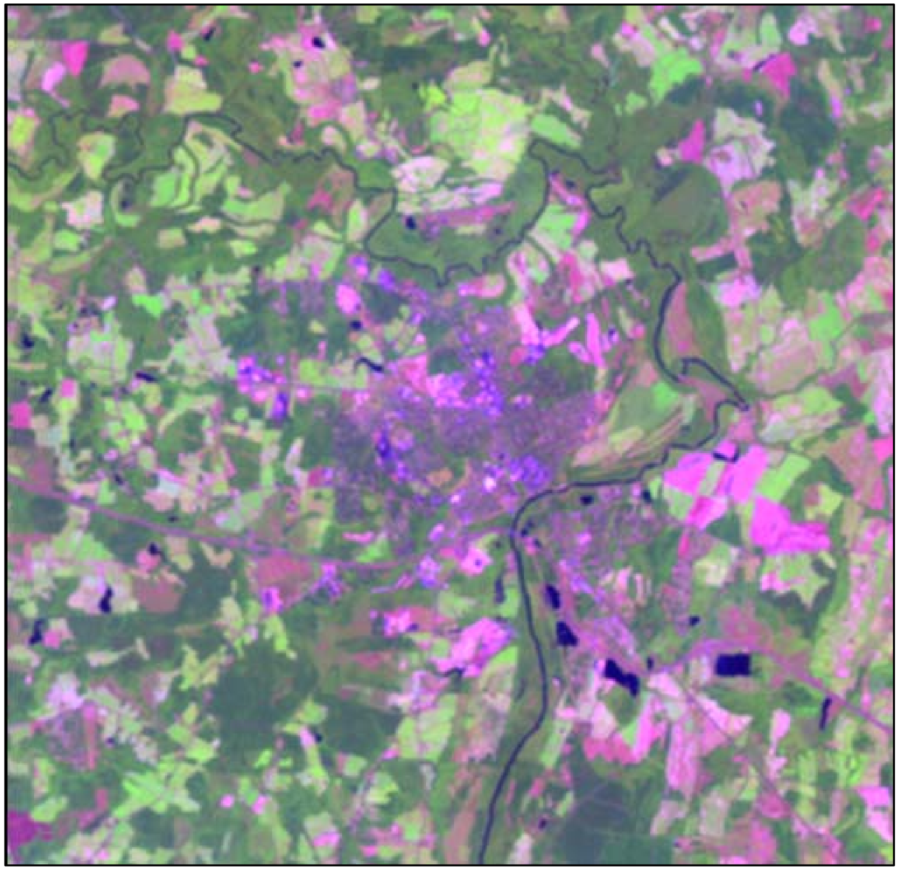
Figure 7.8 The moving window concept: (*a*) projection of 3 × 3 pixel window in image being processed; (*b*) movement of window along a line from pixel to pixel; (*c*) movement of window from line to line. (Adapted from [168].)

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC



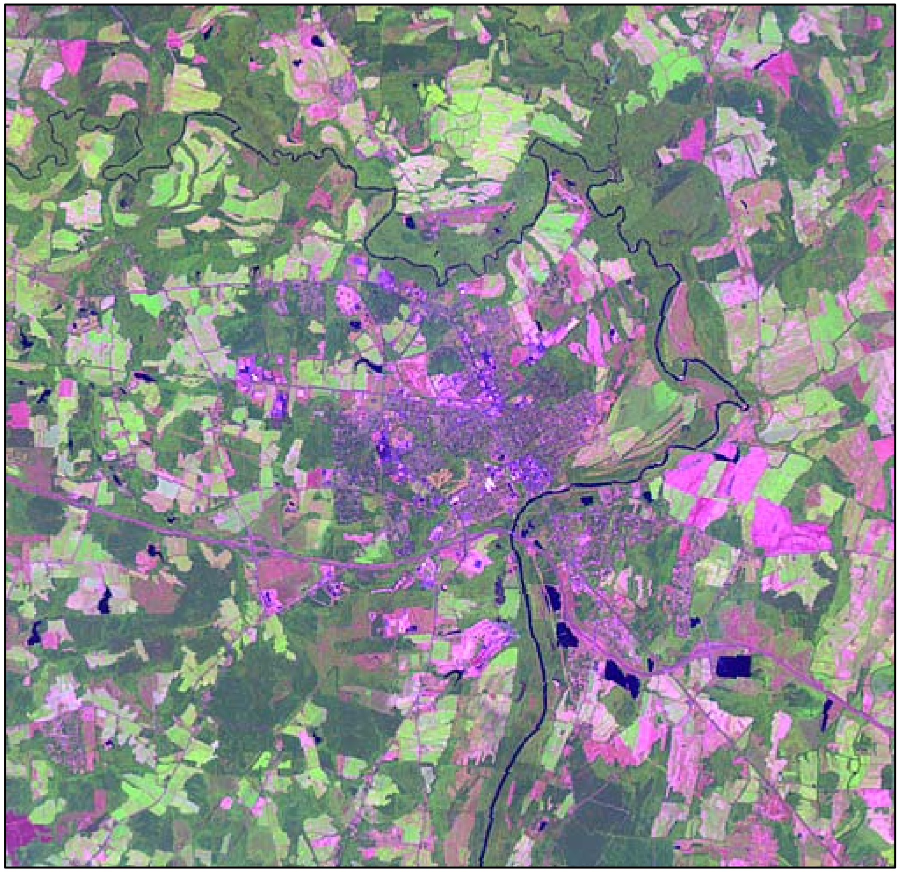
Normal Image



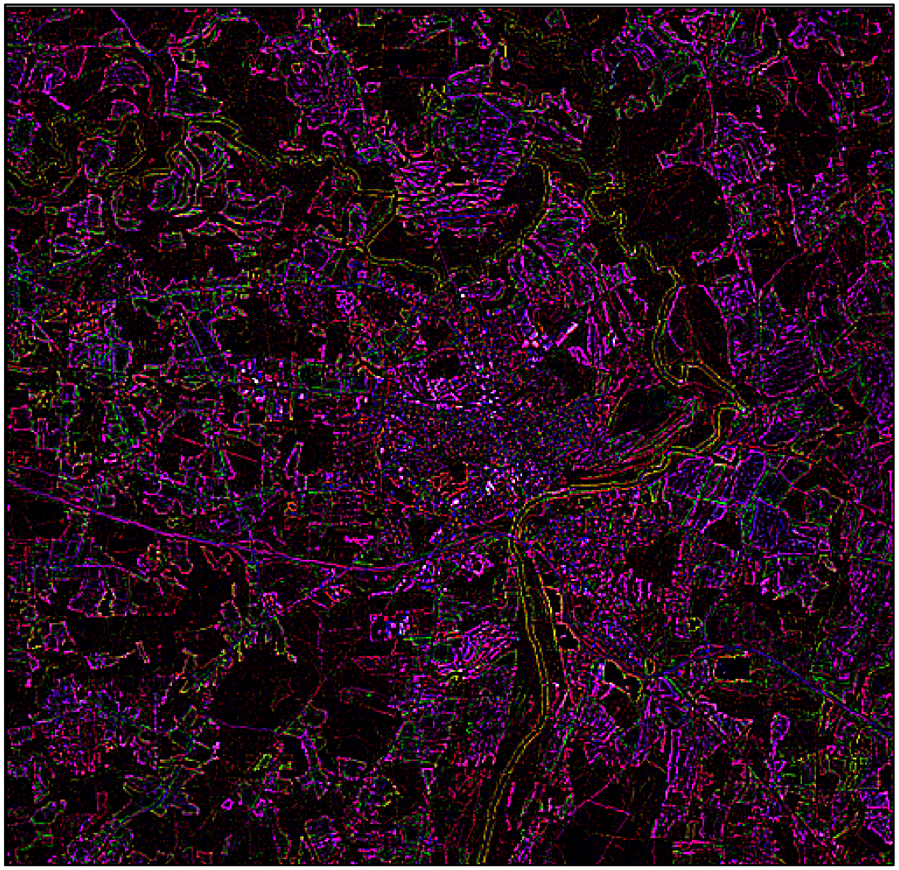
Smoothing Filter

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC



Sharpening Filter



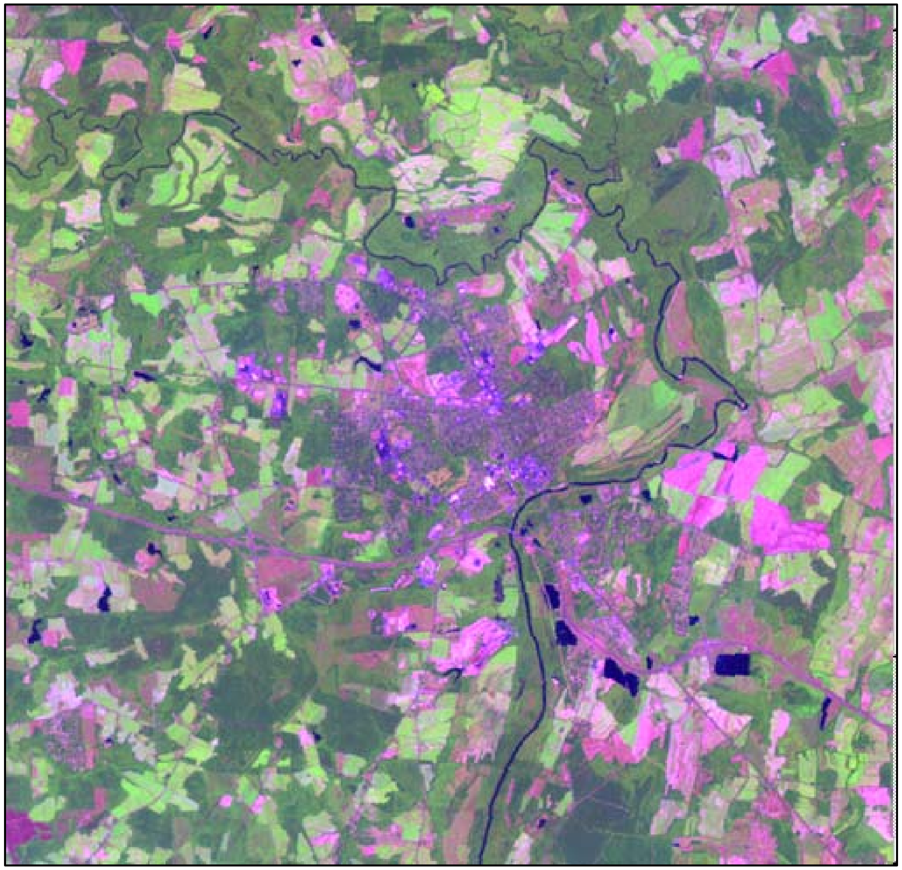
Edge Detection

Spectral Enhancements

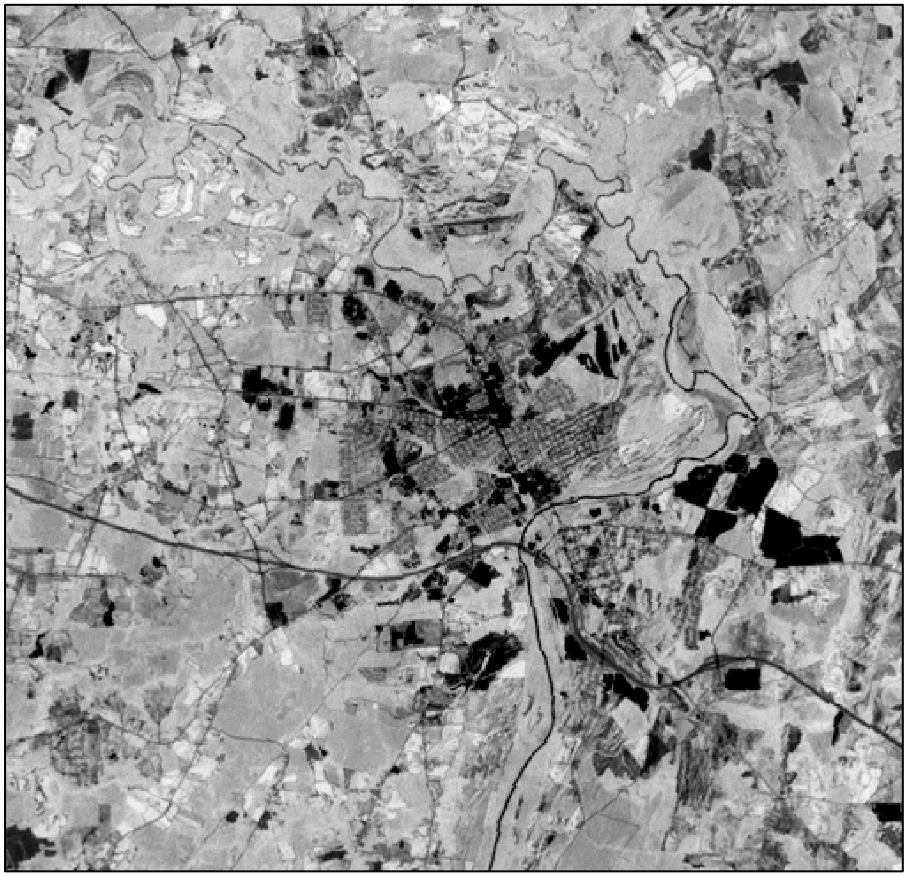
- Often involve taking ratios or other **mathematical combinations of multiple input bands** to produce a derived index of some sort, e.g.:
- **Normalized Difference Vegetation Index (NDVI)**
  - Designed to contrast heavily-vegetated areas with areas containing little vegetation, by taking advantage of vegetation's strong absorption of red and reflection of near infrared:
  - NDVI = (NIR-R) / (NIR + R)
- Other examples: Surface temperature (T_s) from IR bands, TVDI from NDVI and T_s

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC

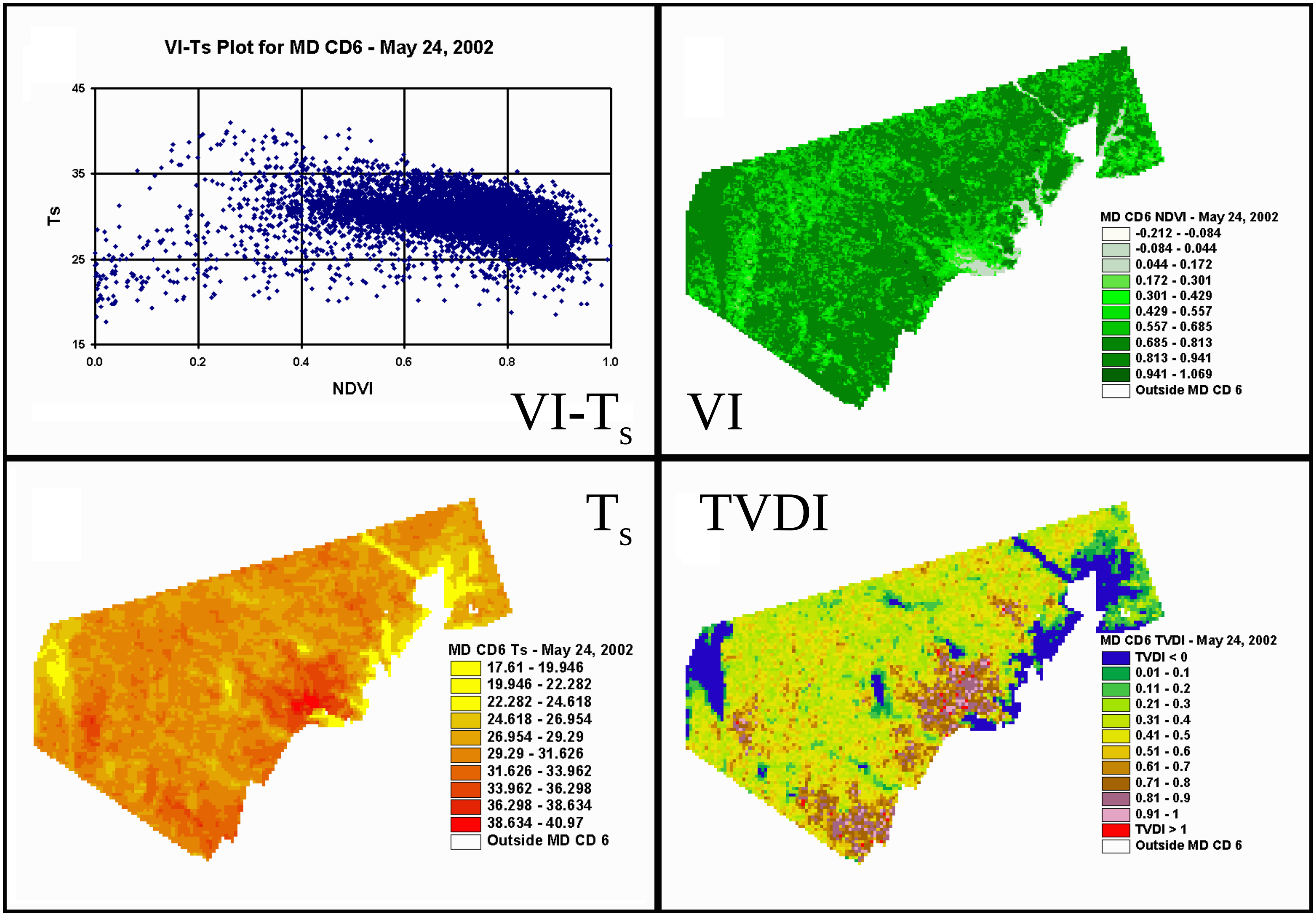


Normal Image



NDVI

Generating TVDI Values



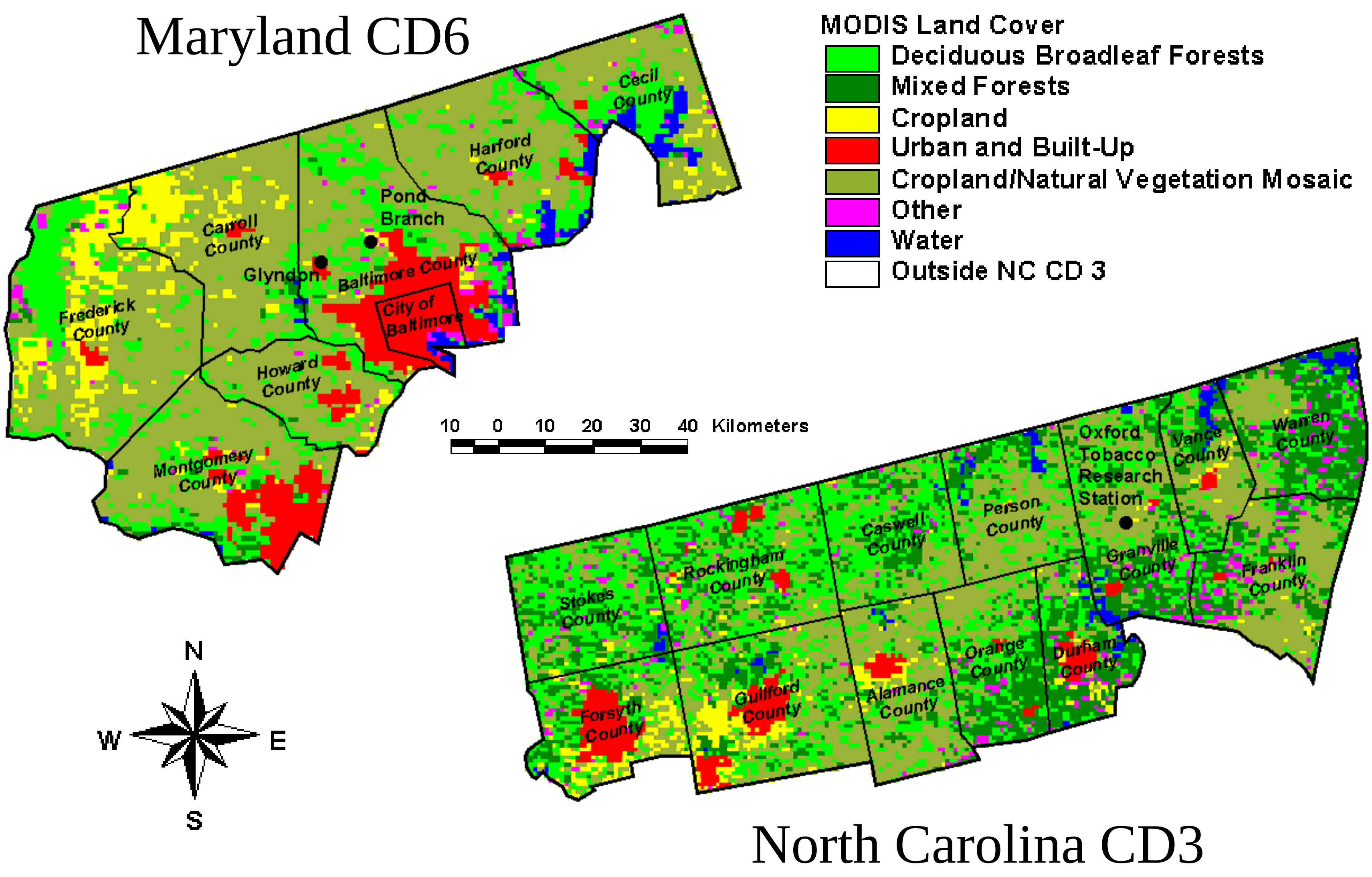
Classification

- One of the key processing techniques in remote sensing
- **Categorizes pixels into thematic categories** that correspond to land cover types
  - e.g. forest, crops, water, urban, etc.
- Complex process that ensures that the **variation** among pixel BVs **within a class** is less than the **variation between classes**
- Basis for differentiation are the **spectral signatures** of the classes (although supplemental information such as texture/pattern etc. can be used in the process as well)

Classification

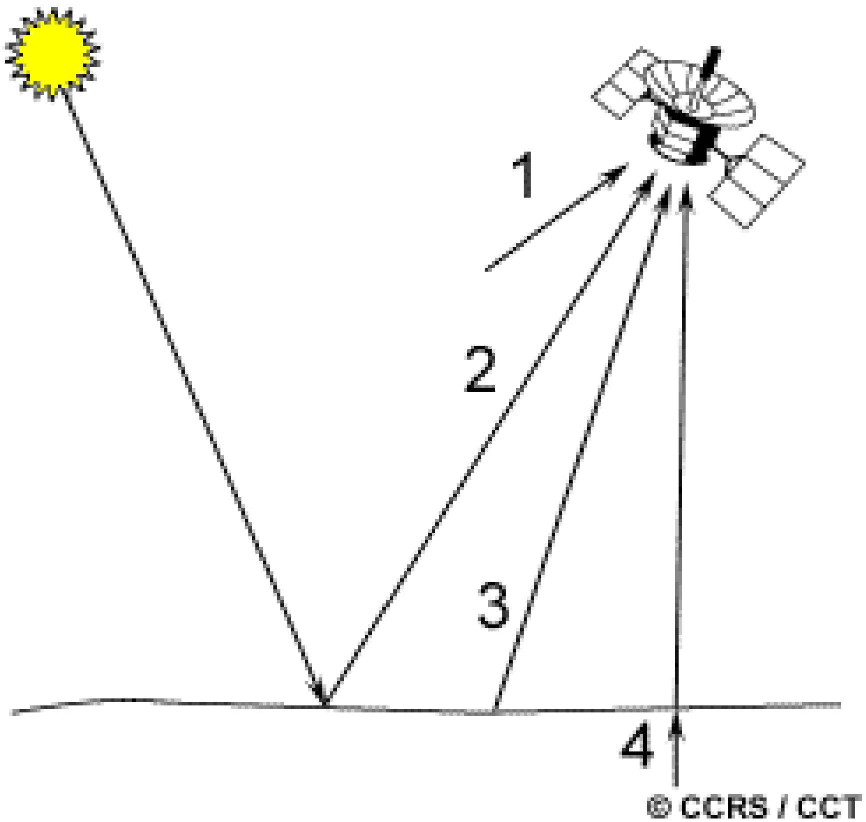
- In classifications, two or more bands are used
- There are two essential types of classification:
  - **Unsupervised**
    - classes based on statistics inherent in the remotely sensed data itself
    - classes do not necessarily correspond to real world land cover types
  - **Supervised**
    - classification algorithm is "trained" using ground truth data
    - classes do correspond to real world land cover types

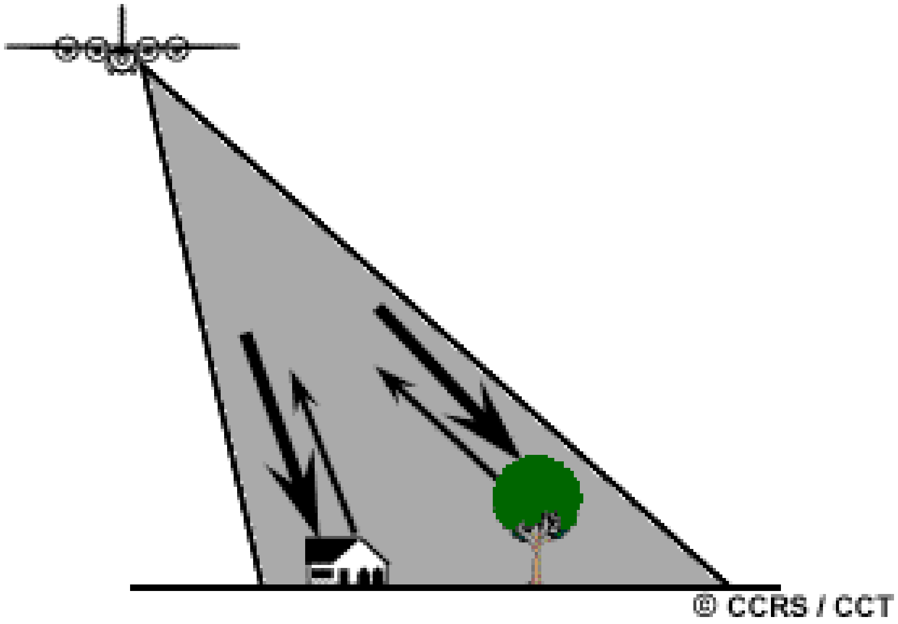
MODIS LULC In Climate Divisions



Passive vs. Active Remote Sensing

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter3/chapter3_1_e.html

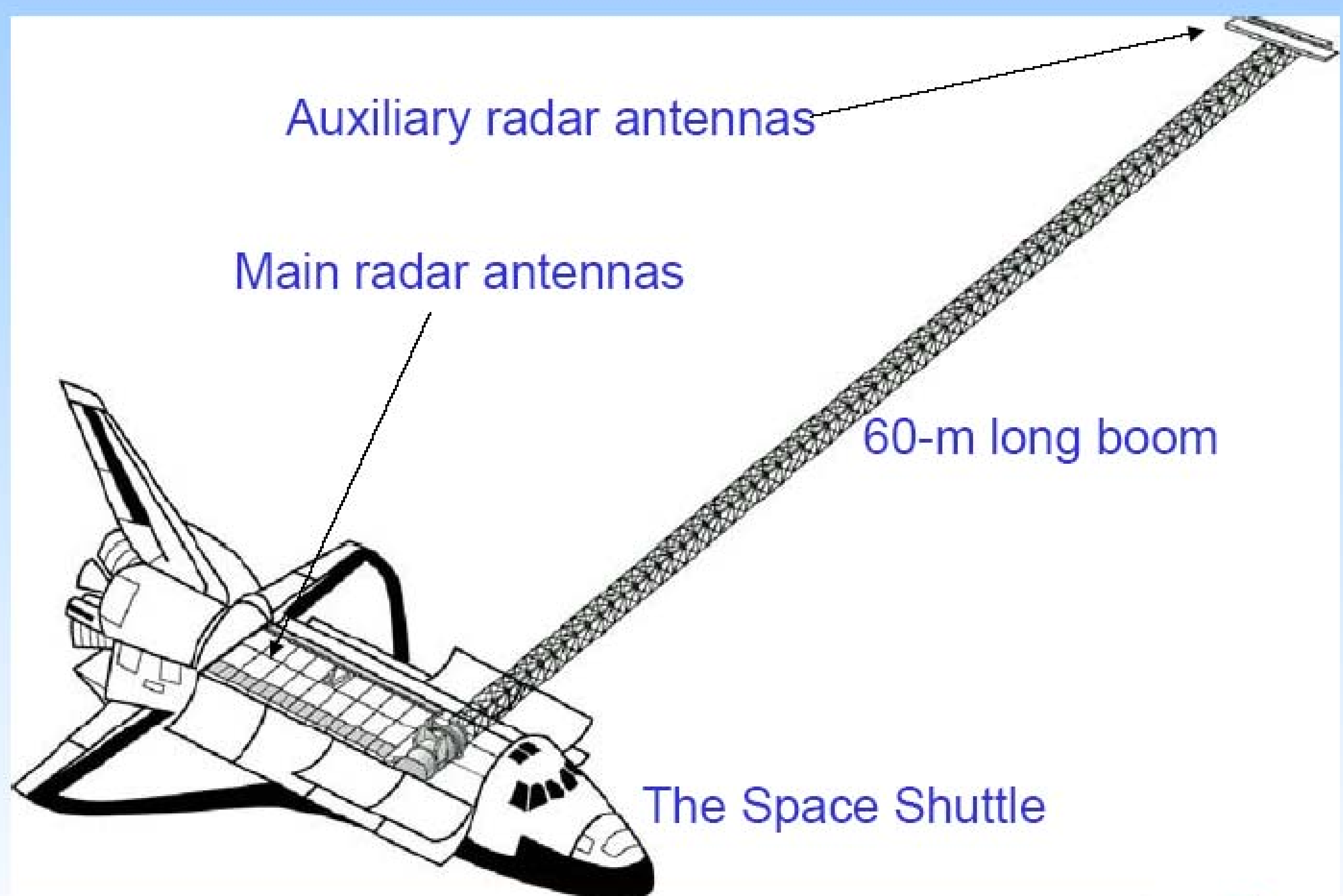




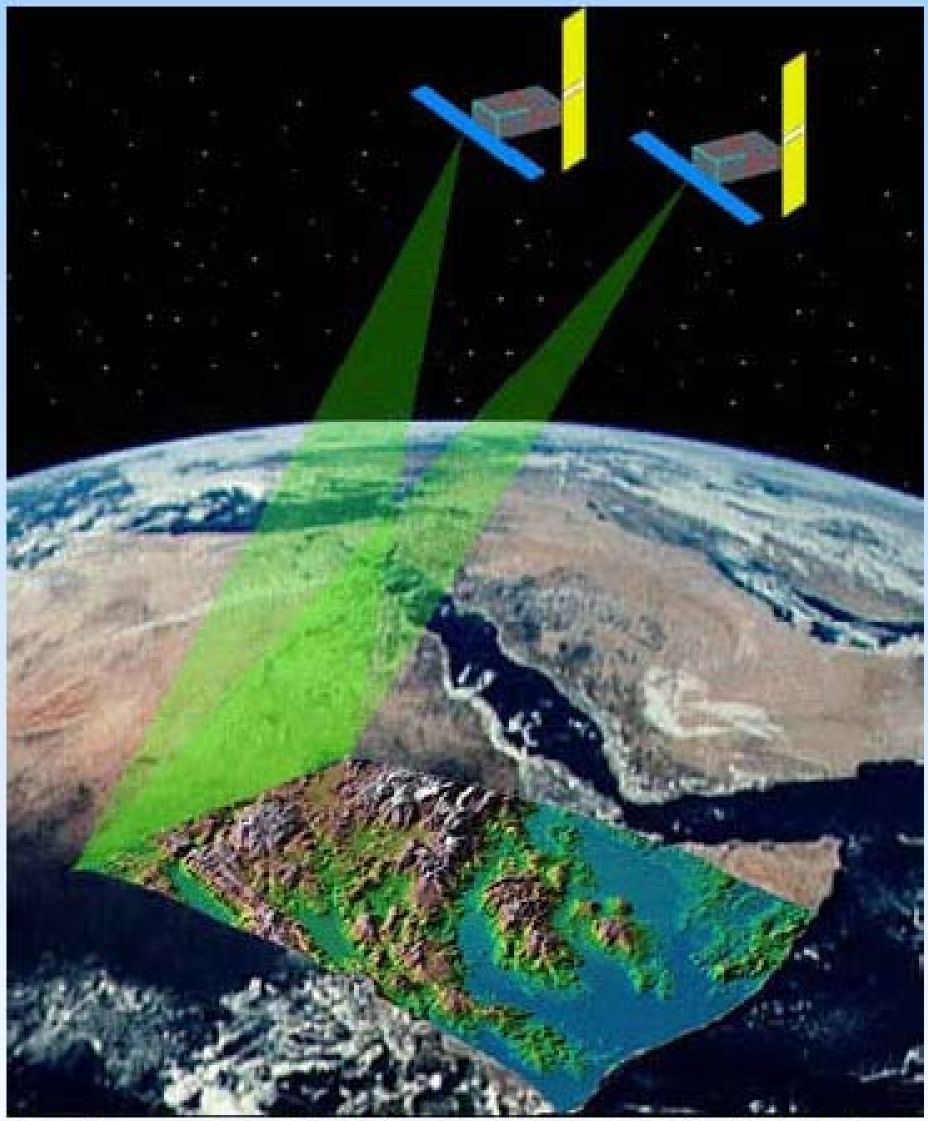
Passive sensors receive **solar energy reflected** by the Earth's surface (2), along with energy emitted by the atmosphere (1), surface (3) and sub-surface (4)

Active sensors receive energy reflected from the Earth's surface that originally came from an **emitter other than the Sun**

The NASA/DLR SRTM Mission



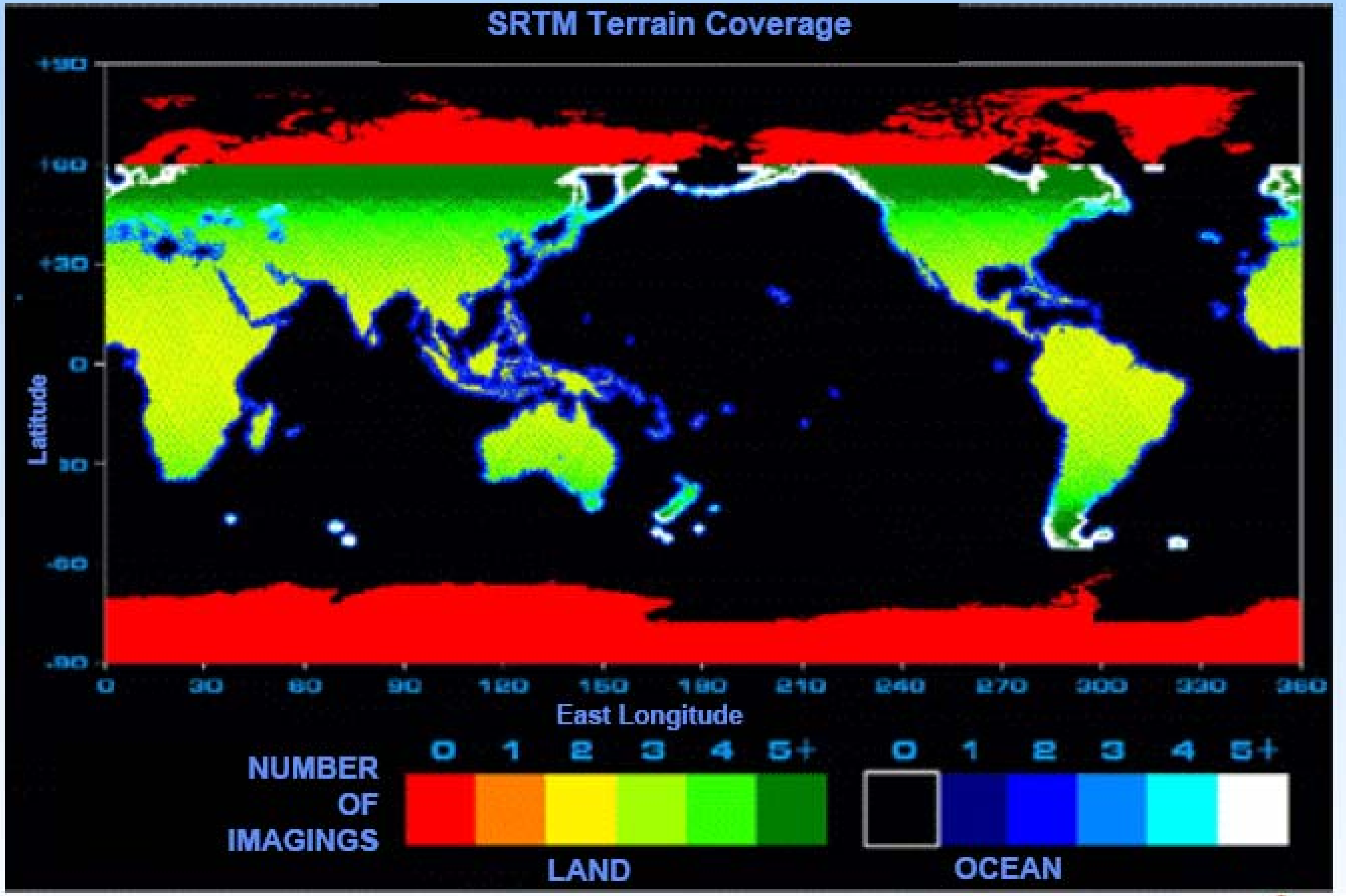
Radar Interferometry from Space



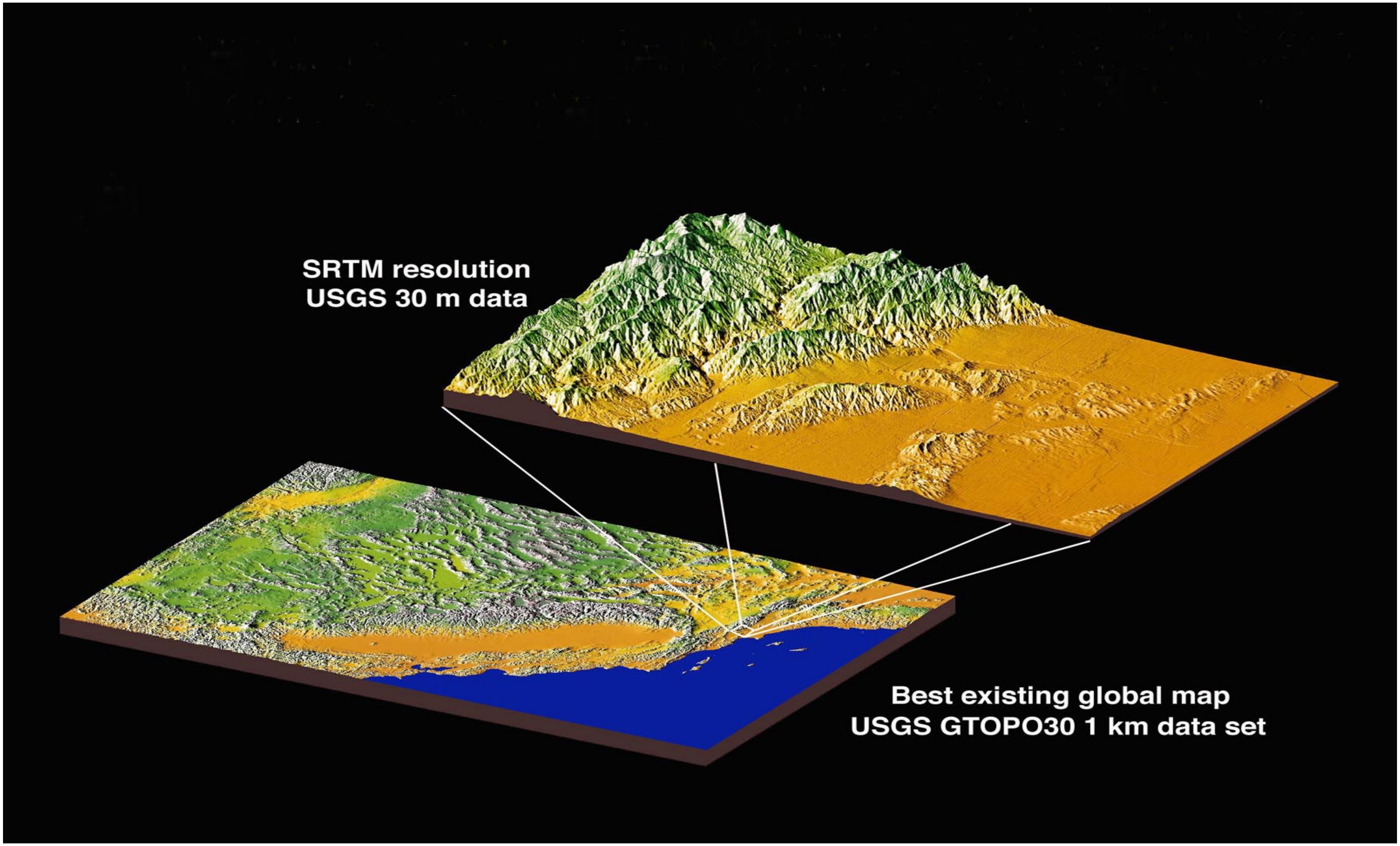
Drawing courtesy of Prof. Howard Zebker, Stanford University

- Two satellites image the Earth's surface
- Or one satellite takes two images a few days apart
- Data are processed into complex SAR images
- The phase difference of the two images is processed to obtain height and/or motion information of the Earth's surface

Coverage of 11-day SRTM Mission

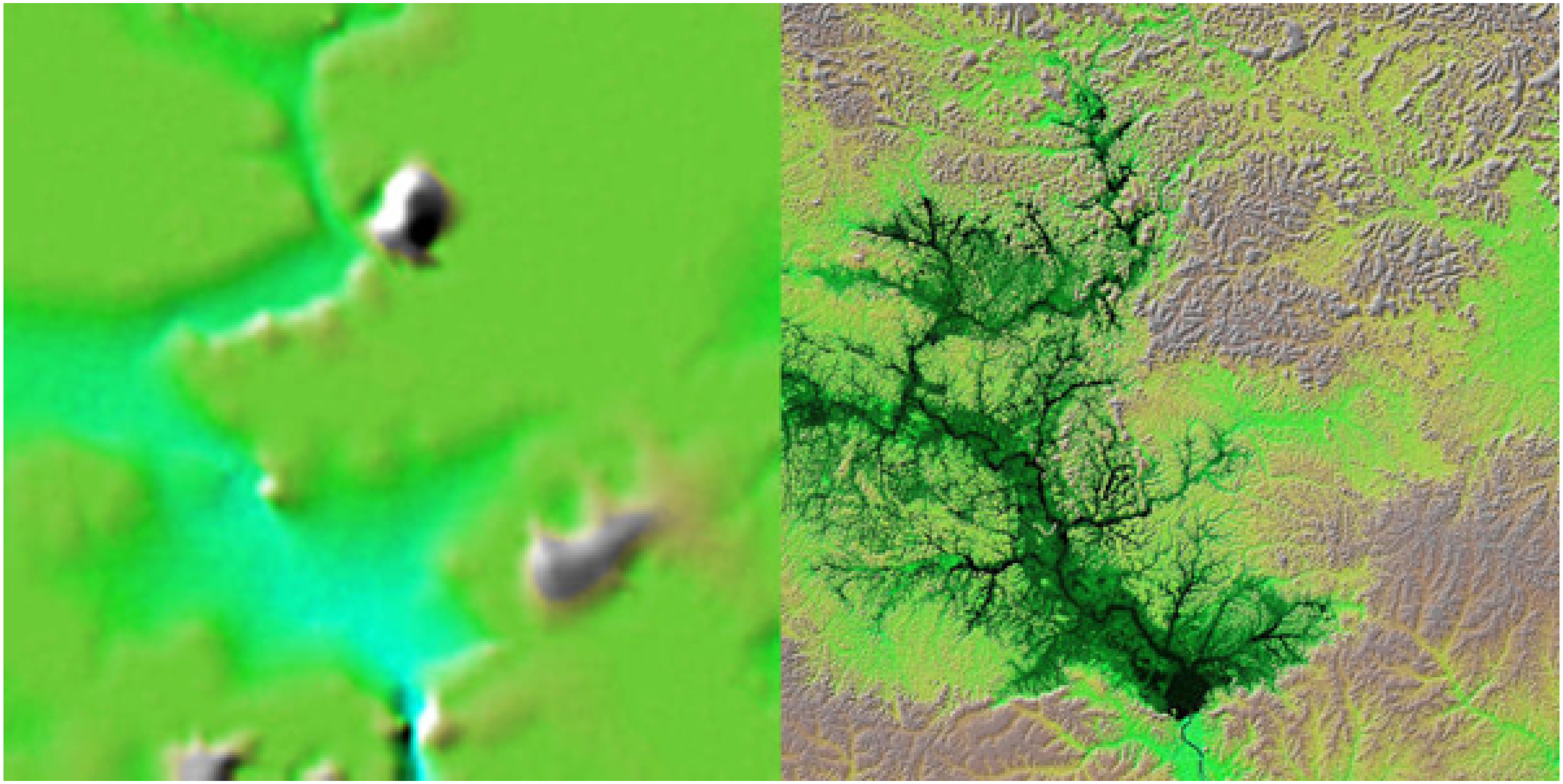


Improvement Over Old Global DEMs



http://srtm.usgs.gov/Mission/srtmcomparison221kb.html

Improvement Over Old Global DEMs



Lake Balbina, near Manaus, Brazil as depicted using old global 1km data (on the left), and the SRTM 30m DEM (on the right)

http://srtm.usgs.gov/srtmimagegallery/Lake%20Balbina,%20near%20Manaus,%20Brazil.htm

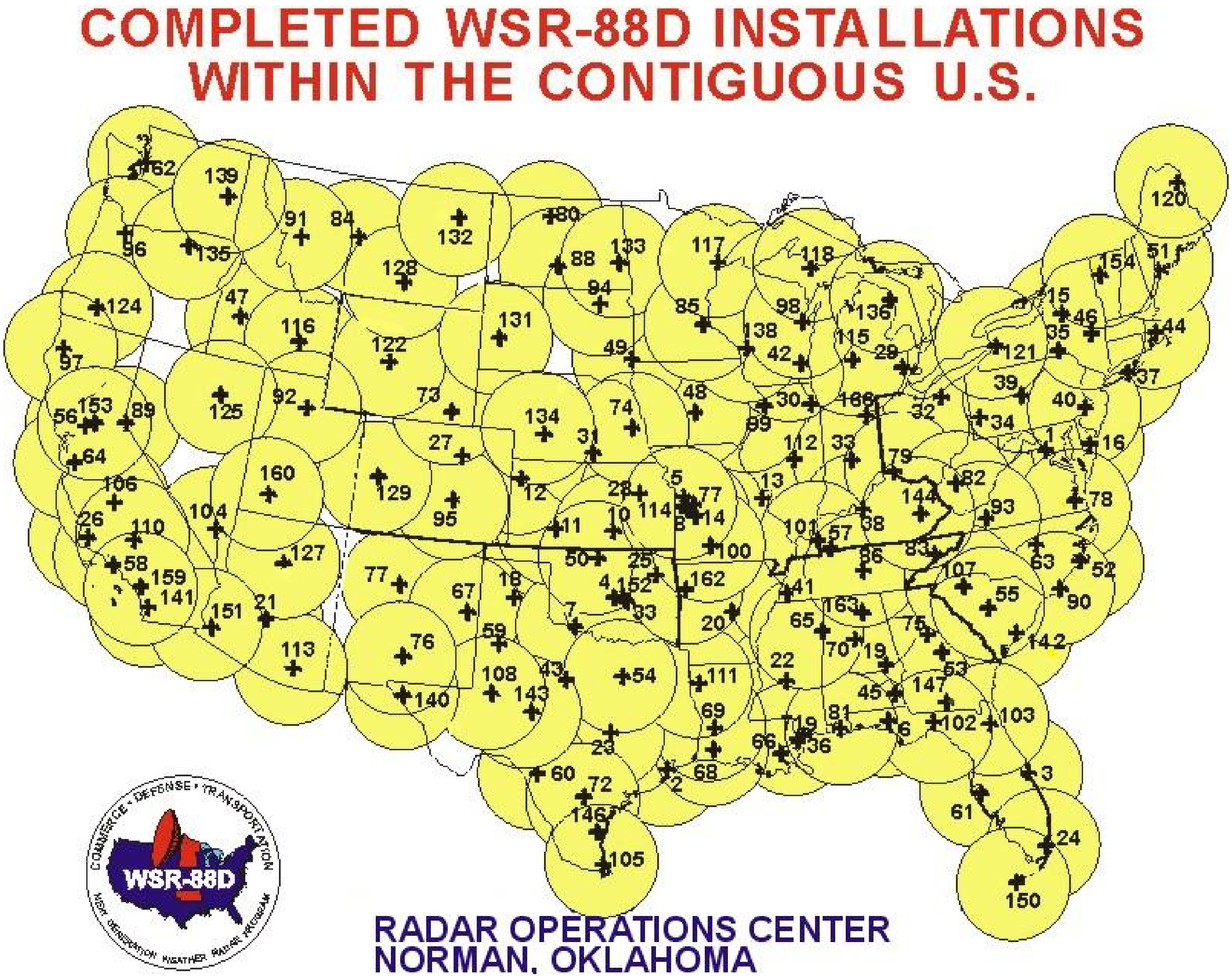
Nexrad Doppler Weather RADAR

- The **Nexrad** network of weather RADAR sensors consists of 158 radars that each have a maximum range of 250 miles that together provide excellent coverage of the continental United States

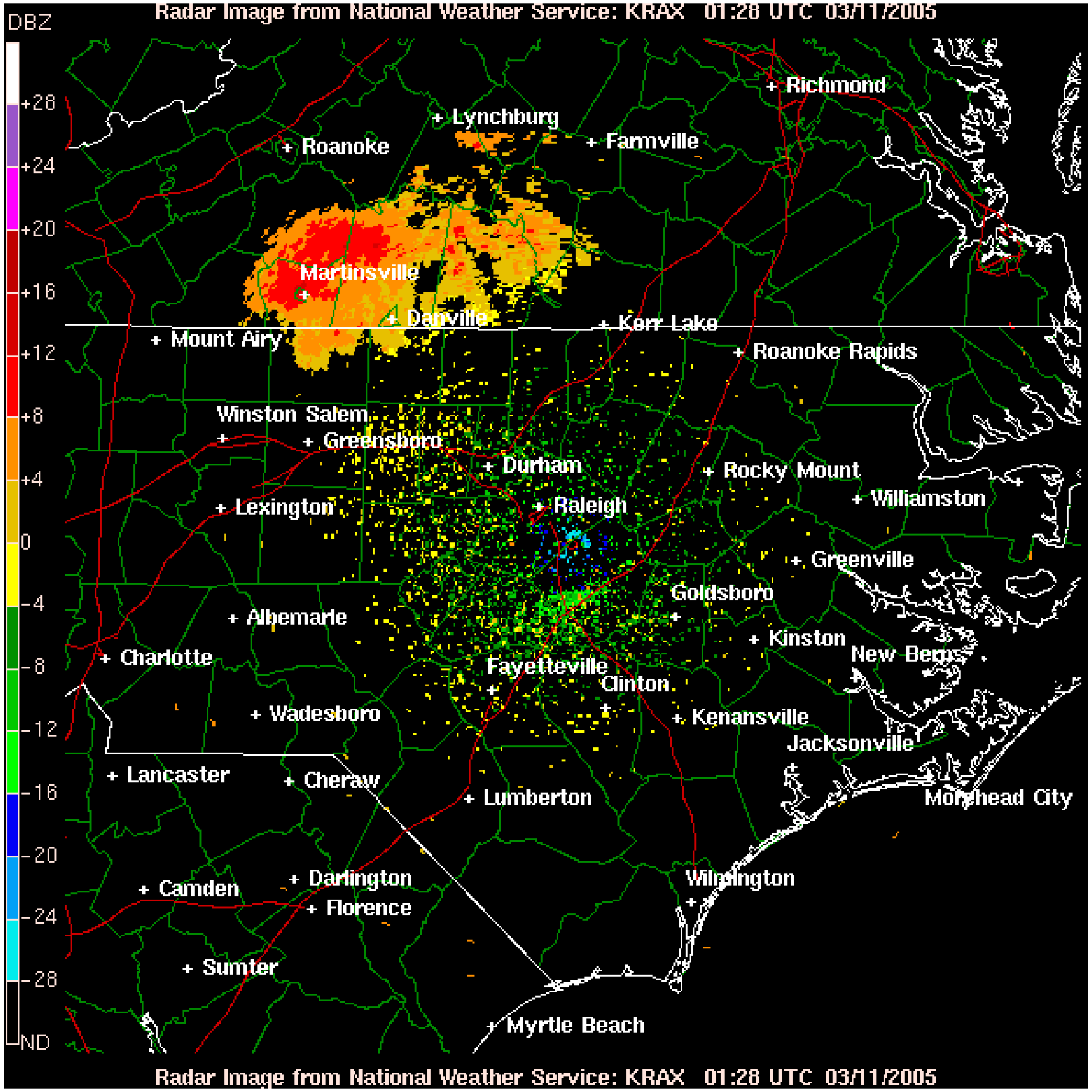
http://www.roc.noaa.gov/

The sensors are known by the designation **WSR-88D** (Weather Surveillance Radar 88 Doppler), and the station in this area is located at RDU airport is #64 - KRAX

Nexrad Doppler Weather RADAR



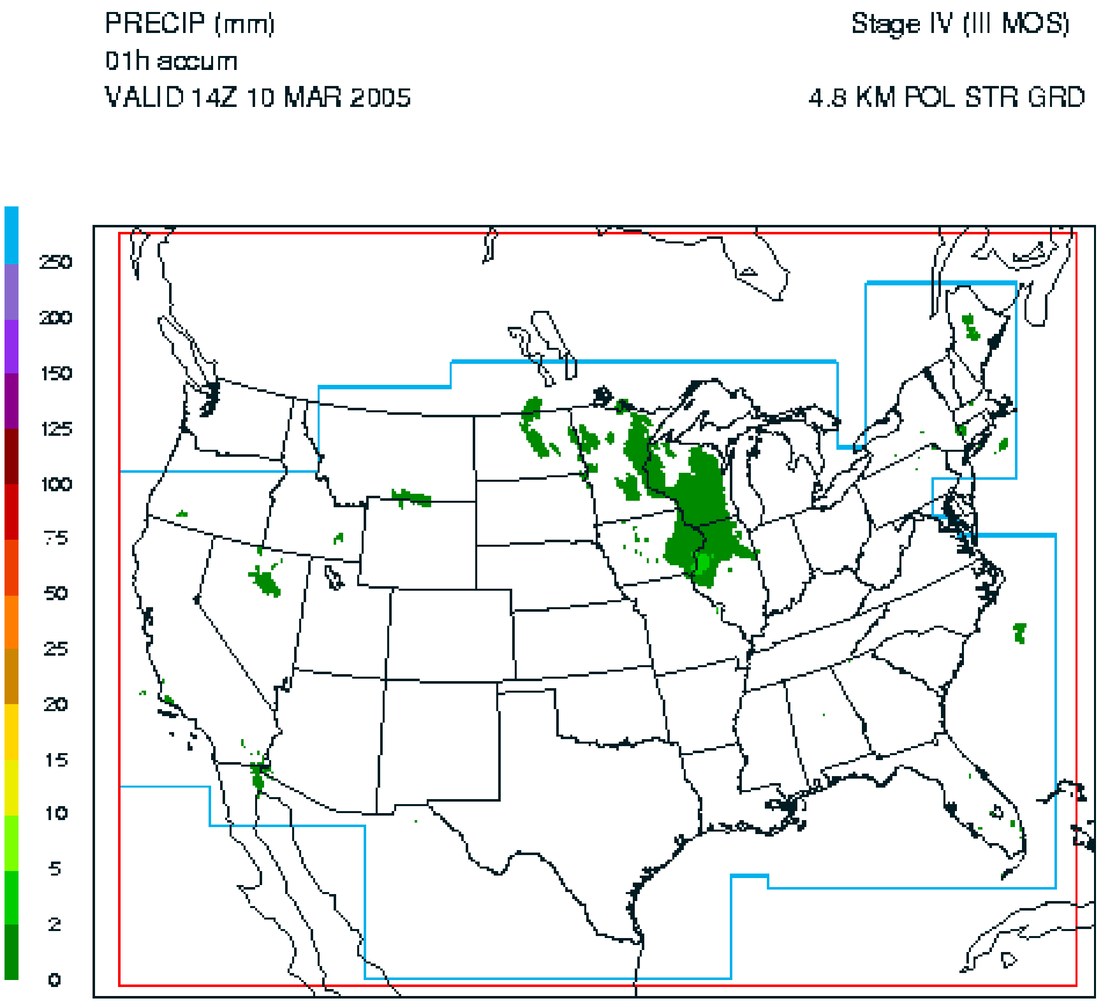
Nexrad Doppler Weather RADAR



http://weather.noaa.gov/radar/latest/DS.p19r0/si.krax.shtml

- At any time, you can **go online and retrieve a weather RADAR image** for any of the 158 operational stations that is **no more than 10 minutes old** (this one is from KRAX at about 8:30 PM on March 10, 2005)
- Note the **scattered signal** from around the Triangle, and the strong, **organized return** from NW of the RADAR

CONUS Hourly Nexrad Rainfall



http://wwwt.emc.ncep.noaa.gov/mmb/ylin/pcpanl/stage4/images/st4.6hrloop.gif

- Here is Nexrad gauge-corrected for **six one-hourly periods** for the afternoon and evening of March 10, 2005

- Note the changes in shape of the **blue bounding box**, which show that some RADARs were offline where no overlapping coverage was present, thus no information was available