What is Remote Sensing?

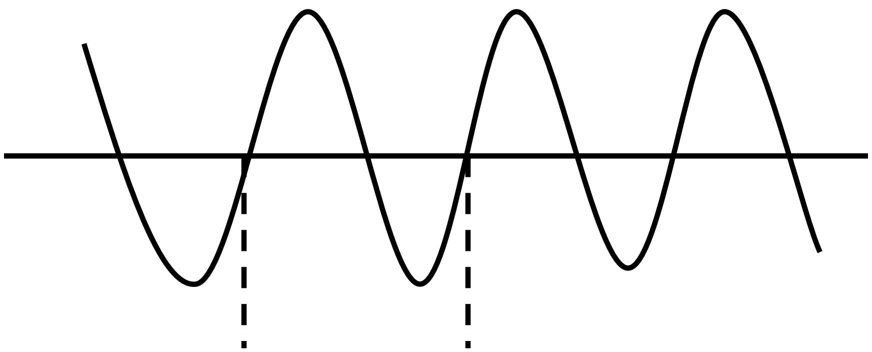
- Remote sensing is the **science and art** of obtaining information about a target, through the analysis of data acquired by a device that is **not in contact** with the target under investigation
- We routinely use remote sensing when we **see** things:
  - Our eyes can see thing around us, and sometimes 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

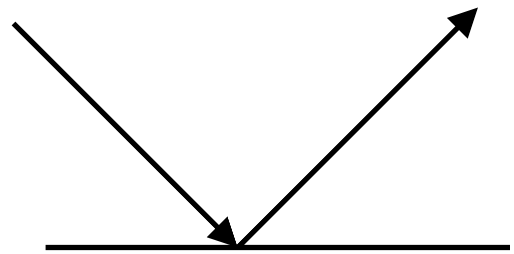
- In remote sensing, the medium that usually carries the information is **electromagnetic radiation**. Using various sensors, we can collect the electromagnetic radiation in **any portion of the spectrum**. Based on the source of the energy, remote sensing can be broken into two categories:
- **Passive 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

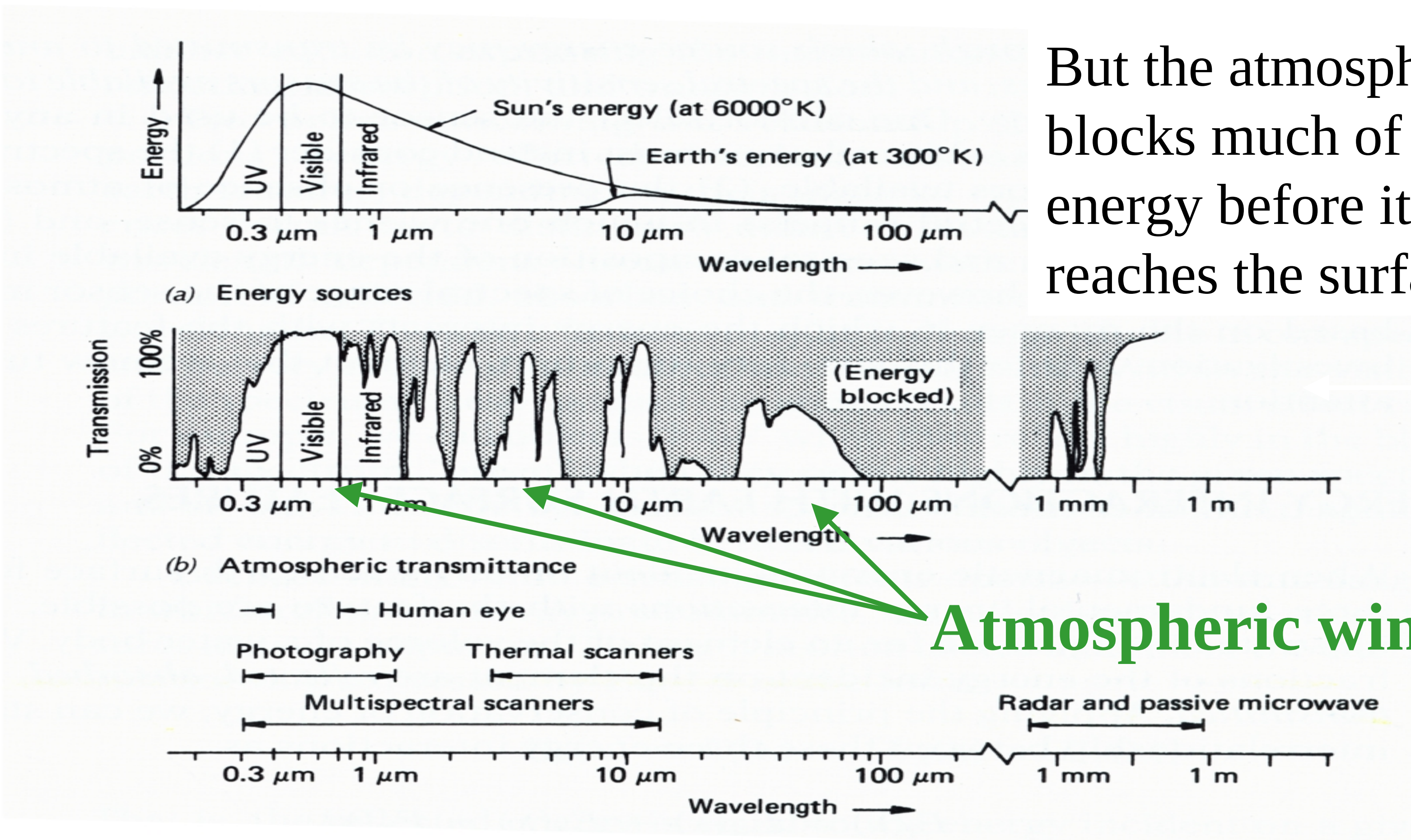
- EMR energy moves at the **speed of light (c)**: $c = f\,\lambda$
- ***f*** **= frequency**: The number of waves passing through a point within a unit time (usually expressed per second)
- **Energy** carried by a photon: $\varepsilon = h\,f$ [h=Planck constant (6.626×10^{-34} Js)]
- The shorter the 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

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

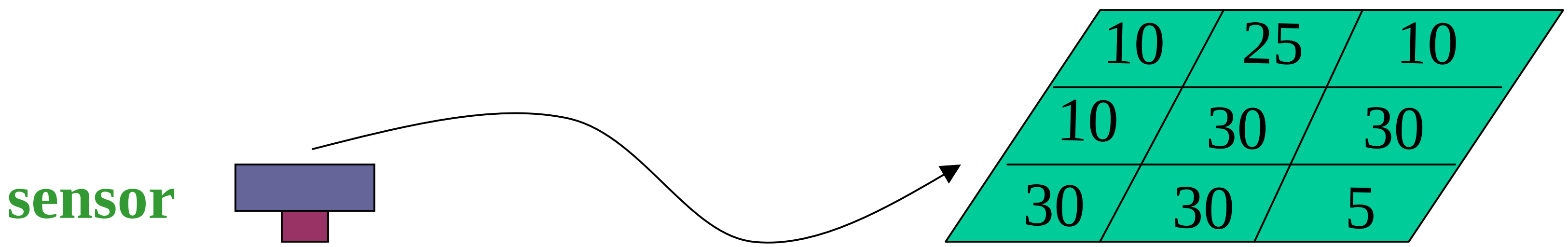
Analog-to-Digital Conversion

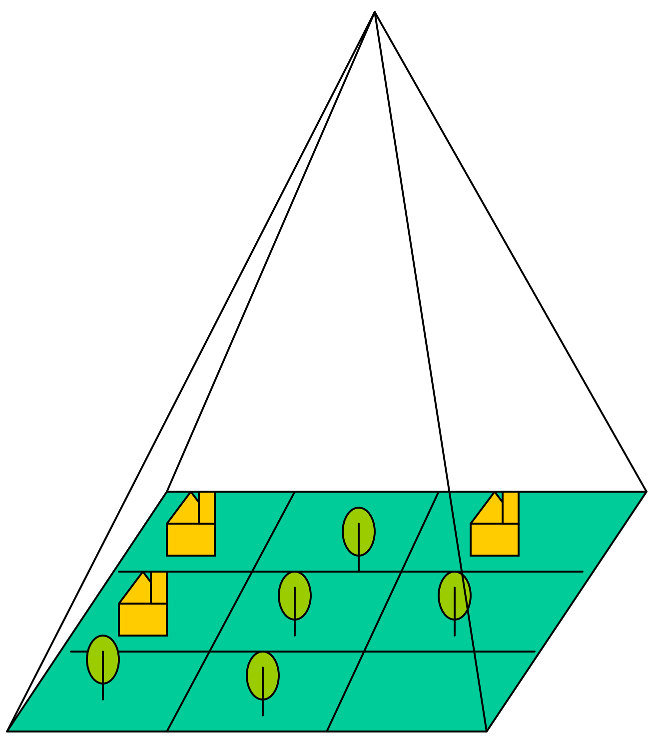
•As long as we can record the amount of **energy** (in a certain wavelength range) received from the ground surface, we **do not have to record it on film**

•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

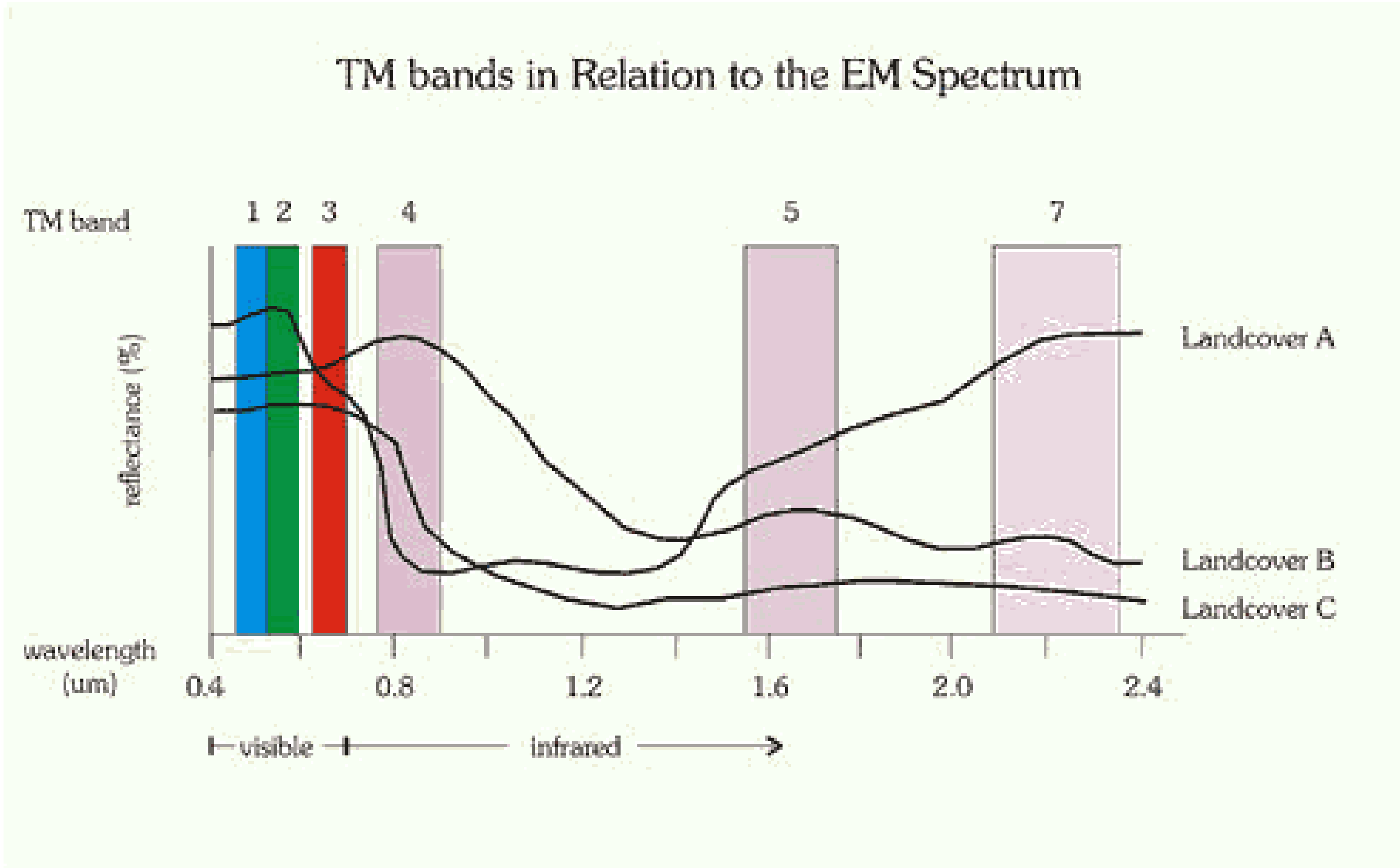
Digital Images





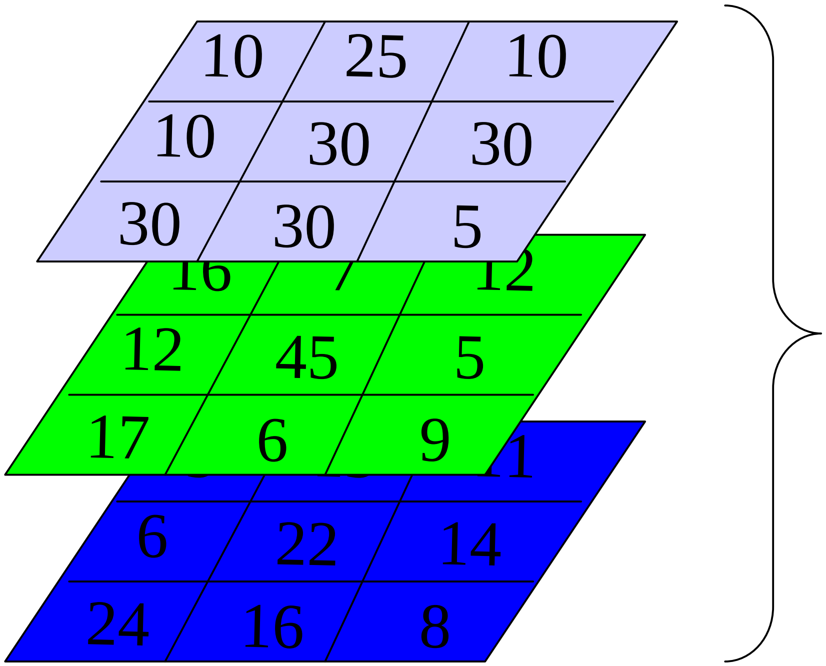
1. The area is covered with a **grid** of cells
2. Each cell has a **digital number** indicating the amount of energy received from the cell (in a certain wavelength range)
3. The cell is called a **pixel** (a picture element)
4. The size of the pixel is the **spatial resolution**

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

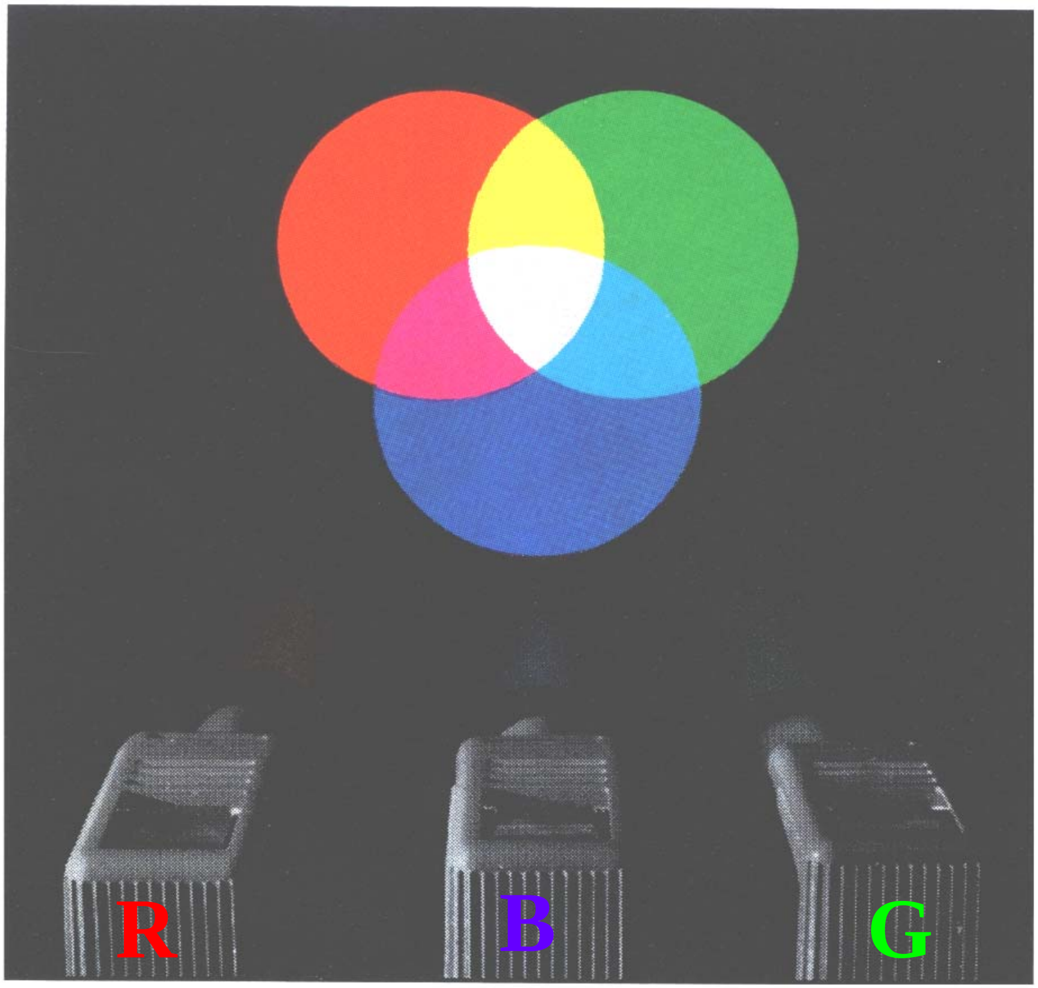
How Do We Display Multispectral Image Data?

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**

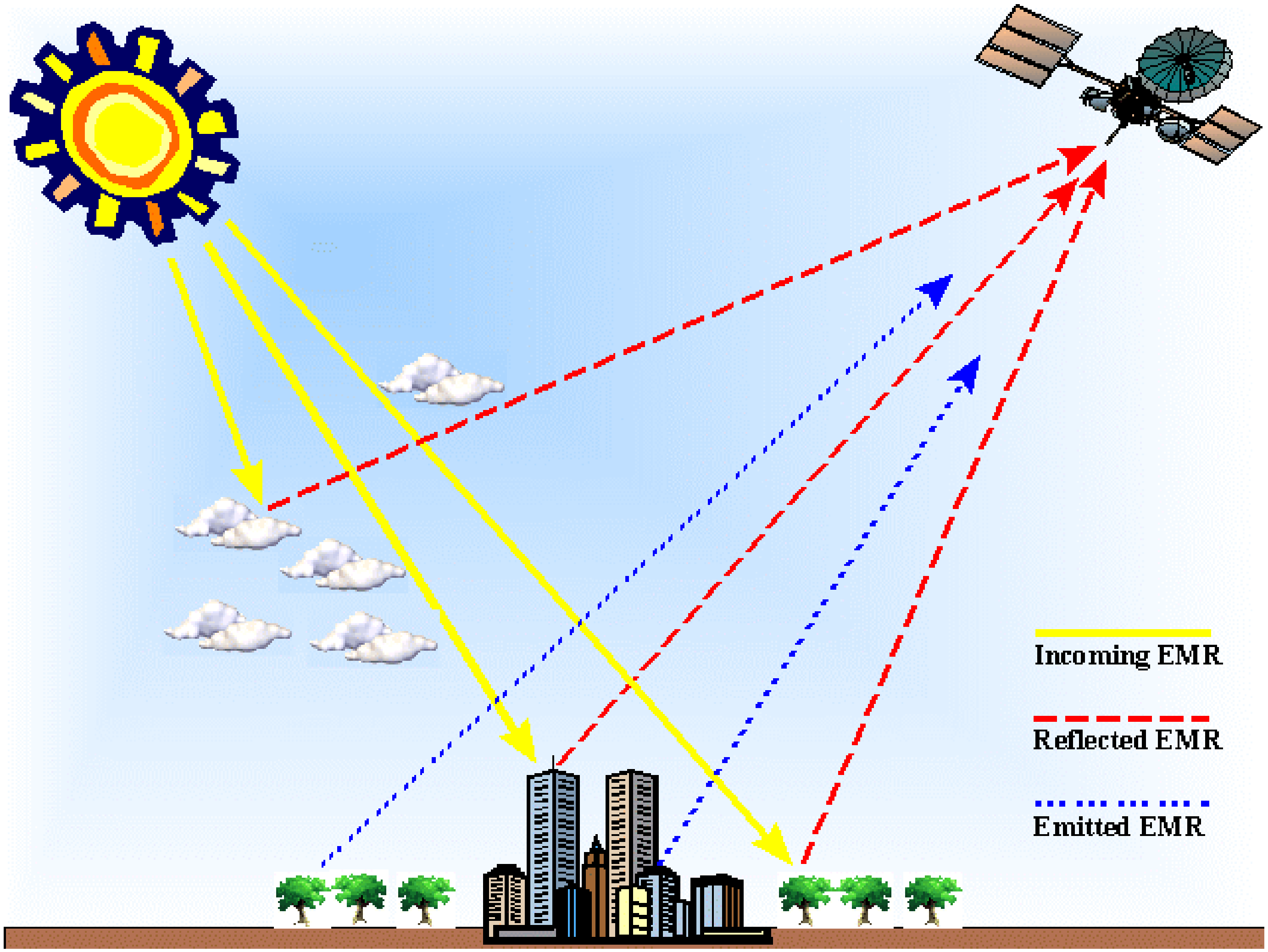
Color Arithmetic



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

Satellite Imagery - Sensing EMR

- Digital data obtained by sensors on satellite platforms

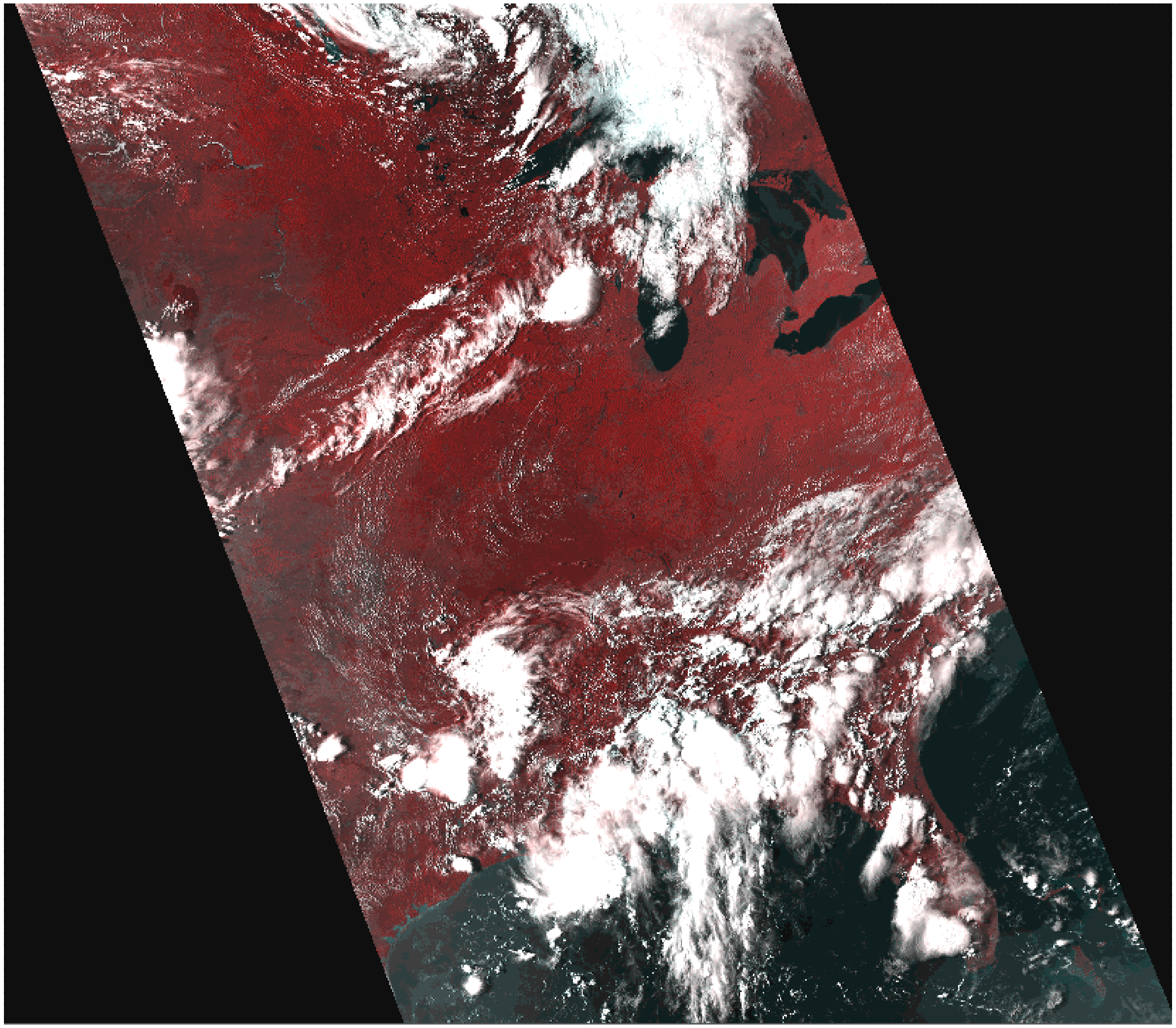


Satellite Imagery - 4 Resolutions

- 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)

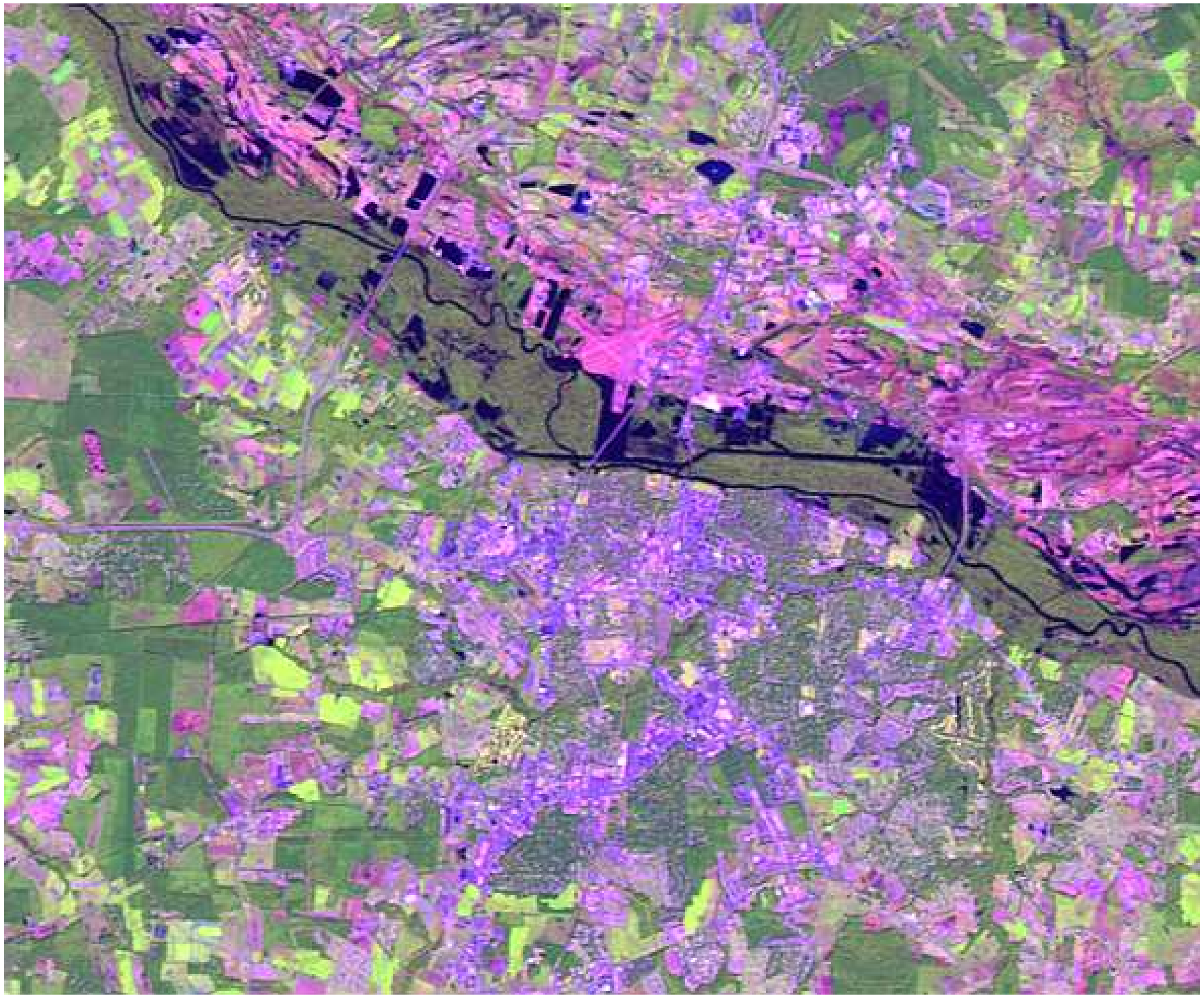
Spatial Resolution

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



Spatial Resolution

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

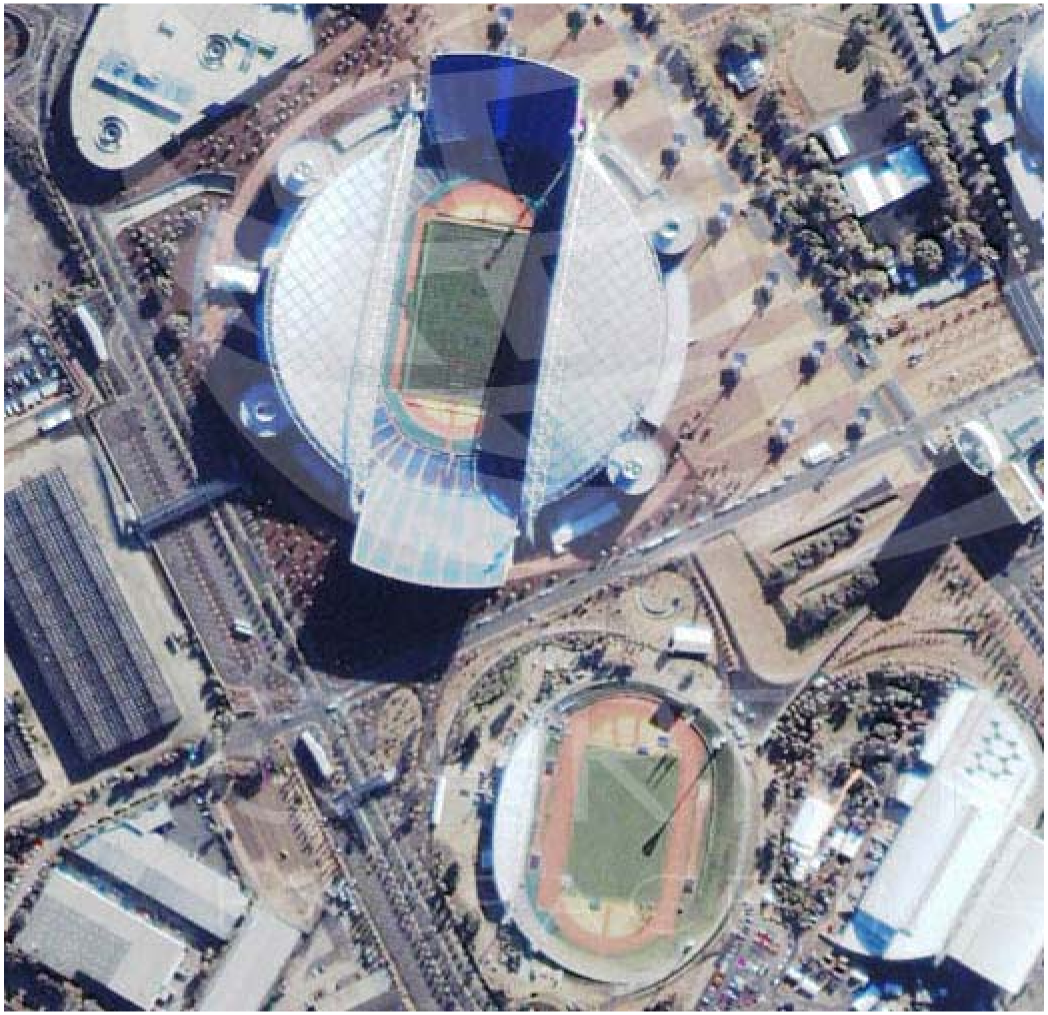


Spatial Resolution

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

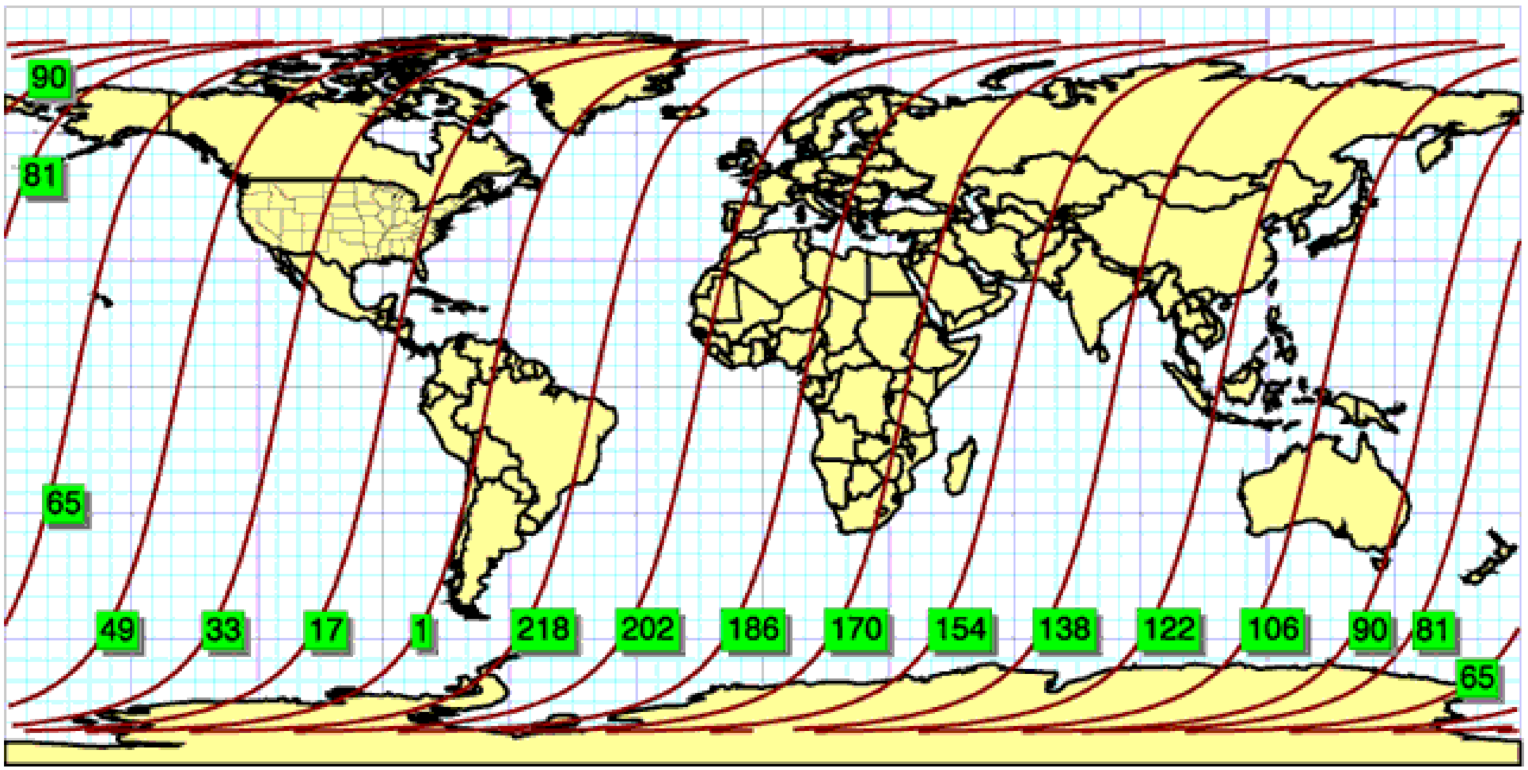
Spatial Resolution

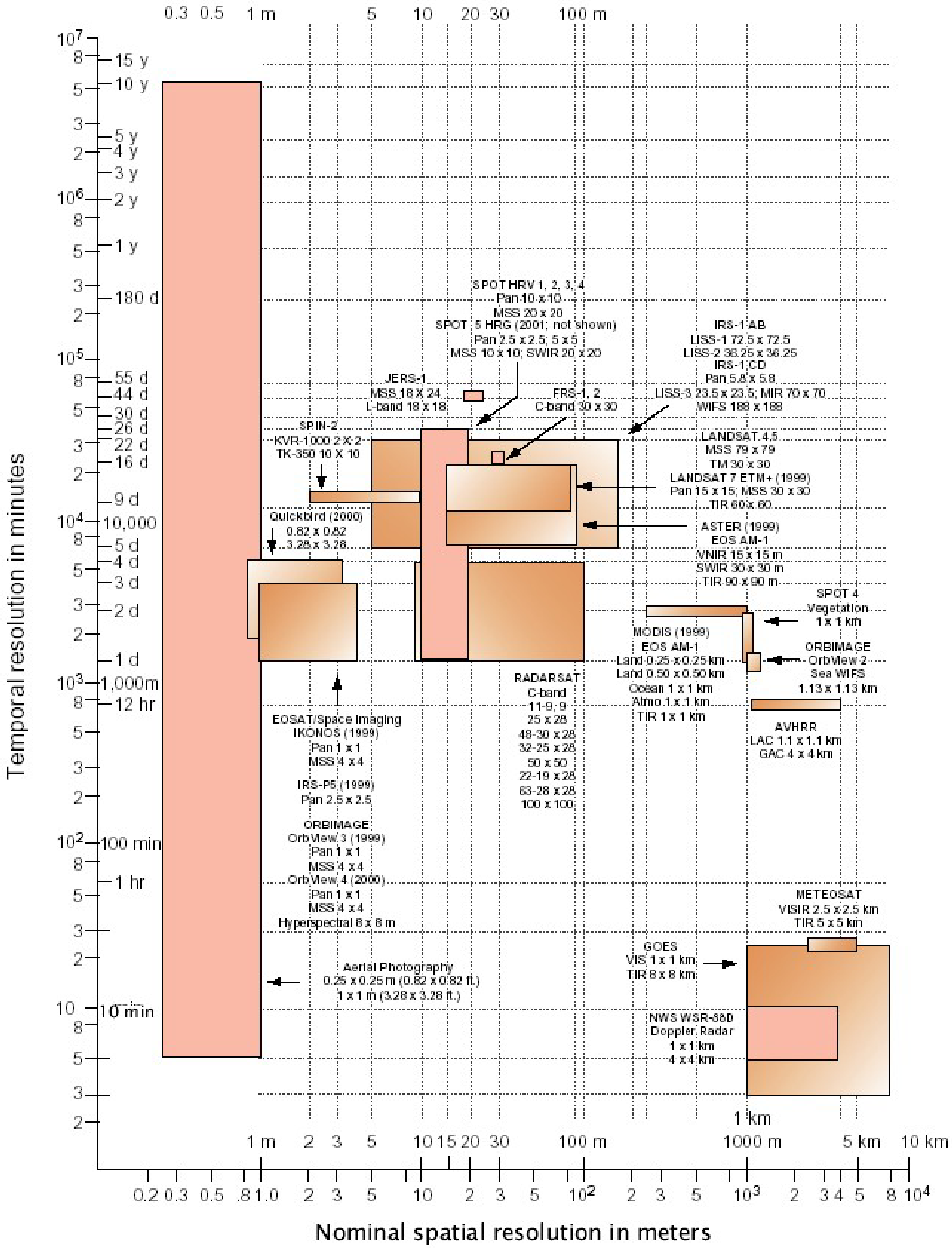
IKONOS panchromatic image of Sydney Olympic Park - 1m



Temporal Resolution

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

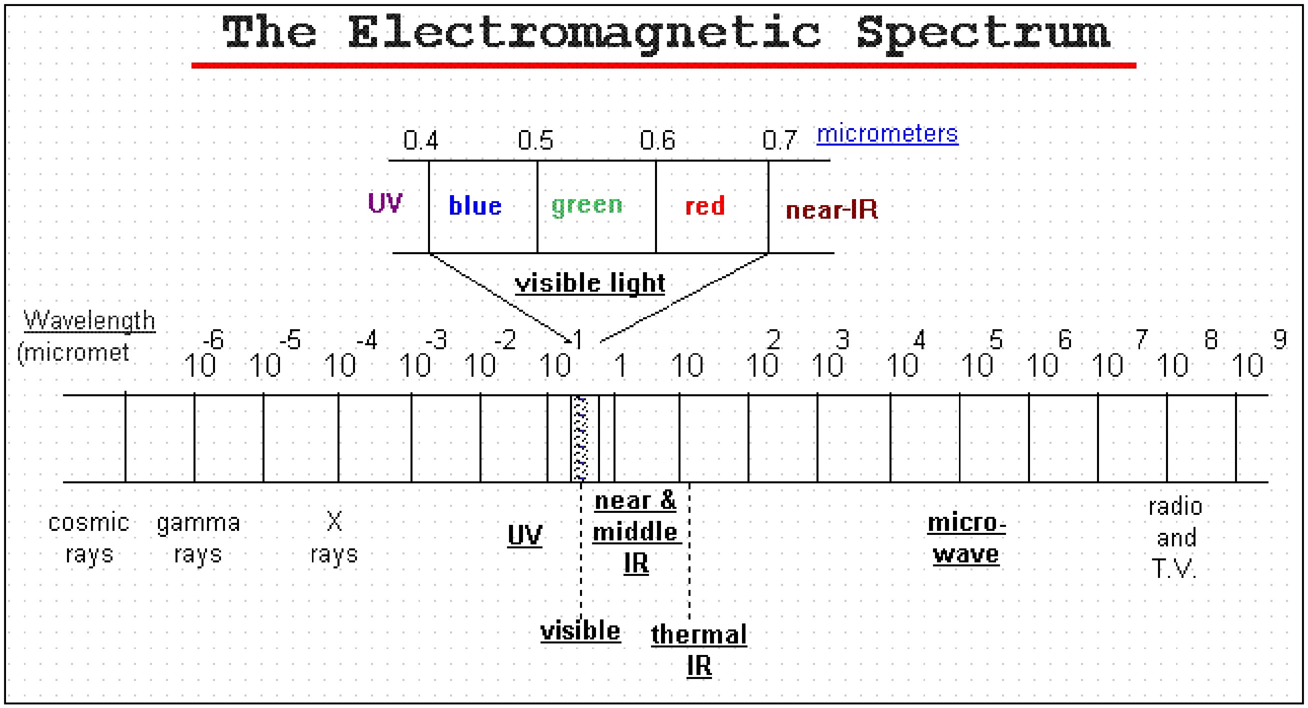




Temporal resolution in minutes
Nominal spatial resolution in meters
SPOT HRV 1, 2, 3, 4
Pan 10 x 10
MSS 20 x 20
SPOT 5 HRG (2001; not shown)
Pan 2.5 x 2.5; 5 x 5
MSS 10 x 10; SWIR 20 x 20
IRS-1 AB
LISS-1 72.5 x 72.5
LISS-2 36.25 x 36.25
IRS-1 CD
Pan 5.8 x 5.8
LISS-3 23.5 x 23.5; MIR 70 x 70
WIFS 188 x 188
JERS-1
MSS 18 X 24
L-band 18 x 18
ERS-1, 2
C-band 30 x 30
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
0.3 0.5 1 m 5 10 20 30 100 m
1 m 2 3 5 10 15 20 30 100 m 1000 m 5 km 10 km
1 km
0.2 0.3 0.5 .8 1.0 2 3 5 10 2 3 5 10^2 2 3 5 10^3 2 3 4 5 8 10^4

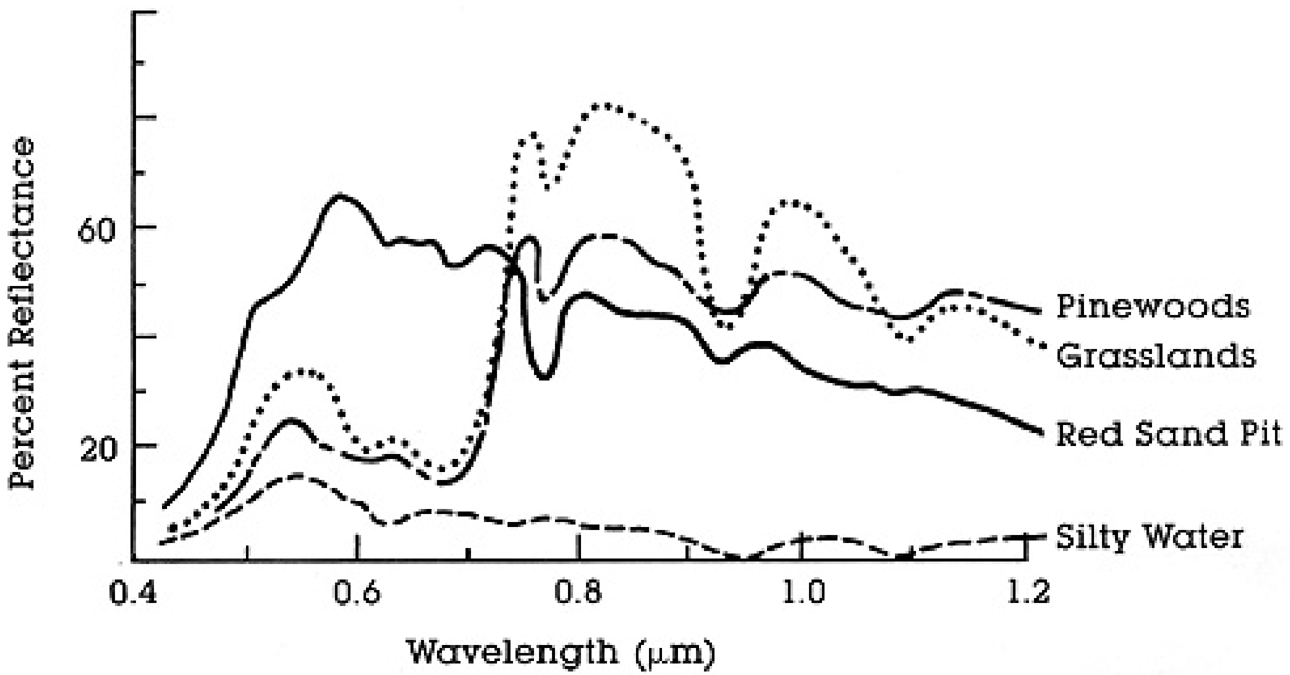
Electromagnetic Spectrum

- 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

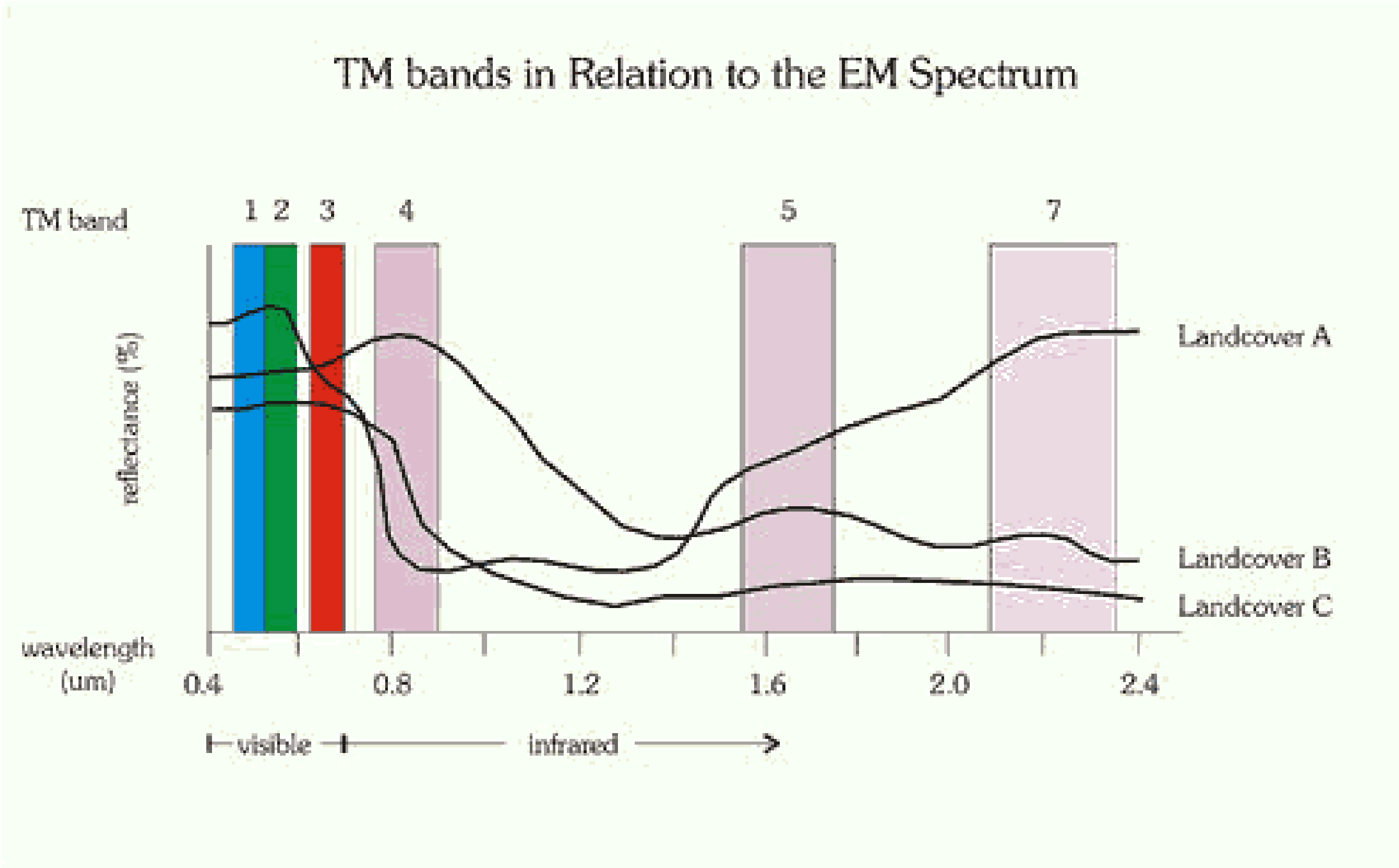


Spectral Resolution

- 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 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**

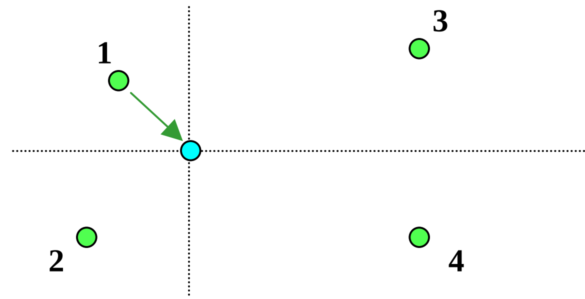
Geometric Correction

- Four Basic Steps of Rectification

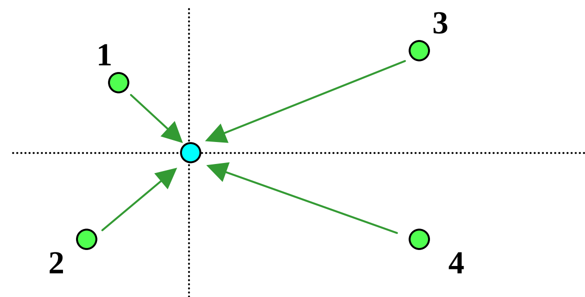
1. Collect **ground control points (GCPs)**
   Points in the image for which you can determine real-world coordinates
2. Create **equations** relating the image pixel coordinates at those GCPs to their real-world coordinates
3. **Transform** the pixel coordinates based on the equations
4. **Resample**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

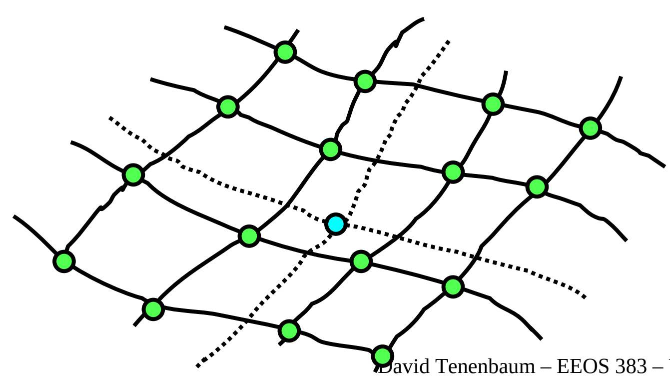


Image Enhancements

- 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

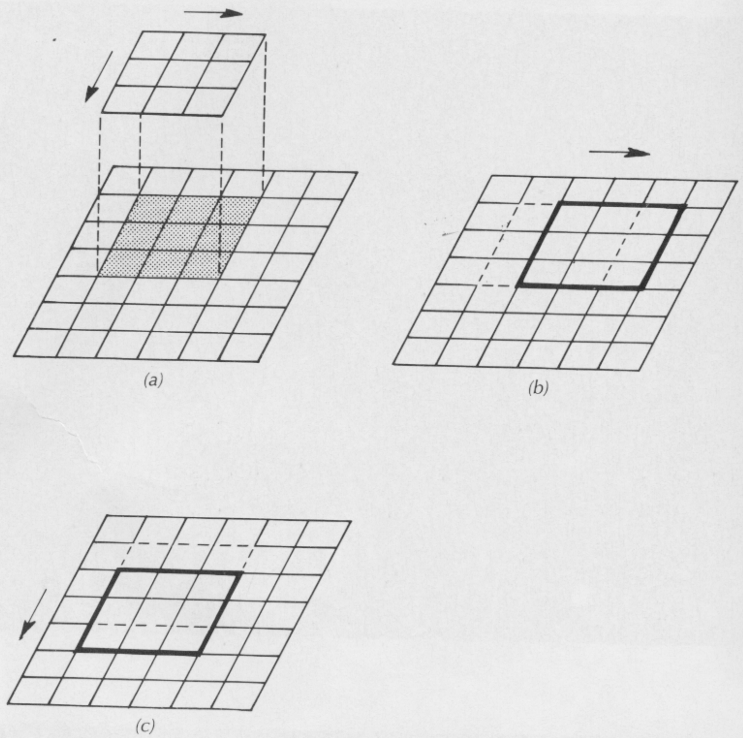
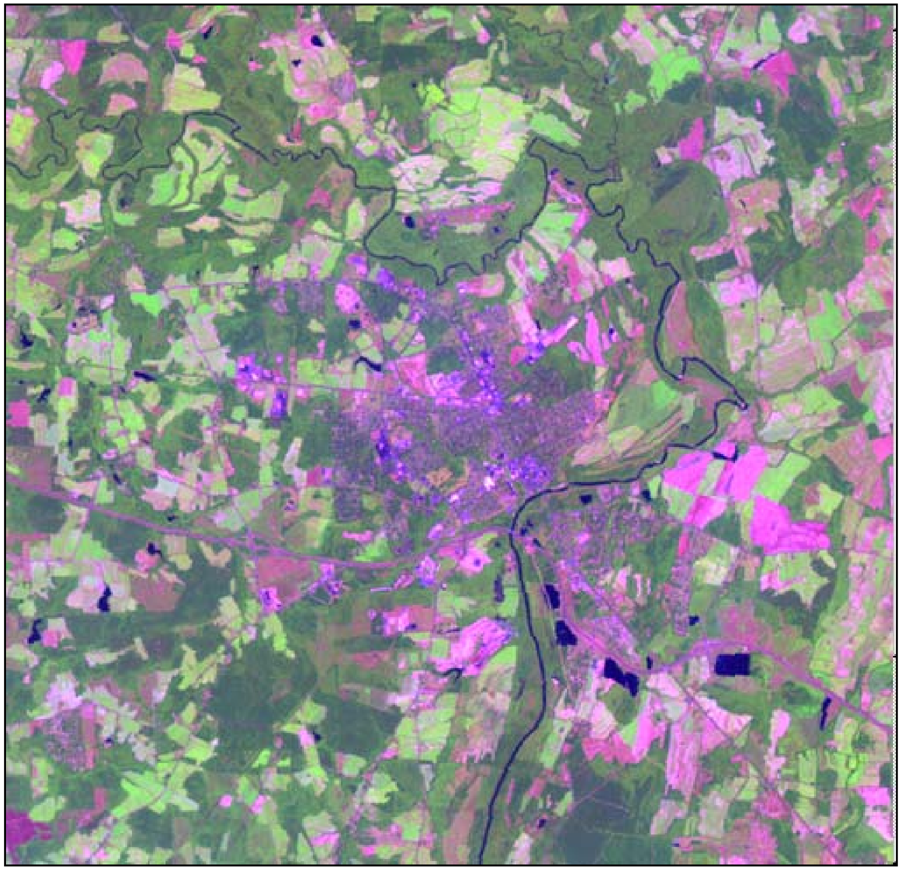


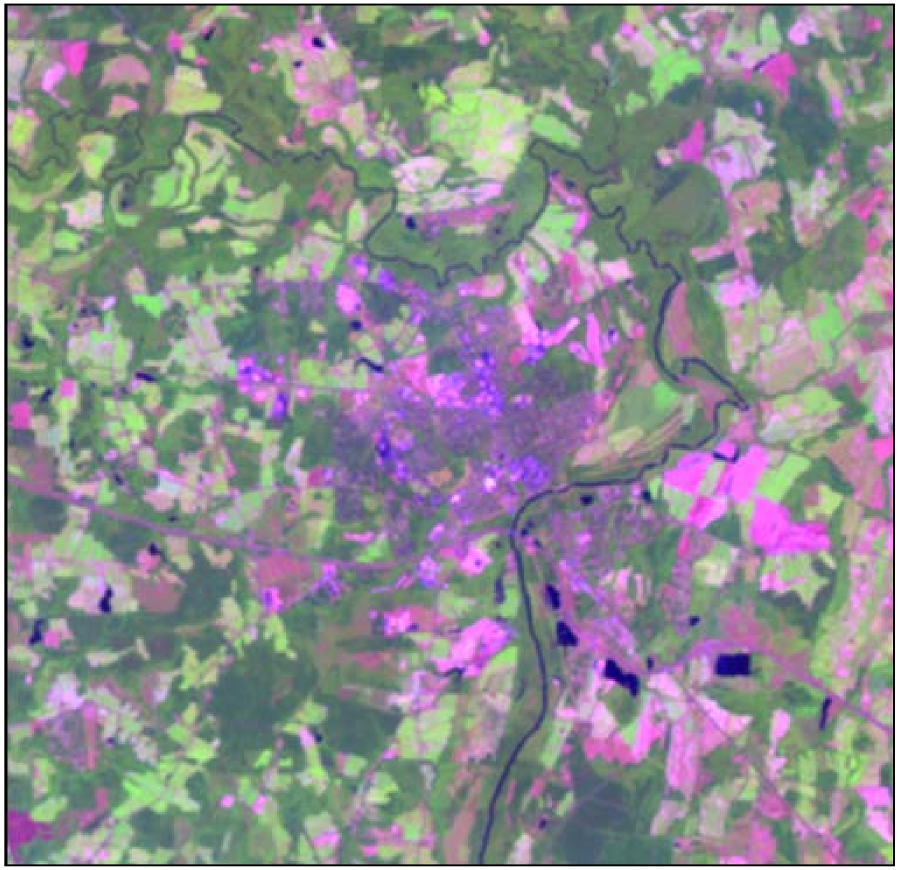
Figure 7.8 The moving window concept: (*a*) projection of 3 × 3 pixel window in image being processed; (*b*) movement of window along a line from pixel to pixel; (*c*) movement of window from line to line. (Adapted from [168].)

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC



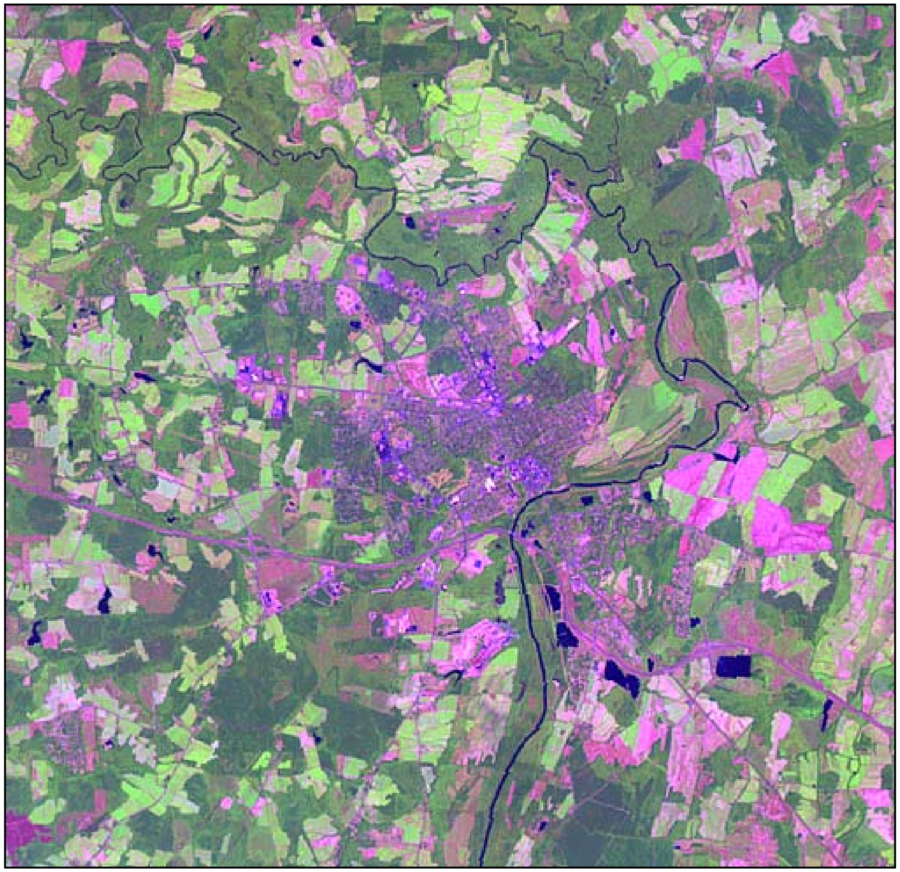
Normal Image



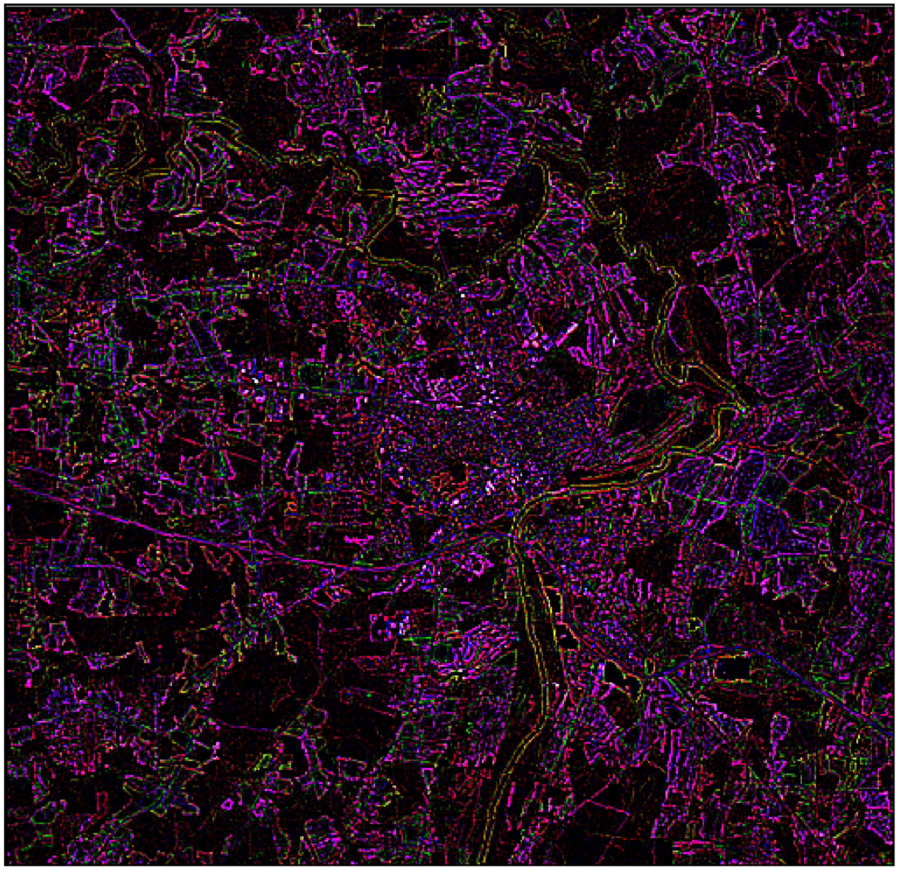
Smoothing Filter

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC



Sharpening Filter



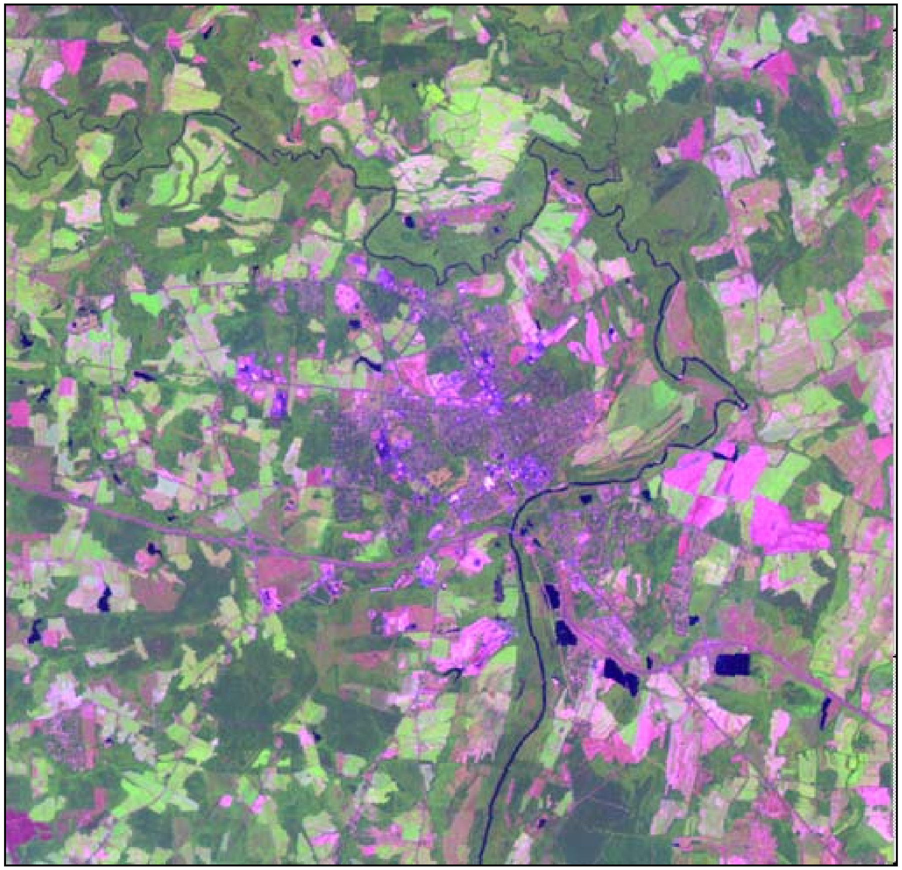
Edge Detection

Spectral Enhancements

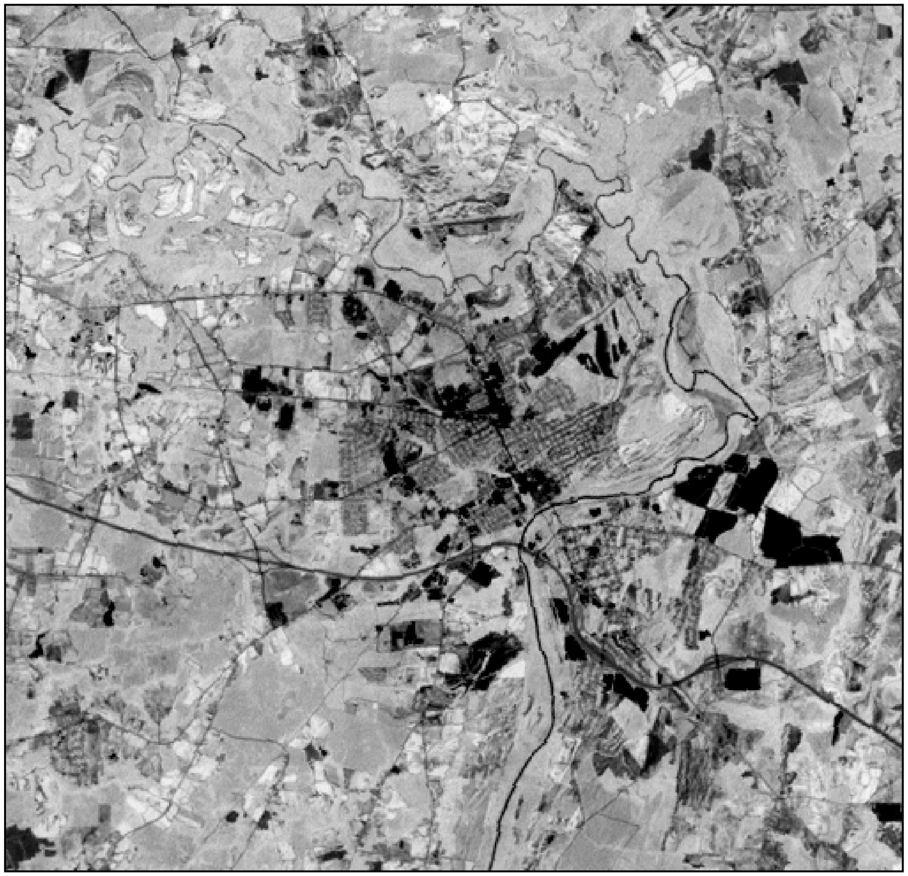
- Can take ratios or other **combinations of multiple input bands** to produce indices, e.g.:
- **Normalized Difference Vegetation Index (NDVI)**
  - Designed to contrast heavily-vegetated areas with areas containing little vegetation, by taking advantage of vegetation's strong absorption of red and reflection of near infrared:
  - NDVI = (NIR-R) / (NIR + R)
- **Surface temperature (T_s)** from IR bands using Price (1984):
  - T_S = TIR1 + 3.33 (TIR1 – TIR2)
    - Wavelengths: TIR1 = 10.8 μm, TIR2 = 11.9 μm

Spatial Enhancements

Landsat TM 543 False Color Image of Tarboro, NC



Normal Image



NDVI

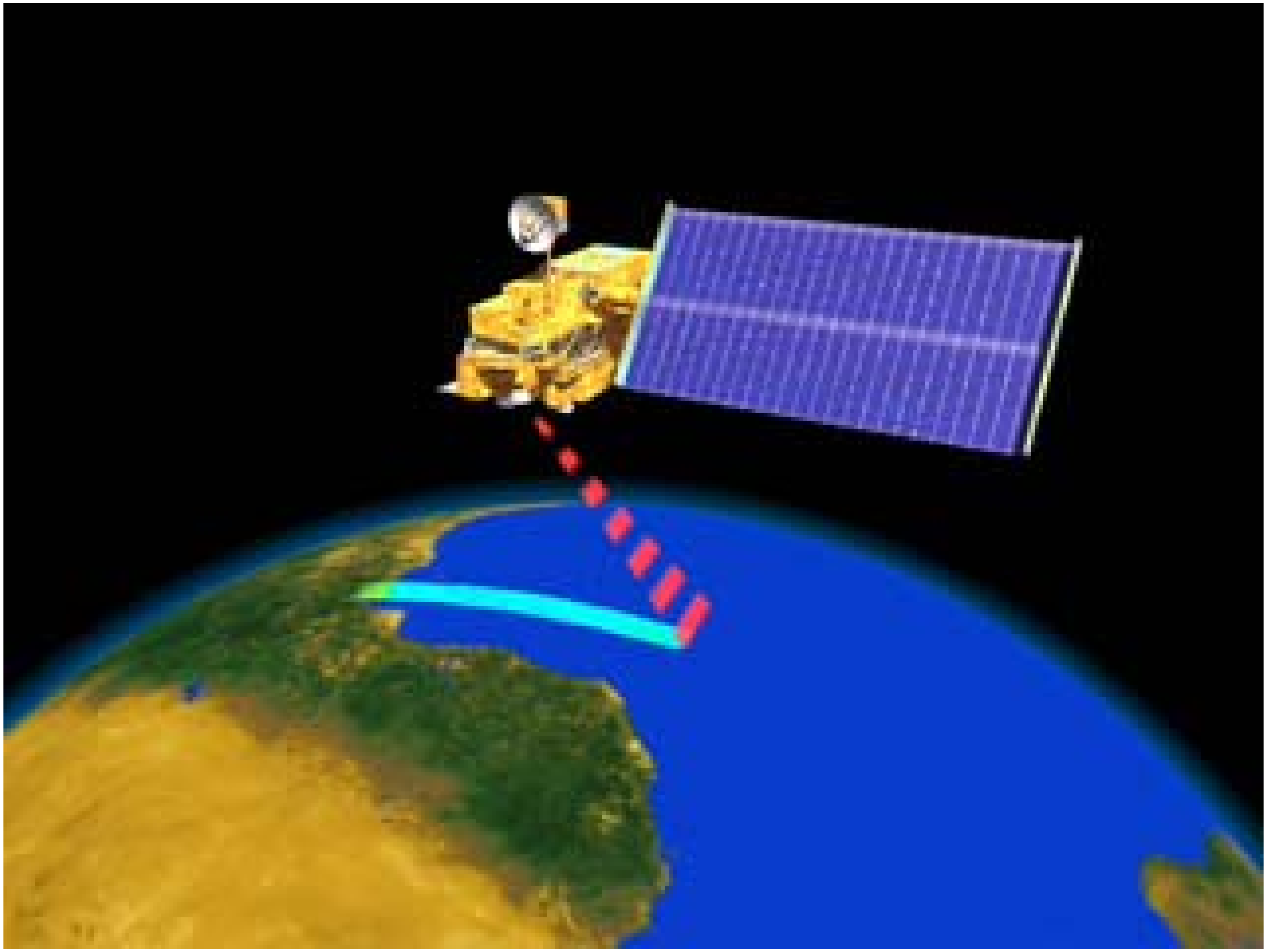
AVHRR

•**AVHRR (Advanced Very High Resolution Radio-meter)** is also a joint venture between NASA and NOAA, and this sensor has been present on many platforms

•AVHRR images **water vapor** in the atmosphere and **surface temperatures**, and does so at a spatial resolution of 1.1 km pixels at nadir, and uses a sun-synchronous orbit that has these satellites image the entire surface of the Earth every 12 hours

•Because AVHRR has **red and near infrared bands**, along with short-wave infrared and thermal infrared bands, it can be used for **vegetation studies** in addition to the applications described above

MODIS Orbit



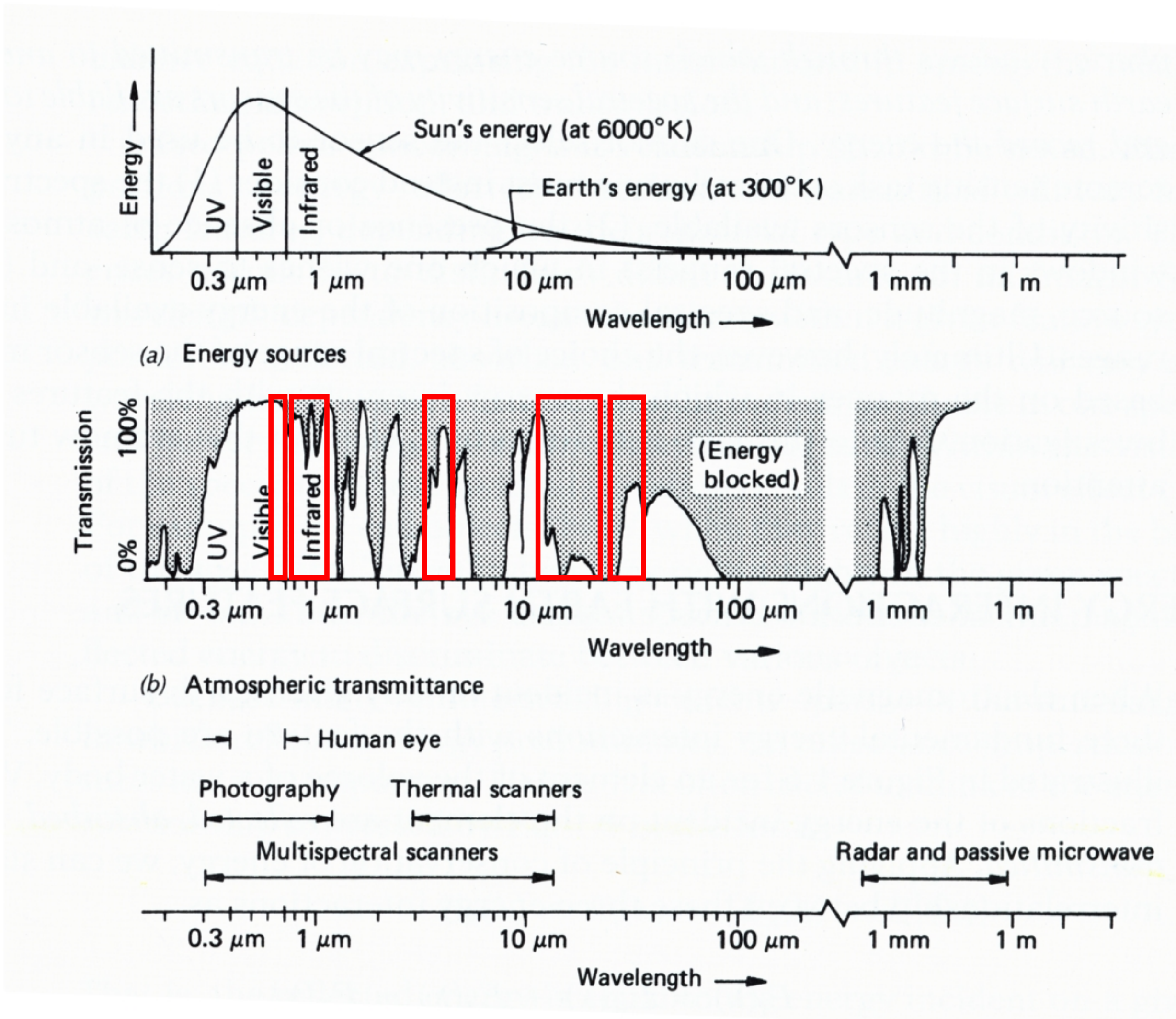
AVHRR Characteristics

TABLE 6.9 Characteristics of NOAA-6 to -15 Missions

Parameter	NOAA-6, -8, -10, -12, and 15	NOAA-7, -9, -11, and -14[a]
Launch	6/27/79, 3/28/83, 9/17/86, 5/14/91, 5/13/98	6/23/81, 12/12/84, 9/24/88, 12/30/94
Altitude, km	833	870
Period of orbit, min	101	102
Orbit inclination	98.7°	98.9°
Orbits per day	14.2	14.1
Distance between orbits	25.6°	25.6°
Day-to-day orbital shift[b]	5.5° E	3.0° E
Orbit repeat period (days)[c]	4–5	8–9
Scan angle from nadir	±55.4°	±55.4°
Optical field of view, mrad	1.3	1.3
IFOV at nadir, km	1.1	1.1
IFOV off-nadir maximum, km		
Along track	2.4	2.4
Across track	6.9	6.9
Swath width	2400 km	2400 km
Coverage	Every 12 hr	Every 12 hr
Northbound equatorial crossing (P.M.)	7:30	1:30–2:30
Southbound equatorial crossing (A.M.)	7:30	1:30–2:30
AVHRR spectral channels, μm		
1	0.58–0.68	0.58–0.68
2	0.72–1.10	0.72–1.10
3	3.55–3.93[d]	3.55–3.93
4	10.5–11.50	10.3–11.30
5	Channel 4 repeat[e]	11.5–12.50

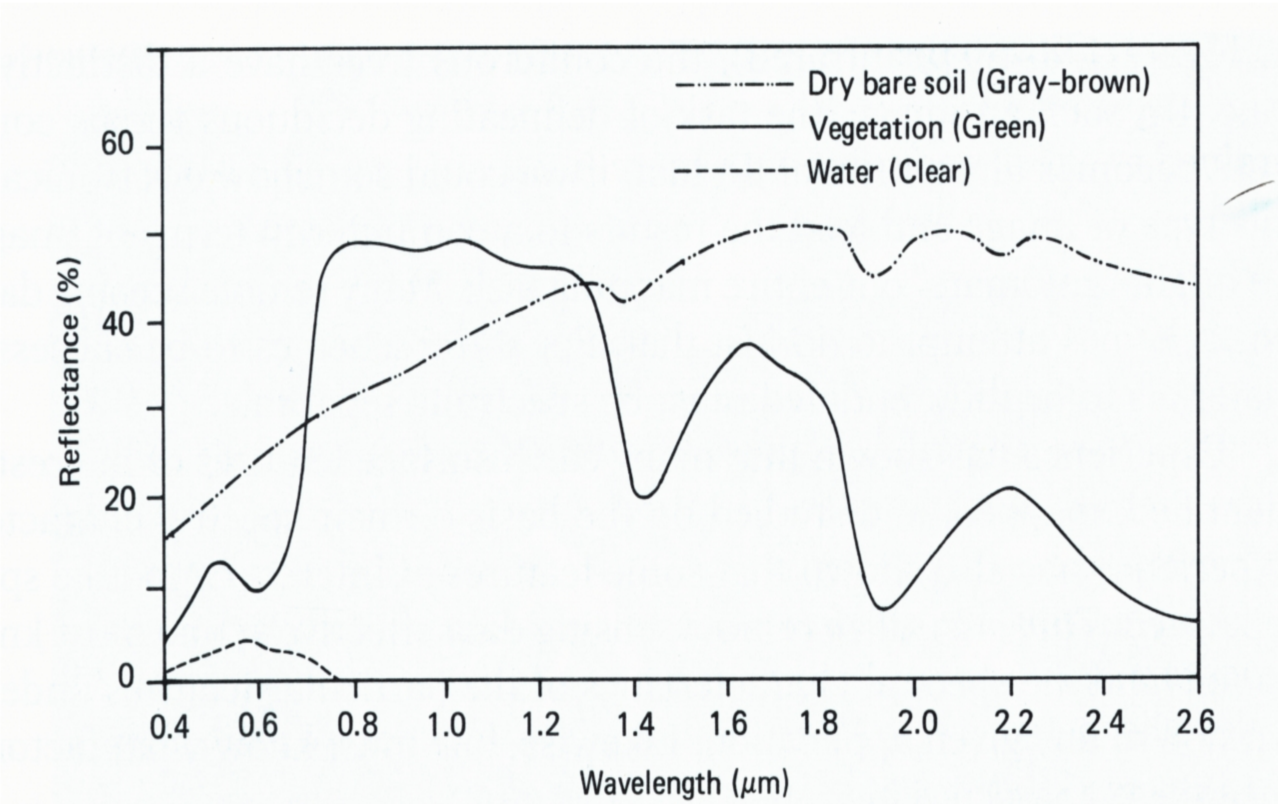
[a]NOAA-13 failed due to a short circuit in its solar array.
[b]Satellite differences due to differing orbital alignments.
[c]Caused by orbits per day not being integers.
[d]NOAA-15 includes two separate channels: 3A (1.58–1.64 μm) and 3B (3.55–3.93 μm).
[e]NOAA-12 and -15 include a separate channel 5.

AVHRR Bands



Energy
UV
Visible
Infrared
Sun's energy (at 6000°K)
Earth's energy (at 300°K)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(a) Energy sources
Transmission
100%
0%
UV
Visible
Infrared
(Energy blocked)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(b) Atmospheric transmittance
Human eye
Photography
Thermal scanners
Multispectral scanners
Radar and passive microwave
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength

Normalized Difference Vegetation Index



$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

NDVI [-1,1]

•Vegetation has a **strong contrast in reflectance** between red and near infrared EMR, and NDVI takes advantage of this to **sense the presence/density of vegetation**

NDVI from AVHRR

Feb 27-Mar 12

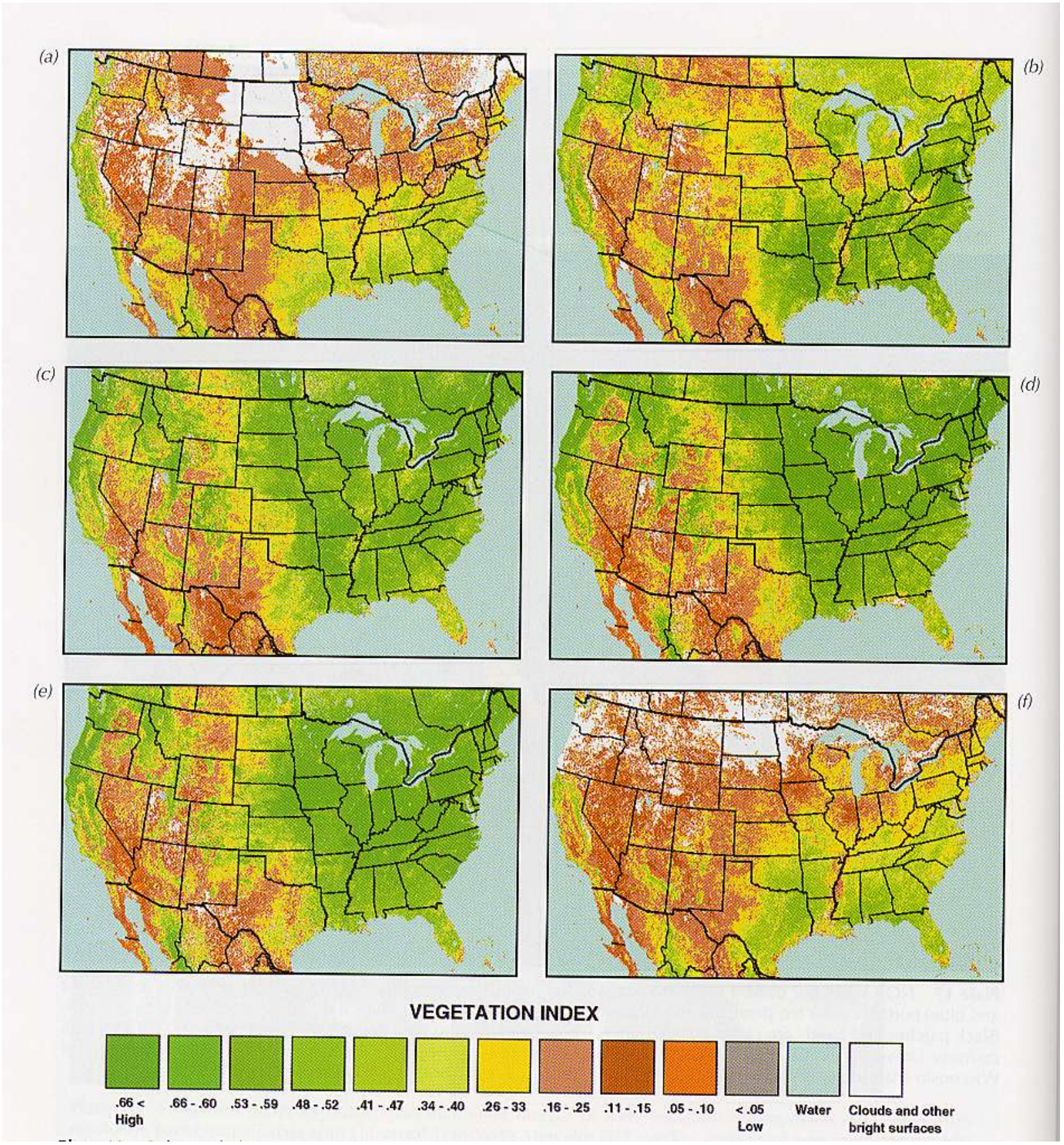
Apr 24-May 7

Jun 19-Jul 2

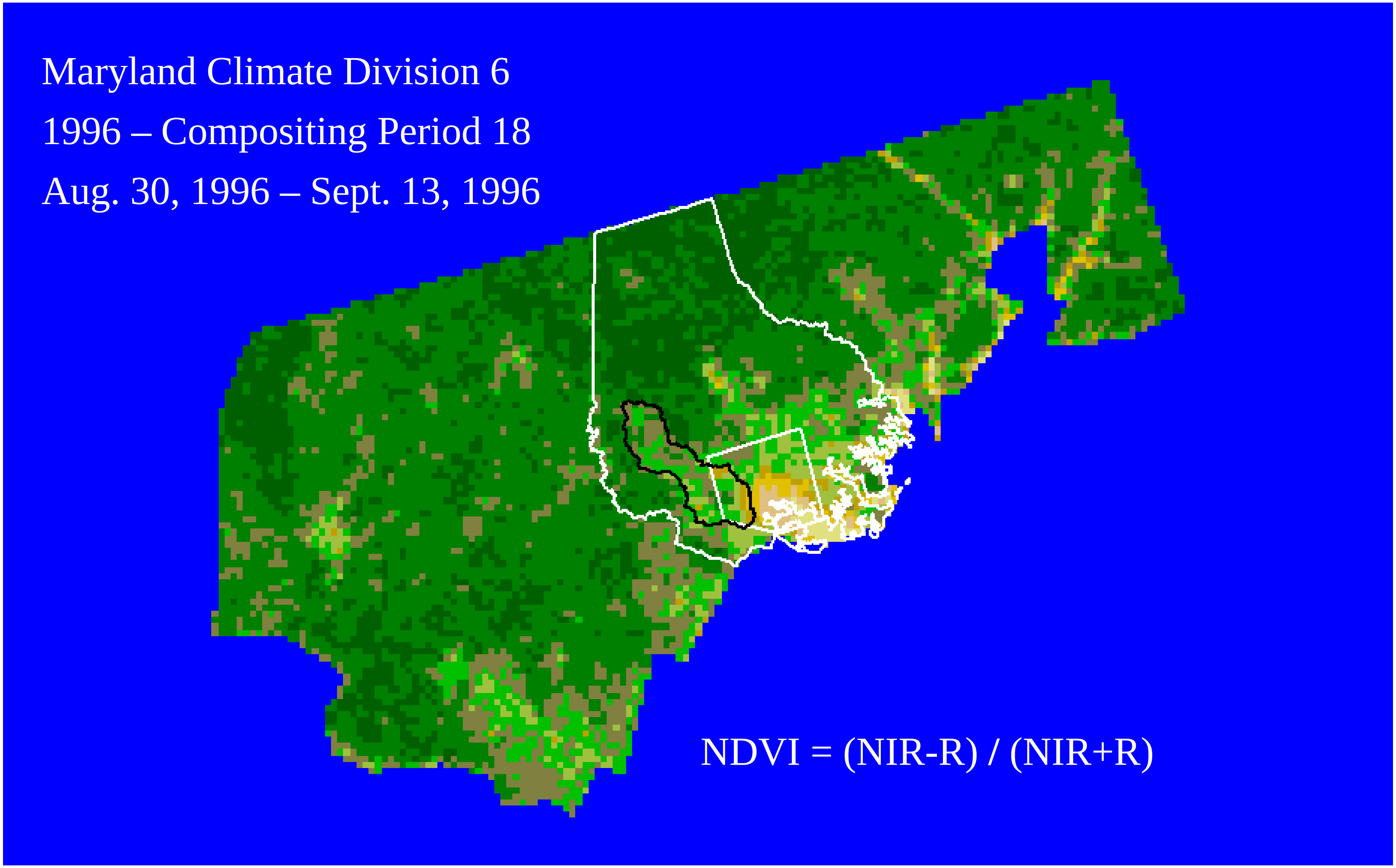
Jul 17-Jul 30

Aug 14-Aug 27

Nov 6- Nov19



AVHRR Satellite Imagery - NDVI

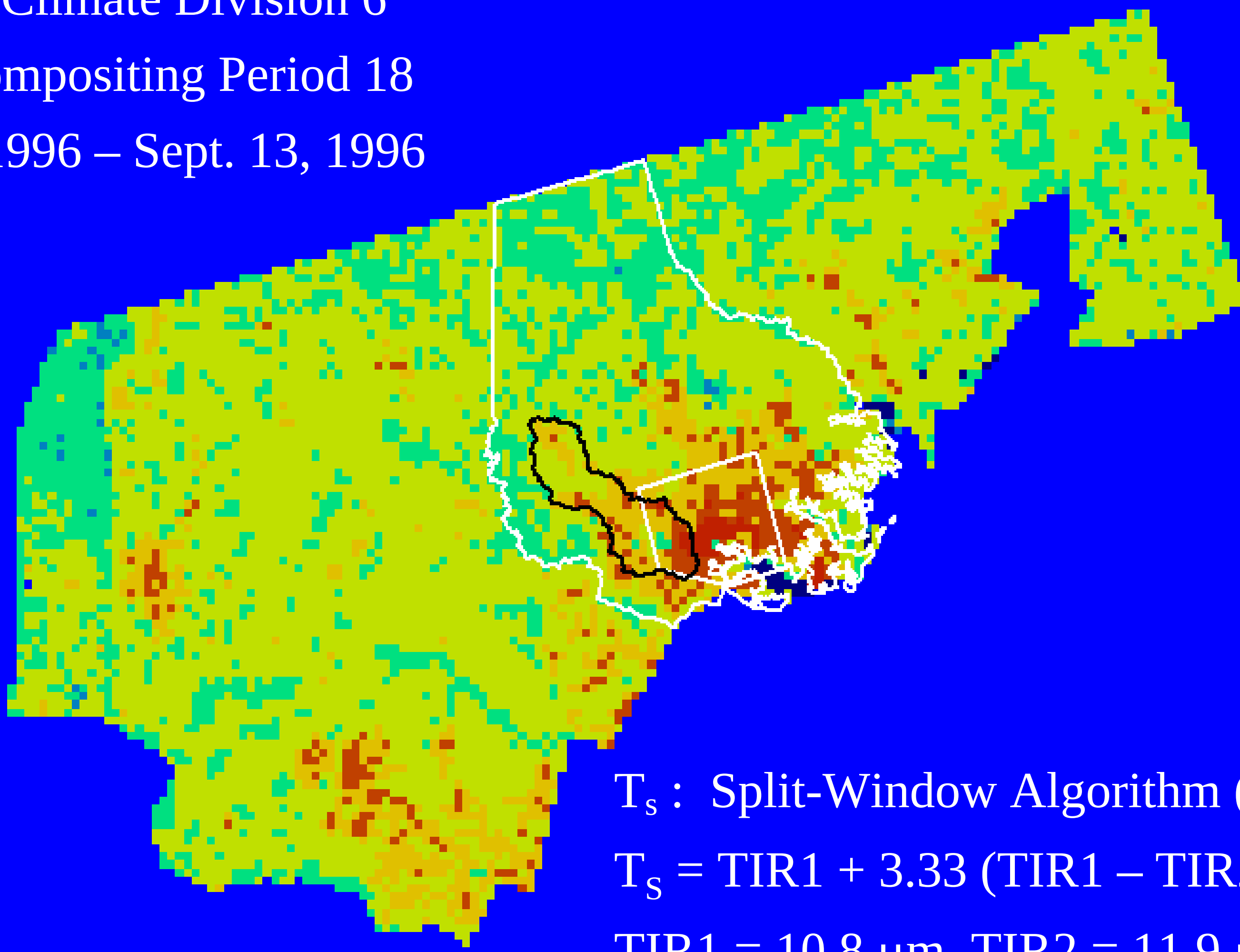


AVHRR Satellite Imagery - T_s

Maryland Climate Division 6

1996 – Compositing Period 18

Aug. 30, 1996 – Sept. 13, 1996

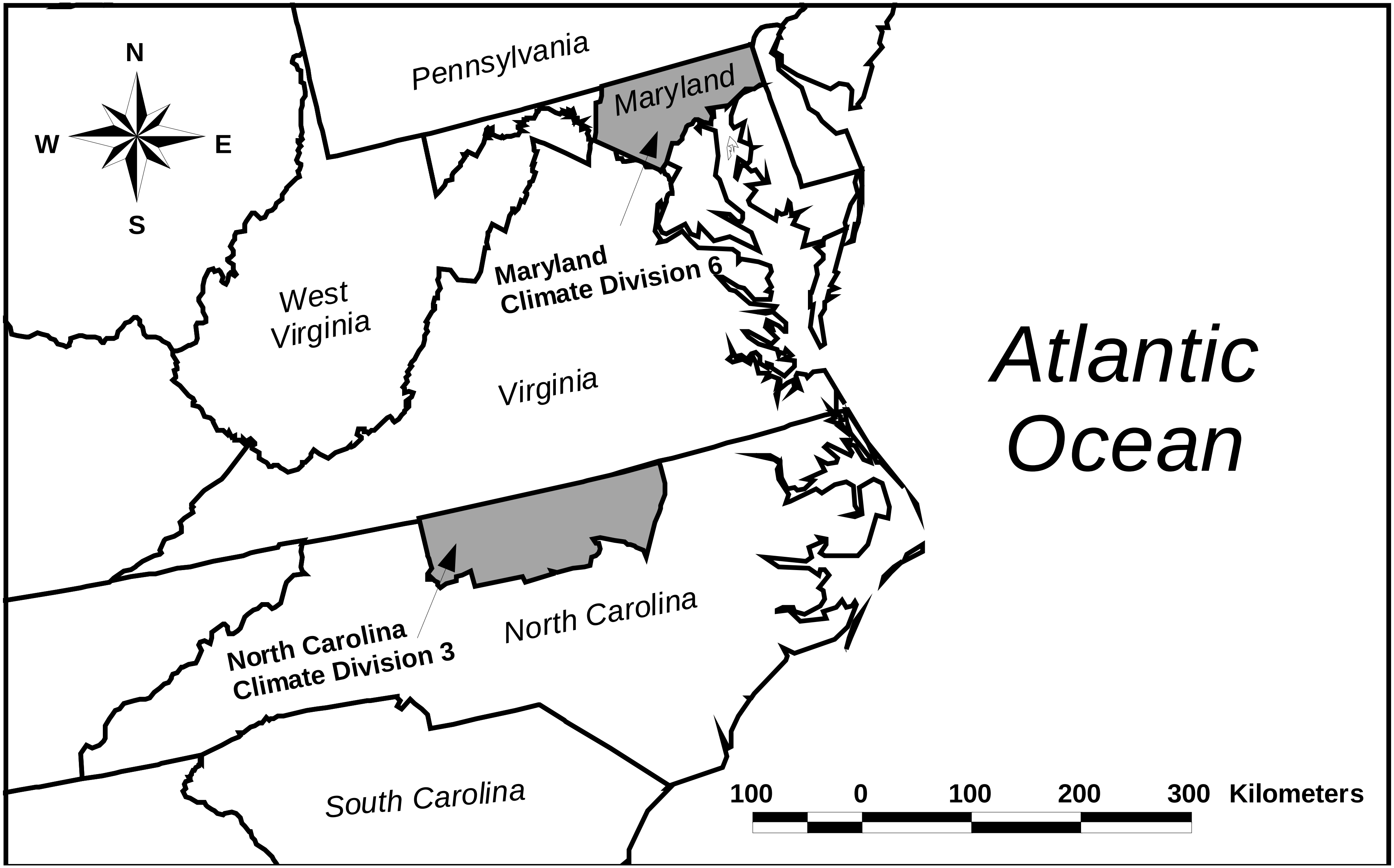


T_s : Split-Window Algorithm (Price 1984)

$T_S = TIR1 + 3.33\ (TIR1 - TIR2)$

TIR1 = 10.8 µm, TIR2 = 11.9 µm

Study Climate Divisions



MODIS LULC In Climate Divisions