Geography 551:
Principles of Remote Sensing

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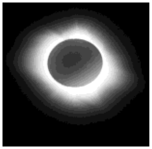
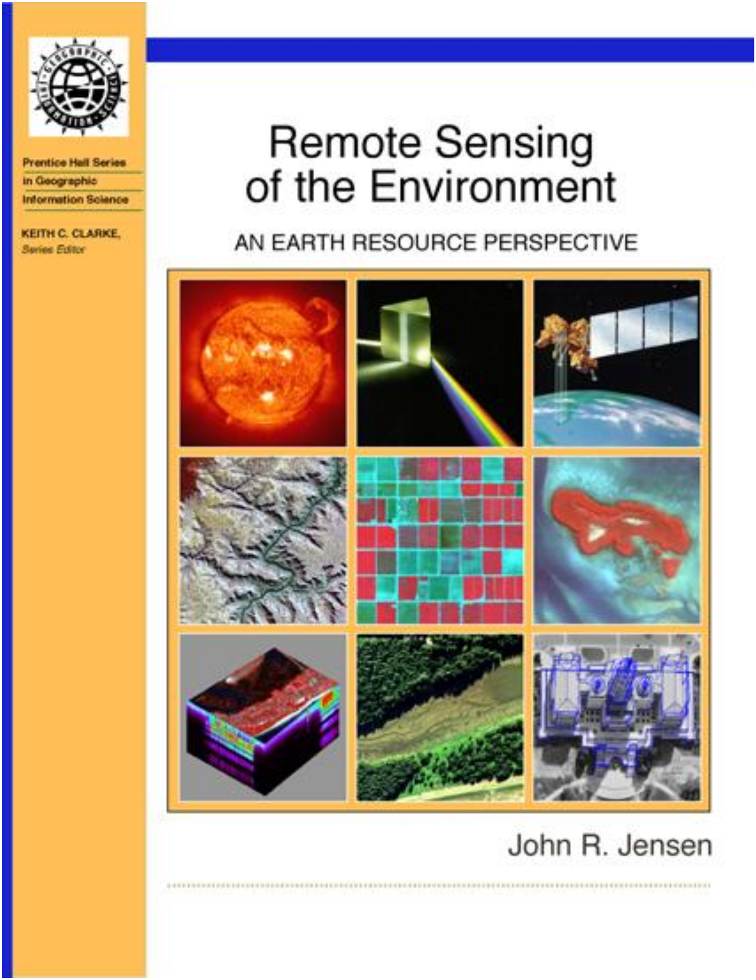


Geography 551:
Principles of Remote Sensing

Required text:



Prentice Hall Series in Geographic Information Science

KEITH C. CLARKE,
Series Editor

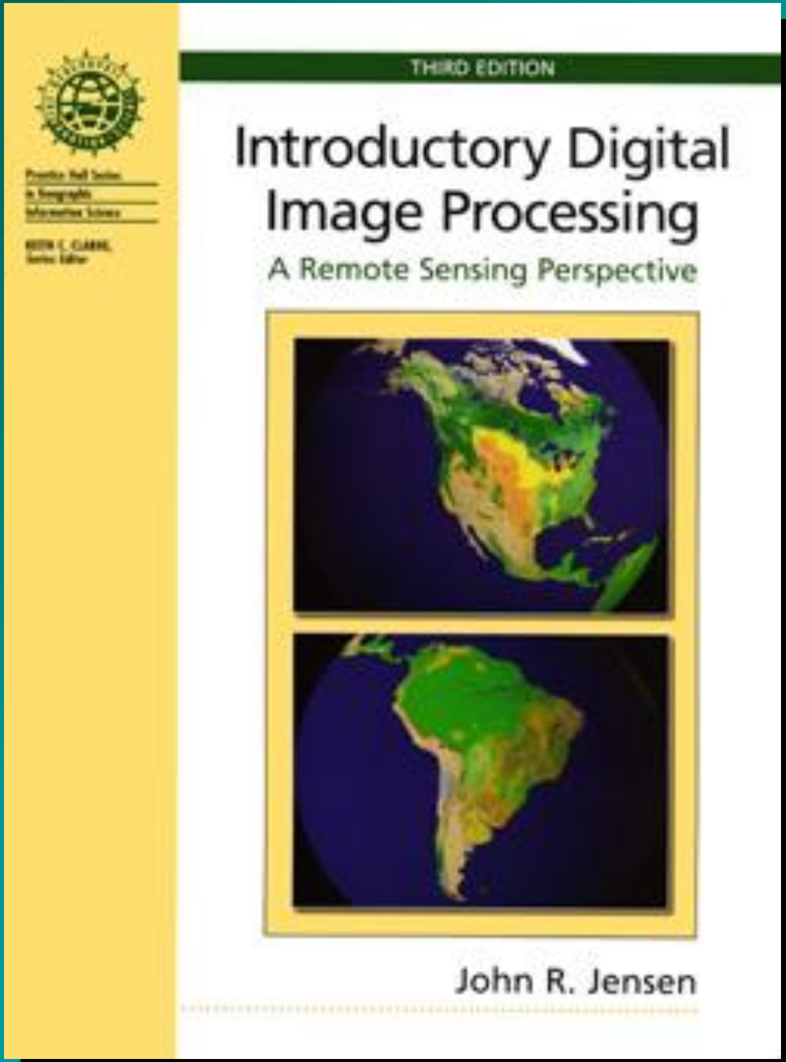
Remote Sensing
of the Environment

AN EARTH RESOURCE PERSPECTIVE

John R. Jensen

Jensen, 2007

Text used in Geography 751: Digital Image Processing



THIRD EDITION

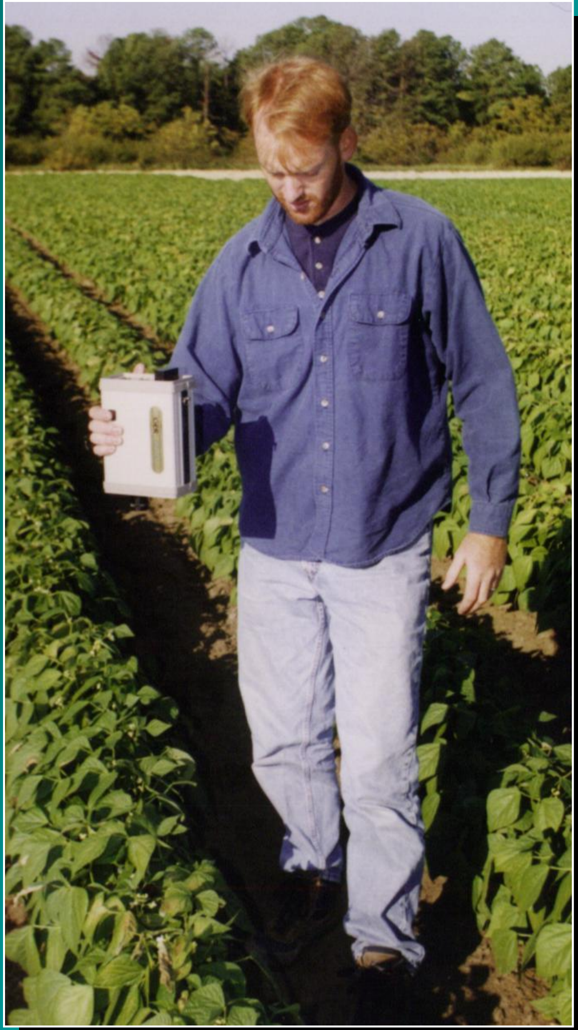
Introductory Digital Image Processing

A Remote Sensing Perspective

John R. Jensen

In situ Measurement in Support of Remote Sensing Measurement

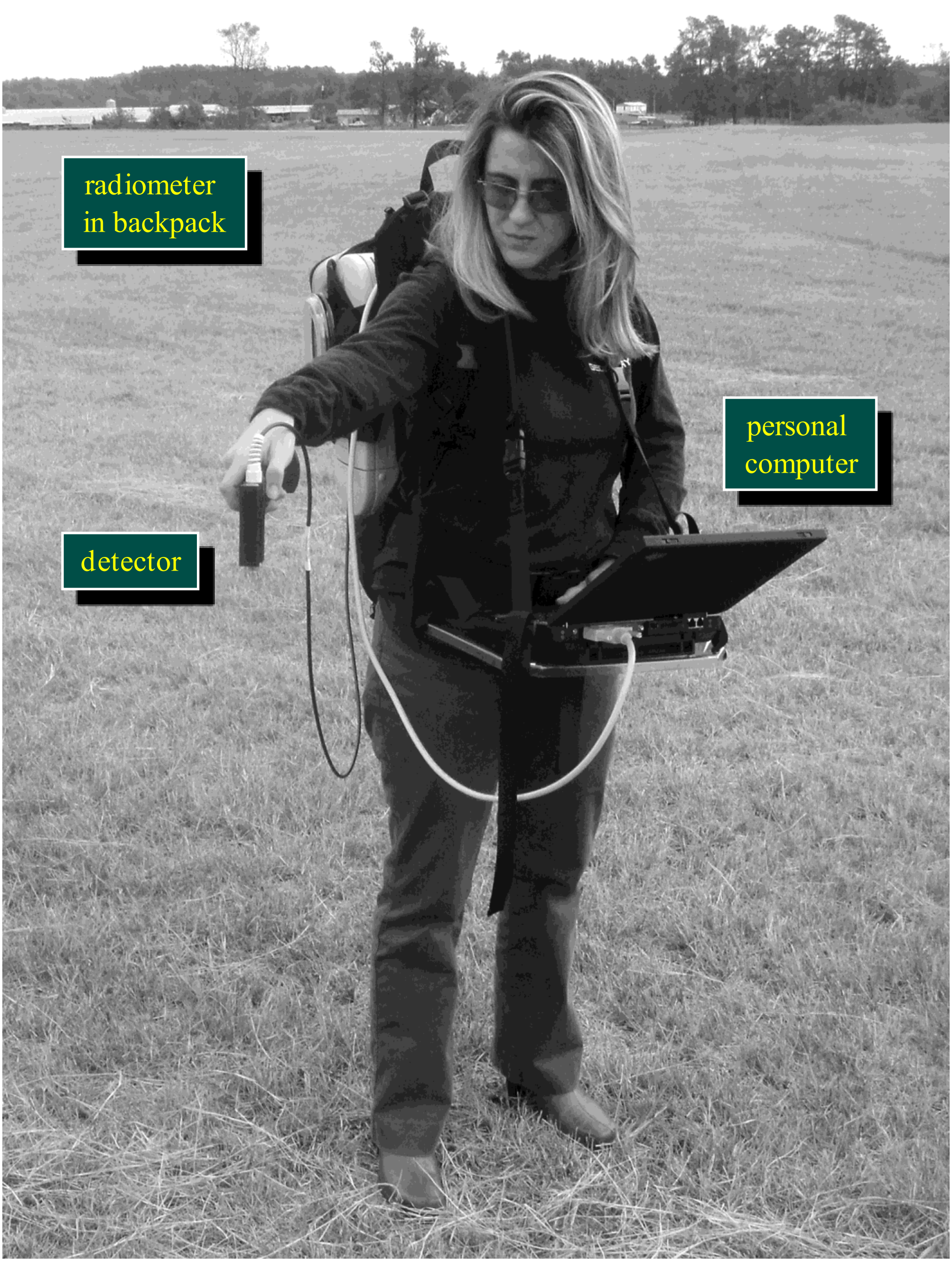
In situ ceptometer leaf-area-index (LAI) measurement



In situ spectroradiometer measurement of soybeans

Jensen, 2007

Spectral Reflectance Measurement using a Spectroradiometer



Jensen, 2007

In Situ Data Collection

a. Spectroradiometer measurement.

b. Global positioning system (GPS) measurement.

Jensen, 2007

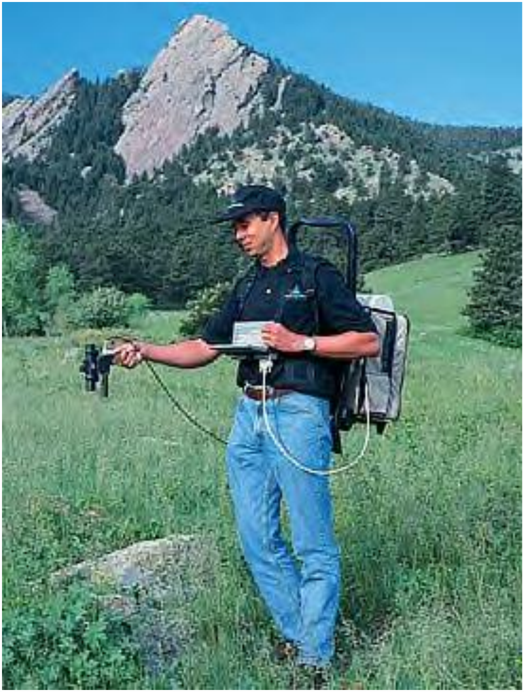
In situ Measurement in Support of Remote Sensing Measurement

To be of greatest value, the original remotely sensed data must usually be calibrated in two distinct ways:

1) It should be geometrically (x,y,z) and radiometrically (e.g, to percent reflectance) calibrated so that remotely sensed data obtained on different dates can be compared with one another.

2) The remotely sensed data must usually be calibrated (compared) with what is on the ground in terms of biophysical (e.g., leaf-area-index, biomass) or cultural characteristics (e.g., land use/cover, population density).

Fieldwork is necessary to achieve both of these objectives . Thus, a person who understands how to collect meaningful field data about the phenomena under investigation is much more likely to use the remote sensing science wisely.



In situ spectroradiometer measurement

Ground Reference Information

It is a misnomer to refer to *in situ* data as *ground truth data*. Instead, we should refer to it simply as *in situ ground reference data*, and acknowledge that it also contains error.

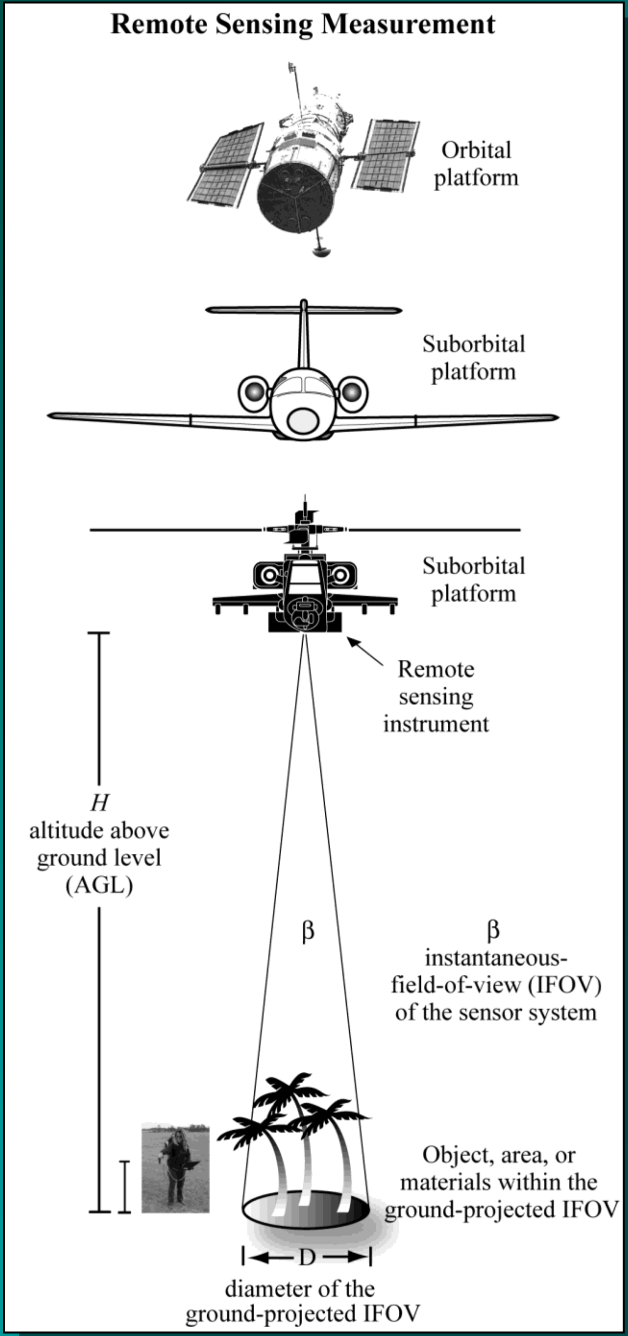
Jensen, 2007

Problems Associated with *In Situ* Data Collection

Scientists can collect data in the field using biased procedures often referred to as *method-produced error*. Such error can be introduced by:

- *sampling design* does not capture the spatial variability of the phenomena under investigation (i.e., some phenomena or geographic areas are oversampled while others are undersampled);
- *improper operation* of *in situ* measurement instruments; or
- uncalibrated *in situ* measurement instruments.

Jensen, 2007



Remote sensing:

"the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study" (Colwell, 1997).

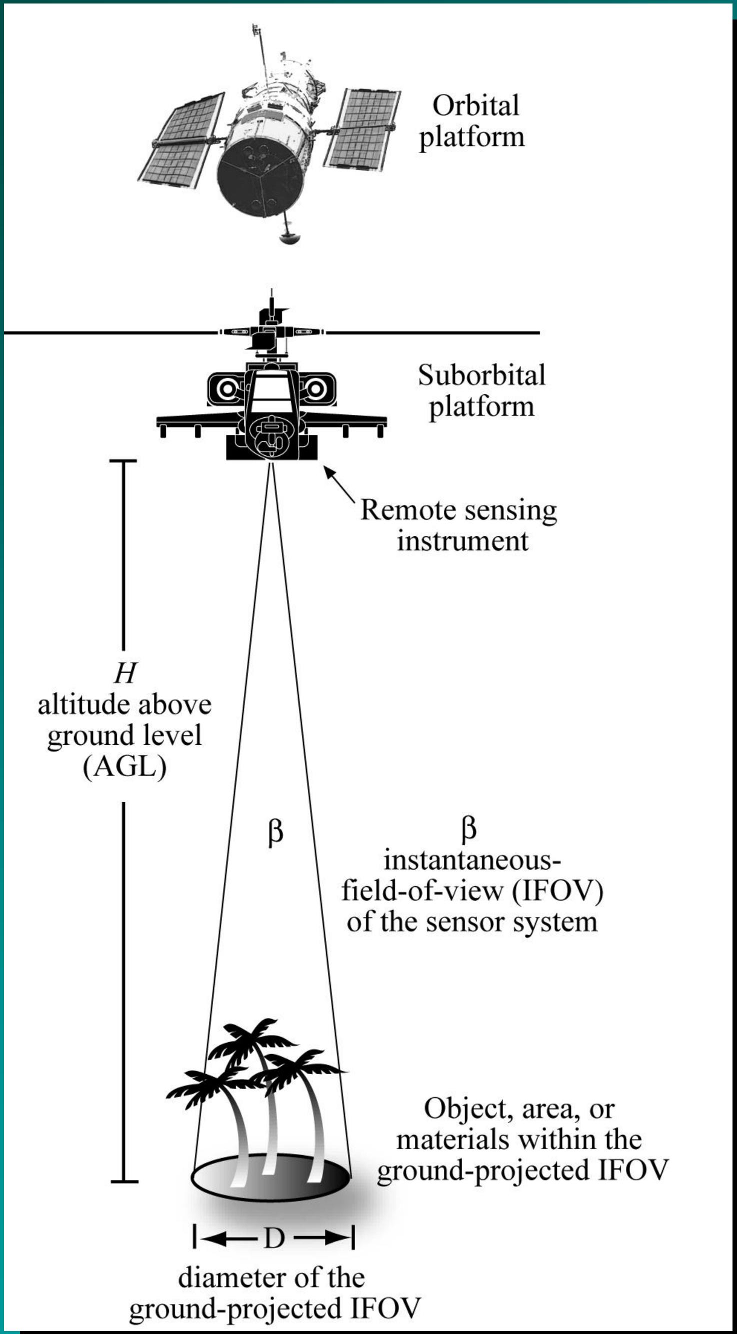
Jensen, 2007

Remote Sensing Data Collection

ASPRS adopted a combined formal definition of *photogrammetry* and *remote sensing* as (Colwell, 1997):

> "the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems".

Jensen, 2007



A remote sensing instrument collects information about an object or phenomenon within the instantaneous-field-of-view (IFOV) of the sensor system without being in direct physical contact with it. The sensor is located on a suborbital or satellite platform.

Jensen, 2004

Observations About Remote Sensing

Is Remote Sensing a Science?

A *science* is defined as the broad field of human knowledge concerned with facts held together by *principles* (rules). Scientists discover and test facts and principles by the scientific method, an orderly system of solving problems. Scientists generally feel that any subject that humans can study by using the scientific method and other special rules of thinking may be called a science. The sciences include 1) *mathematics* and *logic*, 2) the *physical sciences*, such as physics and chemistry, 3) the *biological sciences*, such as botany and zoology, and 4) the *social sciences*, such as geography, sociology, and anthropology.

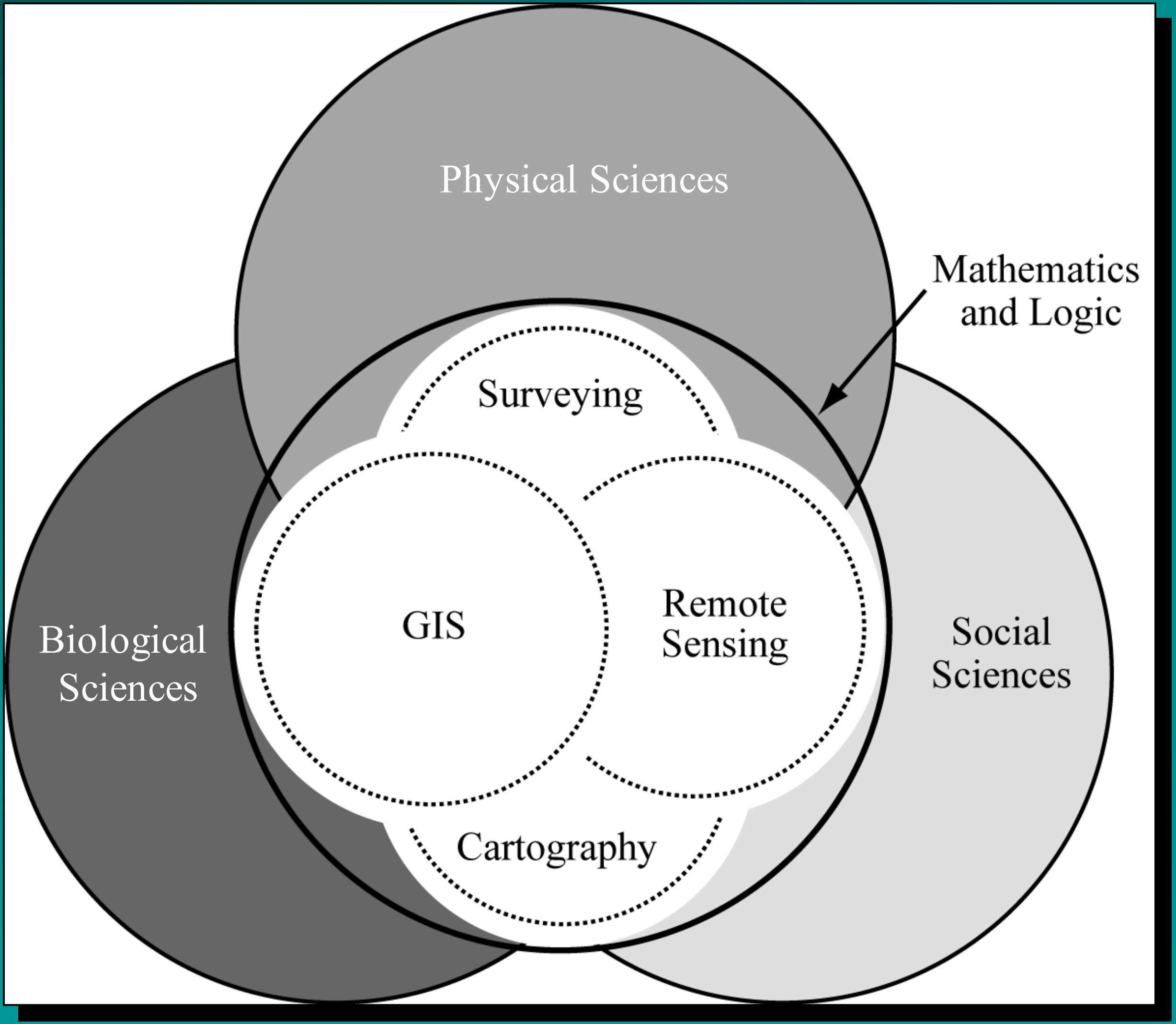
Jensen, 2007

Observations About Remote Sensing

Remote sensing is a tool or technique similar to mathematics. Using sensors to measure the amount of electromagnetic radiation (EMR) exiting an object or geographic area from a distance and then extracting valuable information from the data using mathematically and statistically based algorithms is a *scientific* activity. It functions in harmony with other *spatial* data-collection techniques or tools of the *mapping sciences*, including cartography and geographic information systems (GIS) (Clarke, 2001).

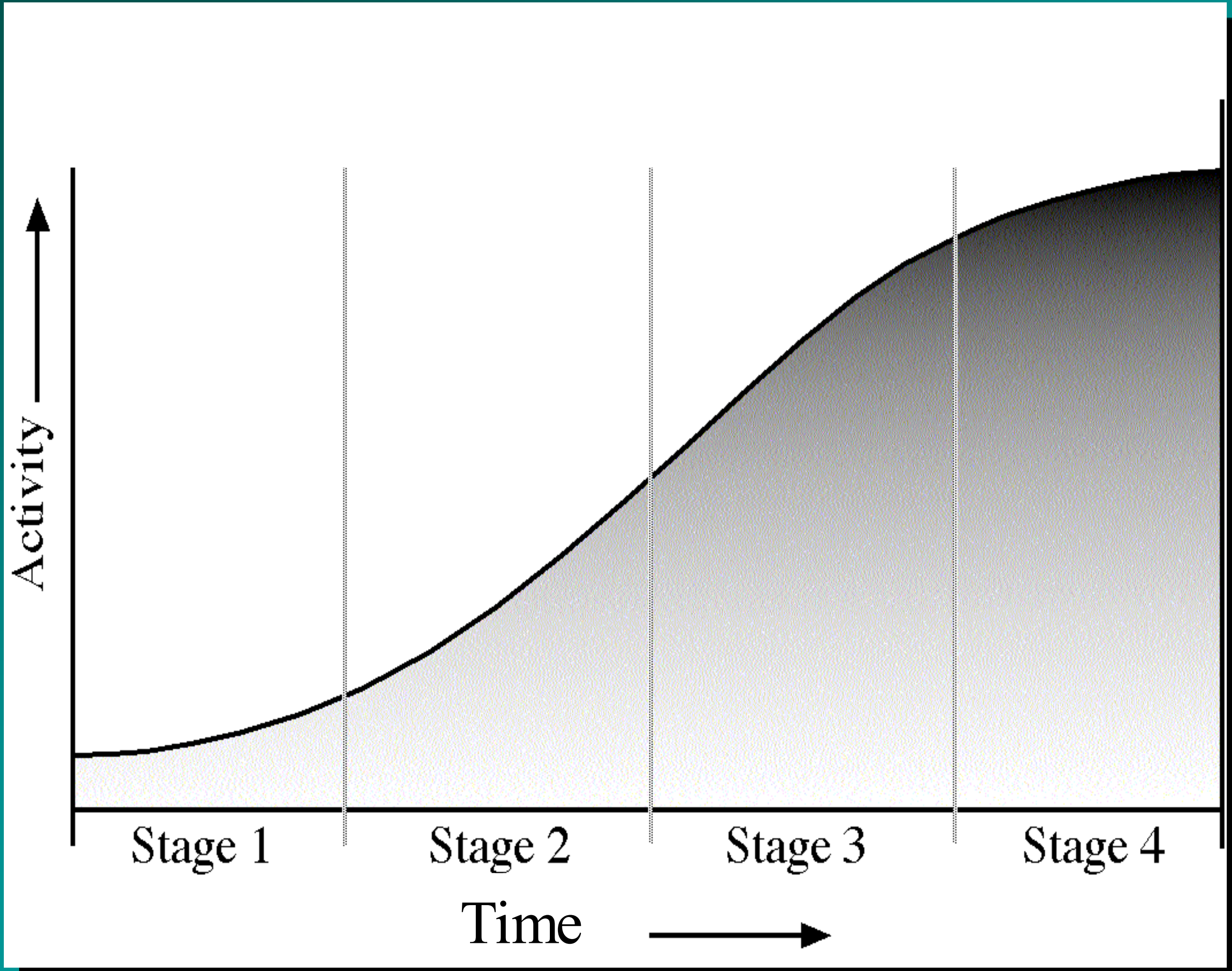
Jensen, 2000; 2004

Interaction Model Depicting the Relationships of the Mapping Sciences as they relate to Mathematics and Logic, and the Physical, Biological, and Social Sciences



Jensen, 2007

Developmental Stages of a Scientific Discipline



Jensen, 2007

Major Milestones in Remote Sensing

1600 and 1700s
1687 - Sir Isaac Newton's *Principia* summarizes basic laws of mechanics

1800s
1826 - Joseph Nicephore Niepce takes first photograph
1839 - Louis M. Daguerre invents positive print daguerrotype photography
1839 - William Henry Fox Talbot invents Calotype negative/positive process
1855 - James Clerk Maxwell postulates additive color theory
1858 - Gaspard Felix Tournachon takes aerial photograph from a balloon
1860s - James Clerk Maxwell puts forth electromagnetic wave theory
1867 - The term *photogrammetry* is used in a published work
1873 - Herman Vogel extends sensitivity of emulsion dyes to longer wavelengths, paving the way for near-infrared photography

1900
1903 - Airplane invented by Wright Brothers (Dec 17)
1903 - Alfred Maul patents a camera to obtain photographs from a rocket

1910s
1910 - International Society for Photogrammetry (ISP) founded in Austria
1913 - First International Congress of ISP in Vienna
1914 to 1918 - World War I photo-reconnaissance

1920s
1920 to 1930 - Increase civilian photointerpretation and photogrammetry
1926 - Robert Goddard launches liquid-powered rocket (Mar 16)

1930s
1934 - American Society of Photogrammetry (ASP) founded
1934 - *Photogrammetric Engineering* (ASP)
1938 - *Photogrammetria* (ISP)
1939 to 1945 - World War II photo-reconnaissance advances

1940s
1940s - RADAR invented
1940s - Jet aircraft invented by Germany
1942 - Kodak patents first false-color infrared film
1942 - Launch of German V-2 rocket by Wernher VonBraun (Oct 3)

1950s
1950s - Thermal infrared remote sensing invented by military
1950 - 1953 Korean War aerial reconnaissance
1953 - *Photogrammetric Record* (Photogrammetric Society, U.K.)
1954 - Westinghouse, Inc. develops side-looking airborne radar system
1955 to 1956 - U.S. Genetrix balloon reconnaissance program
1956 to 1960 - Central Intelligence Agency U-2 aerial reconnaissance program
1957 - Soviet Union launched *Sputnik* satellite (Oct 4)
1958 - United States launched *Explorer 1* satellite (Jan 31)

1960s
1960s - Emphasis primarily on visual image processing
1960s - Michigan Willow Run Laboratory active — evolved into ERIM
1960s - First *International Symposium on Remote Sensing of Environment* at Ann Arbor, MI
1960s - Purdue Laboratory for Agricultural Remote Sensing (LARS) active
1960s - Forestry Remote Sensing Lab at U.C. Berkeley (Robert Colwell)
1960s - ITC– Delft initiates photogrammetric education for foreign students
1960s - Digital image processing initiated at LARS, Berkeley, Kansas, ERIM
1960s - Declassification of radar and thermal infrared sensor systems
1960 - 1972 United States COEONA spy satellite program
1960 - *Manual of Photo-interpretation* (ASP)
1960 - Term *remote sensing* introduced by Evelyn Pruitt and other U. S. Office of Naval Research personnel
1961 - Yuri Gagarin becomes first human to travel in space
1961 - 1963 Mercury space program
1962 - Cuban Missile Crisis — U-2 photo-reconnaissance shown to the public
1964 - SR-71 discussed in President Lyndon Johnson press briefing
1965 to 1966 - Gemini space program
1965 - *ISPRS Journal of Photogrammetry & Remote Sensing*
1969 - *Remote Sensing of Environment* (Elsevier)

1970s
1970s, 80s - Possible to specialize in remote sensing at universities
1970s - Digital image processing comes of age
1970s - Remote sensing integrated with geographic information systems
1972 - ERTS-1 (Earth Resource Technology Satellite) launched (NASA)
1973 - 1979 Skylab program (NASA)
1973 - *Canadian Journal of Remote Sensing* (Canadian RS Society)
1975 - ERTS-2 launched (renamed Landsat 2)
1975 - *Manual of Remote Sensing* (ASP)
1977 - METEOSAT-1 launched (European Space Agency)
1978 - Landsat 3 launched (NASA)
1978 - Nimbus 7 launched - Coastal Zone Color Scanner
1978 - TIROS-N launched with AVHRR sensor
1978 - SEASAT launched (NASA Jet Propulsion Laboratory)

1980s
1980s - AAG Remote Sensing Specialty Group > 500 members
1980s - Commercialization attempted and failed – EOSAT, Inc.
1980 - ISP becomes Intl. Soc. for Photogrammetry & Remote Sensing
1980 - *International Journal of Remote Sensing* (Remote Sensing Society)
1980 - European Space Agency (ESA) created (Oct 30)
1980 - *IEEE Transactions Geoscience and Remote Sensing* (GRSS Society)
1981 - First *International Geoscience and Remote Sensing Symposium*
1981 - NASA Space Shuttle program initiated (STS-1)
1981 - Space Shuttle Imaging Radar (SIR - A) launched (NASA)
1982 - Landsat 4 - Thematic Mapper and MSS launched (NASA)
1983 - *Manual of Remote Sensing*, 2nd Ed. (ASP)
1984 - Landsat 5 - Thematic Mapper launched (NASA)
1984 - Space Shuttle Imaging Radar (SIR-B) launched (NASA)
1986 - SPOT 1 launched (SPOT Image, Inc.)
1986 - *Geocarto International* initiated (Geocarto International Center)
1989 - *The Earth Observer* (NASA Goddard Space Flight Center)

1990s
1990s - Digital soft-copy photogrammetry comes of age
1990s - University degree programs in remote sensing available
1990s - Light Detection and Ranging (LIDAR) comes of age
1990s - NASA assists commercial remote sensing (Stennis Space Center)
1990s - Increased use of hyperspectral and LIDAR sensors
1990 - SPOT 2 launched (Spot Image, Inc.)
1991 - "Mission to Planet Earth" initiated (NASA)
1991 - ERS-1 launched (European Space Agency)
1992 - *U.S. Land Remote Sensing Policy Act* becomes law
1993 - Landsat 6 does not achieve orbit (EOSAT, Inc.)
1993 - SPOT 3 launched (SPOT Image, Inc).
1993 - Space Shuttle Imaging Radar (SIR-C) (NASA)
1995 - RADARSAT-1 launched (Canadian)
1995 - ERS-2 launched (European Space Agency)
1995 - IRS-1C launched (5 × 5 m) (Indian Remote Sensing Program)
1995 - CORONA imagery declassified, transferred to National Archives
1996 - *Manual of Photographic Interpretation*, 2nd Ed. (ASPRS)
1997 - Earlybird does not achieve orbit (EarthWatch, Inc.)
1998 - Mission to Planet Earth becomes Earth Science Enterprise (NASA)
1998 - *Manual of Remote Sensing - Radar* (ASPRS)
1998 - SPOT 4 launched (SPOT Image, Inc.)
1999 - *Manual of Remote Sensing - Geosciences* (ASPRS)
1999 - Landsat 7 ETM^+ launched (NASA; April 15)
1999 - IKONOS does not achieve orbit (Space Imaging, Inc.; Apr 27)
1999 - IKONOS 2 launched (Space Imaging, Inc.; Sept 24)
1999 - *Terra* Earth observing system launched (NASA)
1999 - ImageSat launched (Israel ImageSat International)

2000 – 2006
2000 - New Millennium program initiated (NASA)
2001 - QuickBird launched (DigitalGlobe, Inc.)
2002 - *Aqua* Earth observing system launched (NASA)
2002 - ENVISAT launched (European Space Agency)
2002 - Object-oriented image segmentation algorithms introduced
2003 - OrbView-3 launched (ORBIMAGE, Inc.)
2004 - *GIScience & Remote Sensing* (Bellwether Publishing, Inc.)
2004 - *Manual of Photogrammetry*, 5th Ed. (ASPRS)
2005 - *Google Earth* serves DigitalGlobe and Landsat TM data
2006 - ORBIMAGE purchases Space Imaging and changes name to GeoEye

Jensen, 2007

Observations About Remote Sensing

Is Remote Sensing an Art?

Visual image interpretation brings to bear not only scientific knowledge but all of the *experience* that a person has obtained in a lifetime. The synergism of combining scientific knowledge with *real-world analyst experience* allows the interpreter to develop heuristic rules of thumb to extract information from the imagery. Some image analysts are superior to other image analysts because they 1) understand the scientific principles better, 2) are more widely traveled and have seen many landscape objects and geographic areas, and/or 3) have the ability to synthesize scientific principles and real-world knowledge to reach logical and correct conclusions. Thus, remote sensing image interpretation is both an *art* and a *science*.

Observations About Remote Sensing

Information about an Object or Area

Sensors can be used to obtain specific information about an object (e.g., the diameter of a cottonwood tree crown) or the geographic extent of a phenomenon (e.g., the boundary of a cottonwood stand). The EMR reflected, emitted, or back-scattered from an object or geographic area is used as a *surrogate* for the actual property under investigation. The electromagnetic energy measurements must be calibrated and turned into information using visual and/or digital image processing techniques.

Advantages of Remote Sensing

- Remote sensing is *unobtrusive* if the sensor *passively* records the EMR reflected or emitted by the object of interest. Passive remote sensing does not disturb the object or area of interest.

- Remote sensing devices may be programmed to collect data systematically, such as within a 9 × 9 in. frame of vertical aerial photography. This systematic data collection can remove the sampling bias introduced in some *in situ* investigations.

- Under controlled conditions, remote sensing can provide fundamental biophysical information, including *x*,*y* location, *z* elevation or depth, biomass, temperature, and moisture content.

Advantages of Remote Sensing

- Remote sensing–derived information is now critical to the successful modeling of numerous natural (e.g., water-supply estimation; eutrophication studies; nonpoint source pollution) and cultural (e.g., land-use conversion at the urban fringe; water-demand estimation; population estimation) processes.

Limitations of Remote Sensing

- The greatest limitation is that it is often *oversold*. *Remote sensing is not a panacea* that provides all the information needed to conduct physical, biological, or social science research. It provides some spatial, spectral, and temporal *information* of value in a manner that we hope is efficient and economical.

- *Human beings* select the appropriate remote sensing system to collect the data, specify the various resolutions of the remote sensor data, calibrate the sensor, select the platform that will carry the sensor, determine when the data will be collected, and specify how the data are processed. Human method-produced error may be introduced as the remote sensing instrument and mission parameters are specified.

Limitations of Remote Sensing

- Powerful *active* remote sensor systems that emit their own electromagnetic radiation (e.g., LIDAR, RADAR, SONAR) can be intrusive and affect the phenomenon being investigated. Additional research is required to determine how intrusive these active sensors can be.

- Remote sensing instruments may become *uncalibrated*, resulting in uncalibrated remote sensor data.

- Remote sensor data may be *expensive to collect and analyze*. Hopefully, the information extracted from the remote sensor data justifies the expense.

The Remote Sensing Process

The remote sensing data-collection and analysis procedures used for Earth resource applications are often implemented in a systematic fashion referred to as the *remote sensing process*.

The Remote Sensing Process

Statement of the Problem → **Data Collection** → **Data-to-Information Conversion** → **Information Presentation**

- **Formulate Hypothesis** (if appropriate)
- **Select Appropriate Logic**
  - Inductive and/or
  - Deductive
  - Technological
- **Select Appropriate Model**
  - Deterministic
    - Empirical
    - Knowledge-based
    - Process-based
  - Stochastic

- ***In Situ* Measurements**
  - Field (e.g., *x,y,z* from GPS, biomass, reflectance)
  - Laboratory (e.g., reflectance, leaf area index)
- **Collateral Data**
  - Digital elevation models
  - Soil maps
  - Surficial geology maps
  - Population density, etc.
- **Remote Sensing**
  - Passive analog
    - Frame camera
    - Videography
  - Passive digital
    - Frame camera
    - Scanners
      - Multispectral
      - Hyperspectral
    - Linear and area arrays
      - Multispectral
      - Hyperspectral
  - Active
    - Microwave (RADAR)
    - Laser (LIDAR)
    - Acoustic (SONAR)

- **Analog (Visual) Image Processing**
  - Using the *Elements of Image Interpretation*
- **Digital Image Processing**
  - Preprocessing
    - Radiometric Correction
    - Geometric Correction
  - Enhancement
  - Photogrammetric analysis
  - Parametric, such as
    - Maximum likelihood
  - Nonparametric, such as
    - Artificial neural networks
  - Nonmetric, such as
    - Expert systems
    - Decision-tree classifiers
    - Machine learning
  - Hyperspectral analysis
  - Change detection
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling
  - Scientific geovisualization
    - 1, 2, 3, and *n* dimensions
- **Hypothesis Testing**
  - Accept or reject hypothesis

- **Image Metadata**
  - Sources
  - Processing lineage
- **Accuracy Assessment**
  - Geometric
  - Radiometric
  - Thematic
  - Change detection
- **Analog and Digital**
  - Images
    - Unrectified
    - Orthoimages
  - Orthophotomaps
  - Thematic maps
  - GIS databases
  - Animations
  - Simulations
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3 dimensions

Jensen, 2007

Remote Sensing Data Collection

The amount of electromagnetic radiance, *L* (watts m^{-2} sr^{-1}; watts per meter squared per steradian) recorded within the IFOV of an optical remote sensing system (e.g., a picture element in a digital image) is a function of:

$$L = f\left(\lambda, s_{x,y,z}, t, \theta, P, \Omega\right)$$

where,

λ = wavelength (spectral response measured in various bands or at specific frequencies). Wavelength (λ) and frequency (υ) may be used interchangeably based on their relationship with the speed of light (*c*) where .

Jensen, 2007

Remote Sensing Data Collection

$s_{x,y,z}$ = x, y, z location of the picture element and its size (x, y)

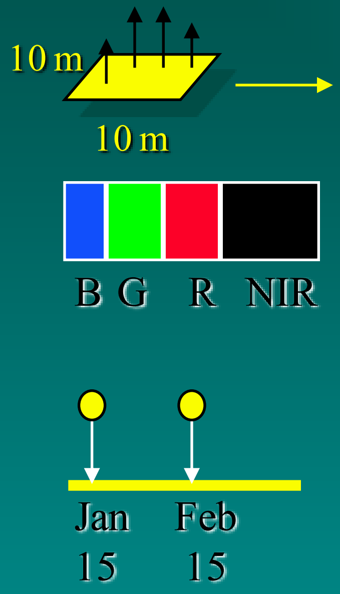
t = temporal information, i.e., when and how often the information was acquired

θ = set of angles that describe the geometric relationships among the radiation source (e.g., the Sun), the terrain target of interest (e.g., a corn field), and the remote sensing system

P = polarization of back-scattered energy recorded by the sensor

Ω = radiometric resolution (precision) at which the data (e.g., reflected, emitted, or back-scattered radiation) are recorded by the remote sensing system.

Remote Sensor Resolution



- **Spatial** - the size of the field-of-view, e.g. 10 x 10 m.
- **Spectral** - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared thermal infrared, microwave (radar).
- **Temporal** - how often the sensor acquires data, e.g. every 30 days.
- **Radiometric** - the sensitivity of detectors to small differences in electromagnetic energy.

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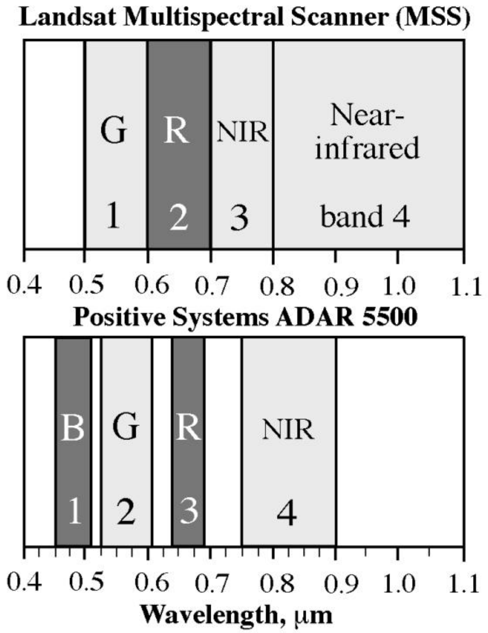
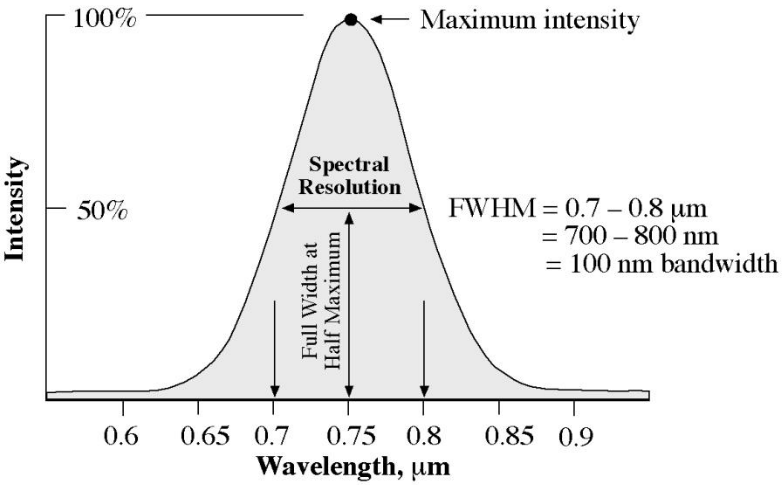
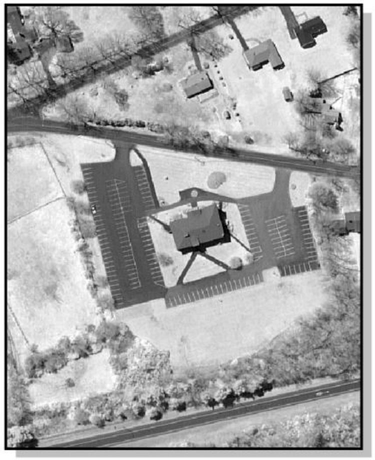
Spectral Resolution



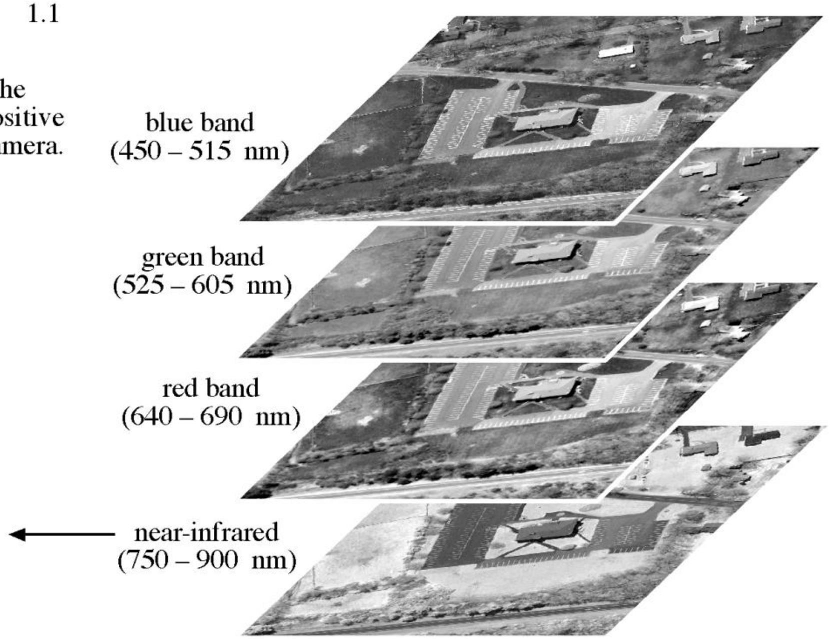
a. Nominal spectral resolution of the Landsat Multispectral Scanner and Positive Systems ADAR 5500 digital frame camera.



b. Precise bandpass measurement of a detector based on Full Width at Half Maximum (FWHM) criteria



c. Single band of ADAR 5500 data



d. Multispectral remote sensing

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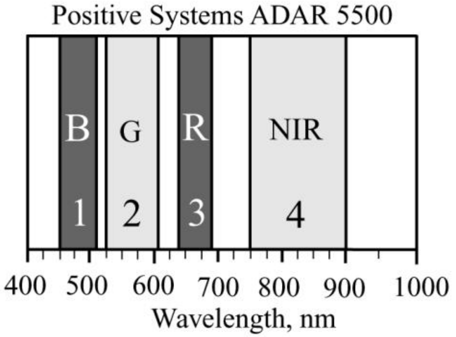
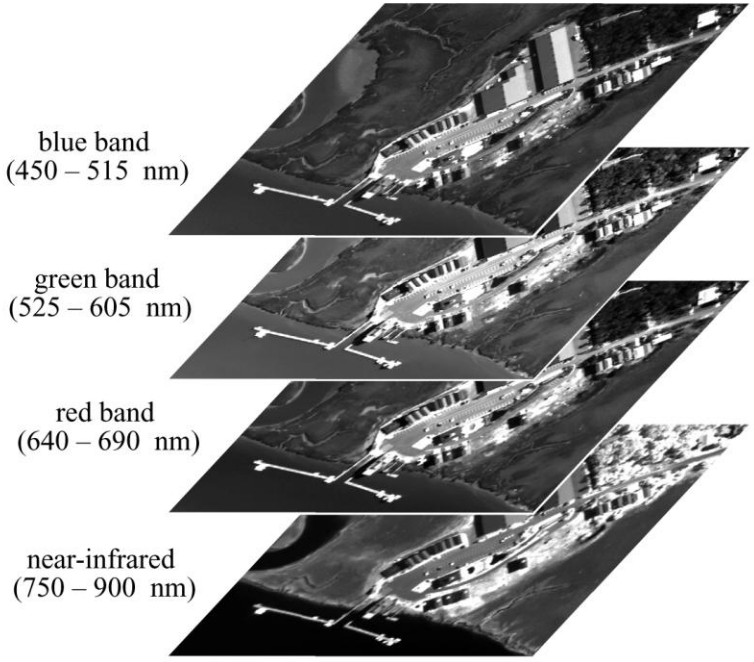
Marina in the Ace Basin, South Carolina

Spectral Resolution



a. Nominal spectral resolution of the Positive Systems ADAR 5500 digital frame camera.



b. Multispectral remote sensing

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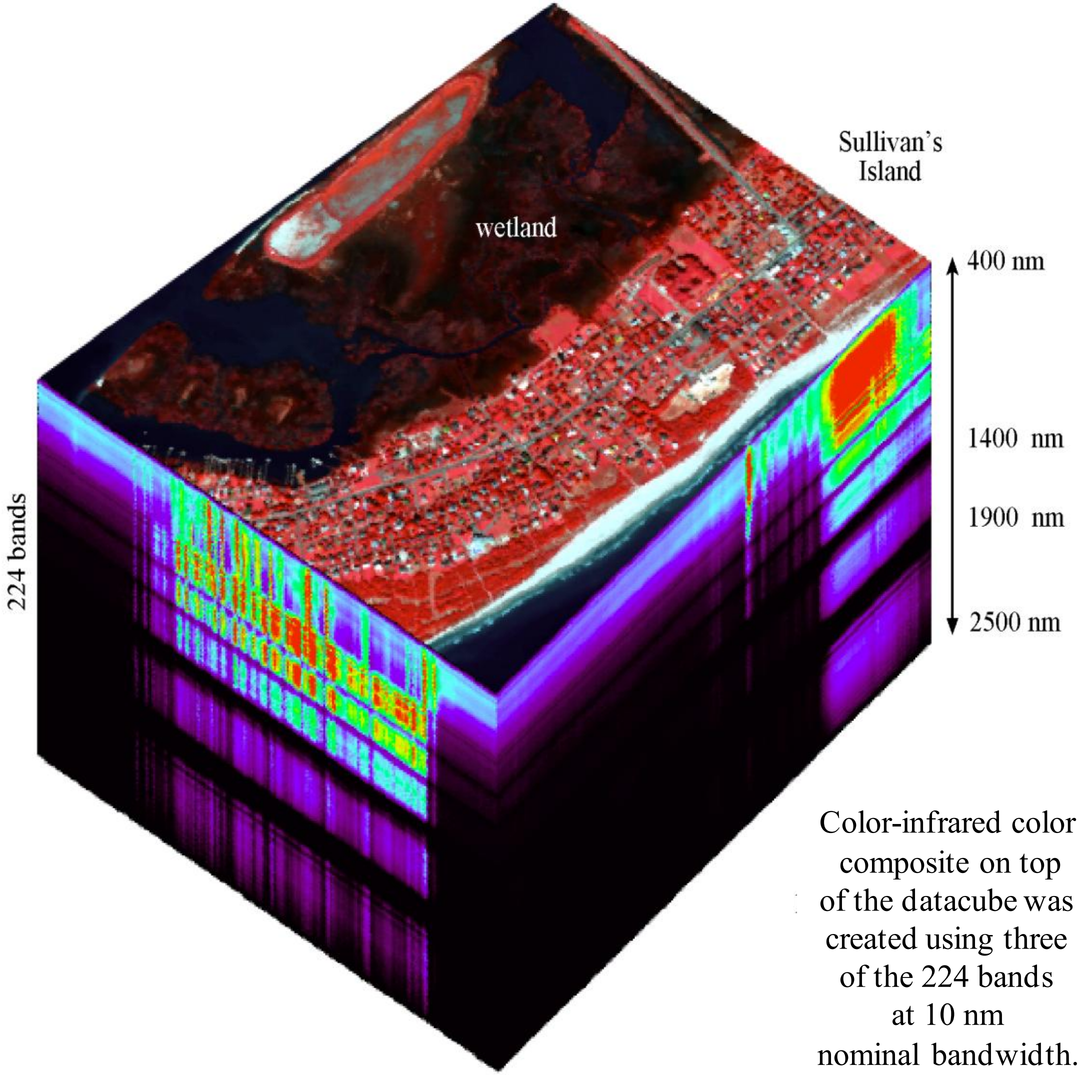
Spectral Resolution

Deciduous versus coniferous forest at 1 x 1 m recorded by Spatial Emerge digital camera in green, red, and near-infrared bands

Jensen, 2007

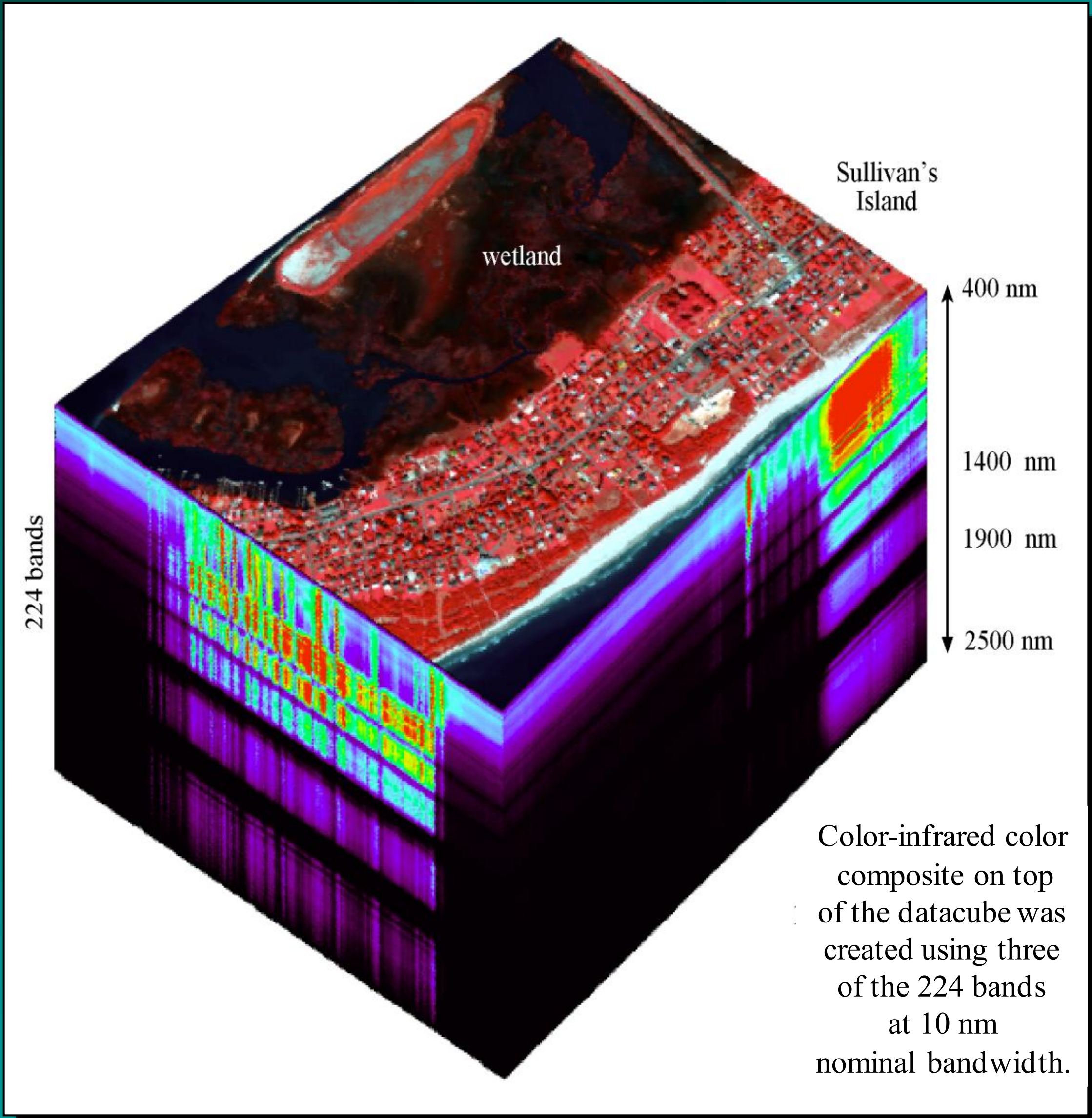
Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island Obtained on October 26, 1998



Color-infrared color composite on top of the datacube was created using three of the 224 bands at 10 nm nominal bandwidth.

Jensen, 2007

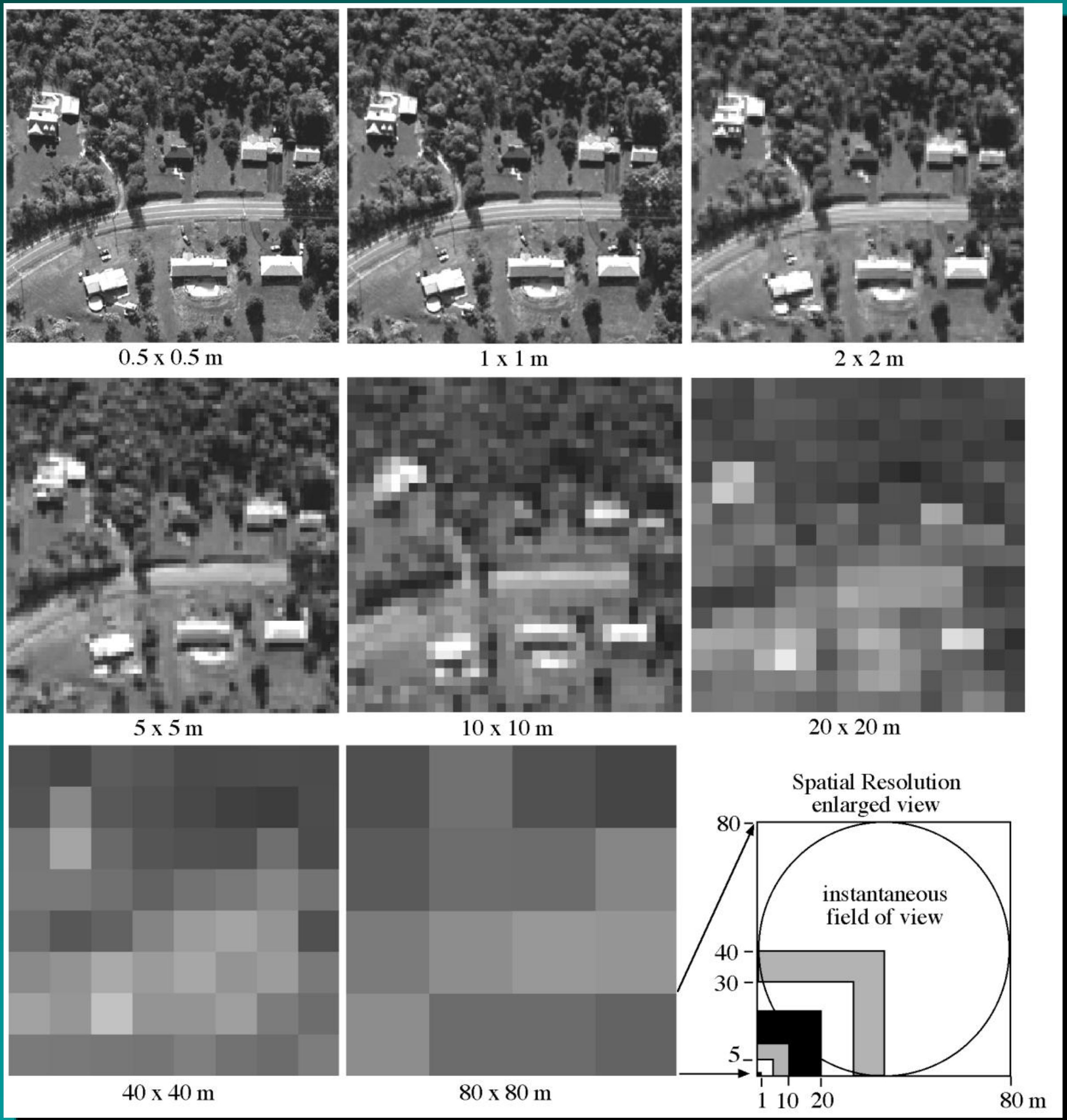
Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island Obtained on October 26, 1998



Color-infrared color composite on top of the datacube was created using three of the 224 bands at 10 nm nominal bandwidth.

Jensen, 2007

Spatial Resolution


0.5 x 0.5 m

1 x 1 m

2 x 2 m

5 x 5 m

10 x 10 m

20 x 20 m

40 x 40 m

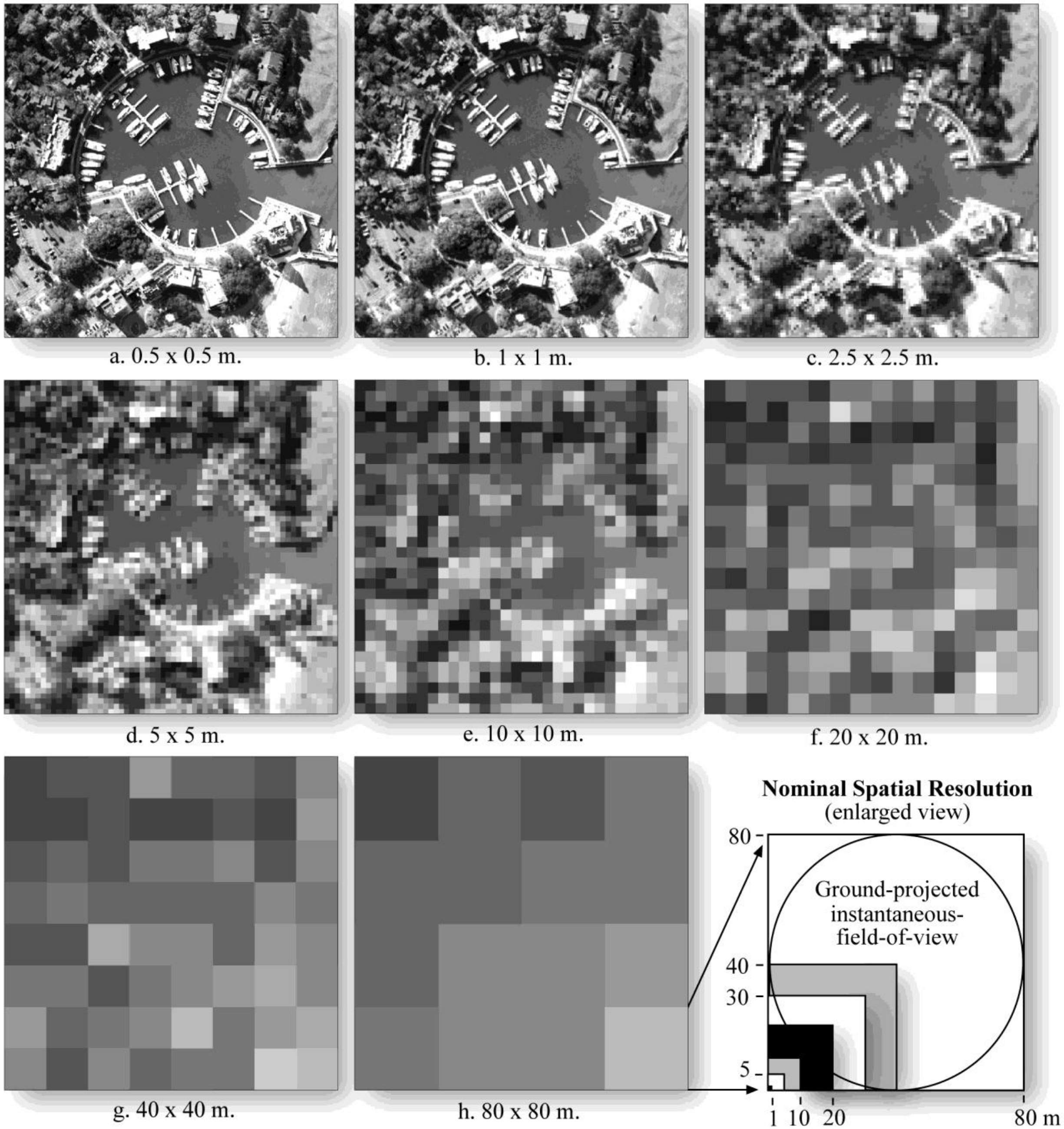
80 x 80 m

Imagery of residential housing in Mechanicsville, New York, obtained on June 1, 1998, at a nominal spatial resolution of
0.3 x 0.3 m (approximately 1 x 1 ft.) using a digital camera.

Jensen, 2007

Spatial Resolution

Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions



a. 0.5 x 0.5 m.

b. 1 x 1 m.

c. 2.5 x 2.5 m.

d. 5 x 5 m.

e. 10 x 10 m.

f. 20 x 20 m.

g. 40 x 40 m.

h. 80 x 80 m.

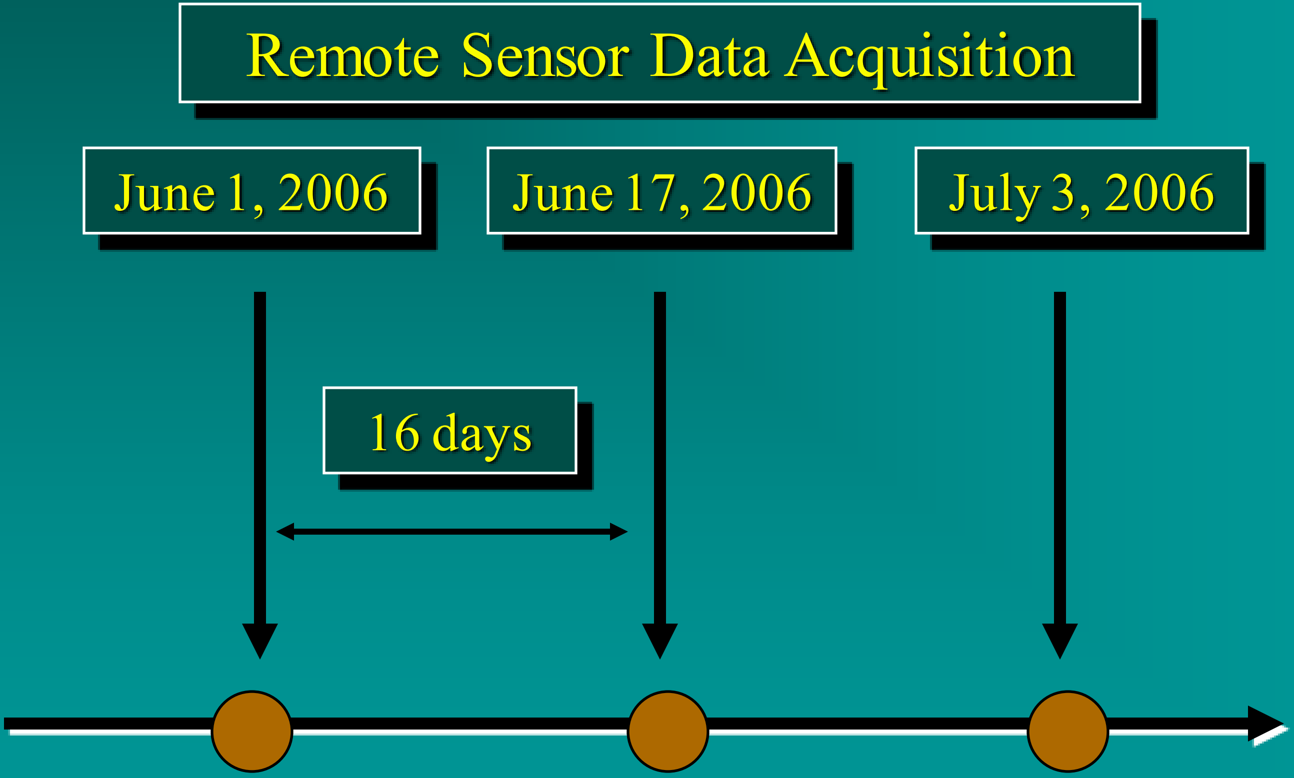
Jensen, 2007

Spatial Resolution

1 x 1 m of Ronald Reagan International Airport in Washington, DC by Digital Globe, Inc.

Jensen, 2007

Temporal Resolution



Remote Sensor Data Acquisition

June 1, 2006

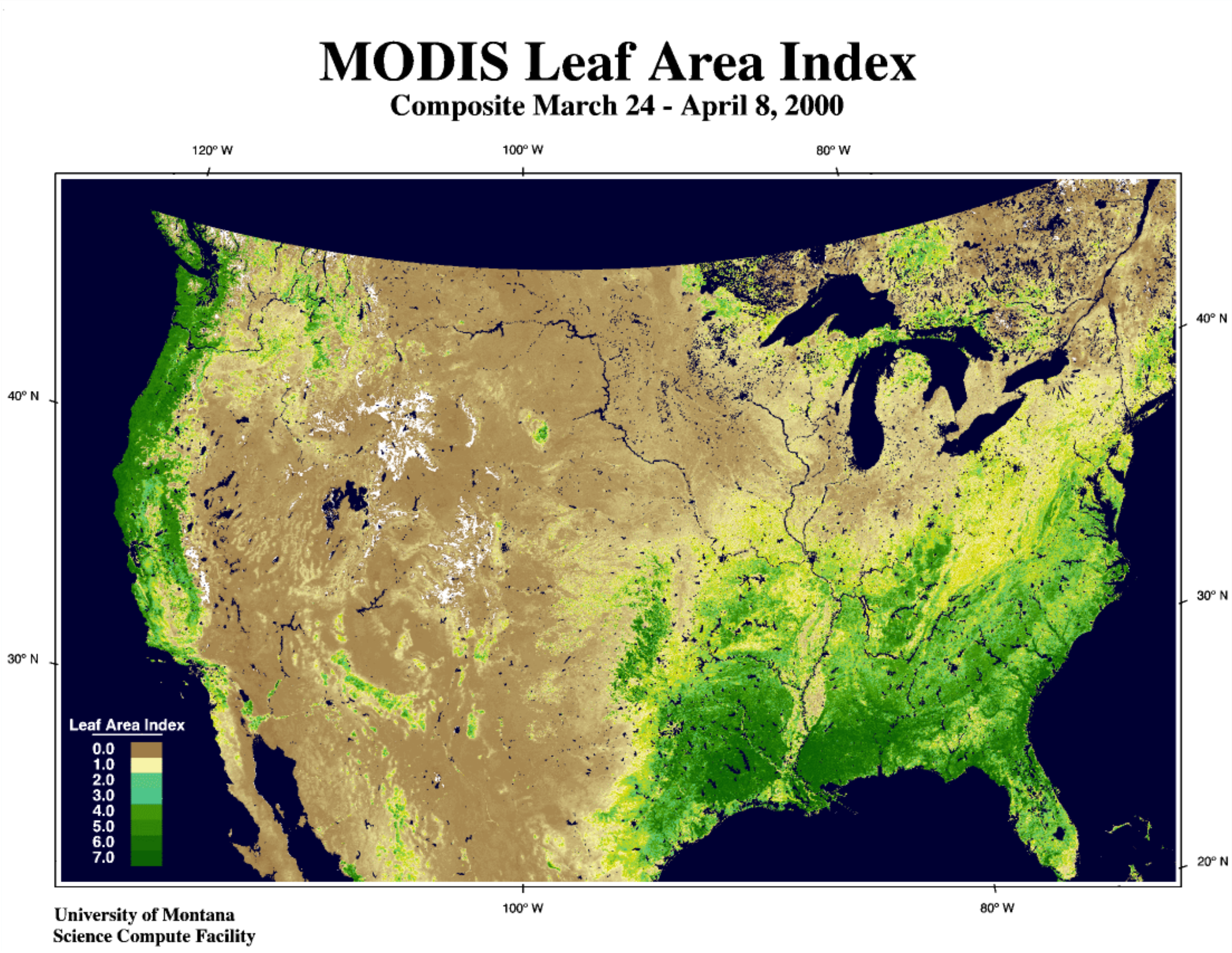
June 17, 2006

July 3, 2006

16 days

Jensen, 2007

Temporal Resolution

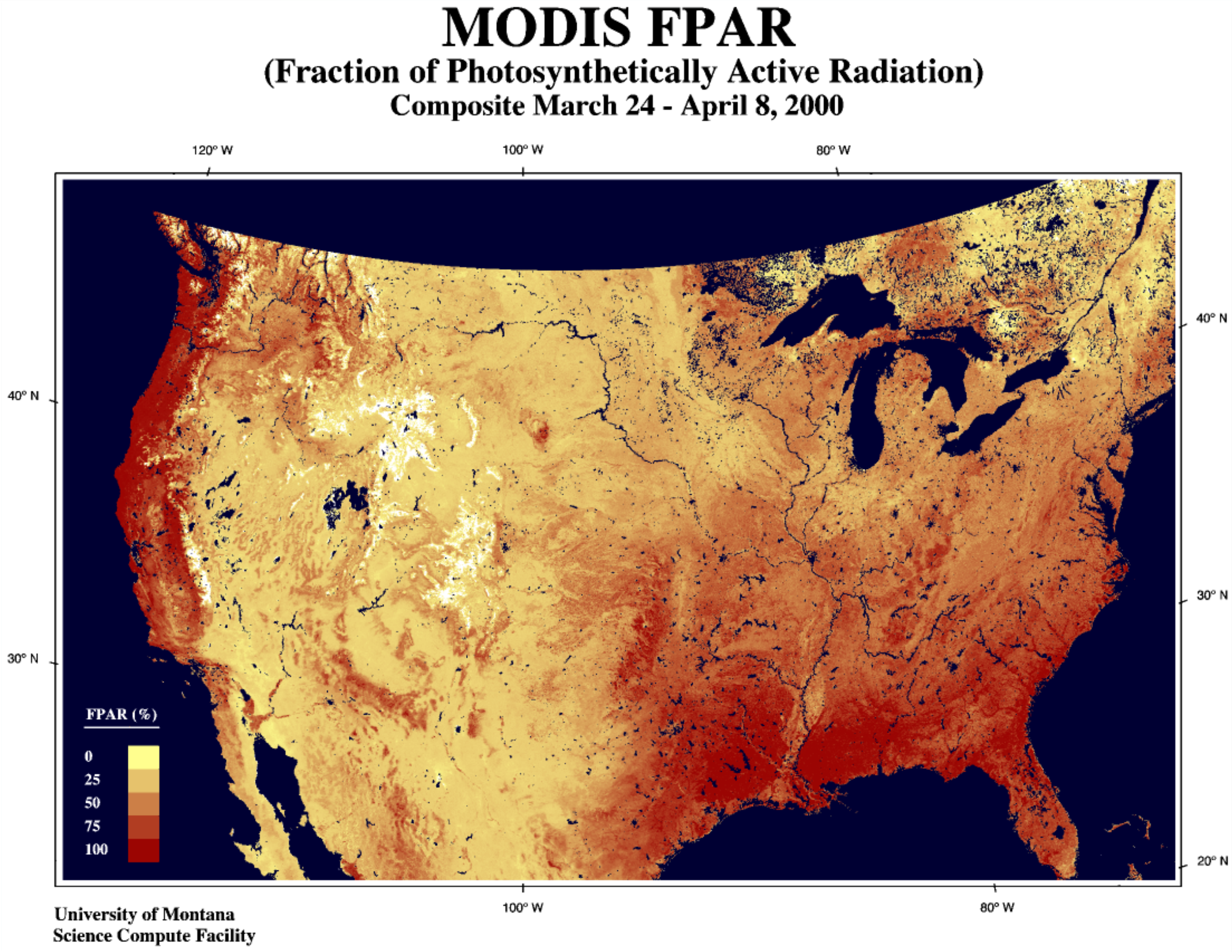


MODIS Leaf Area Index

Composite March 24 - April 8, 2000

University of Montana
Science Compute Facility

Temporal Resolution



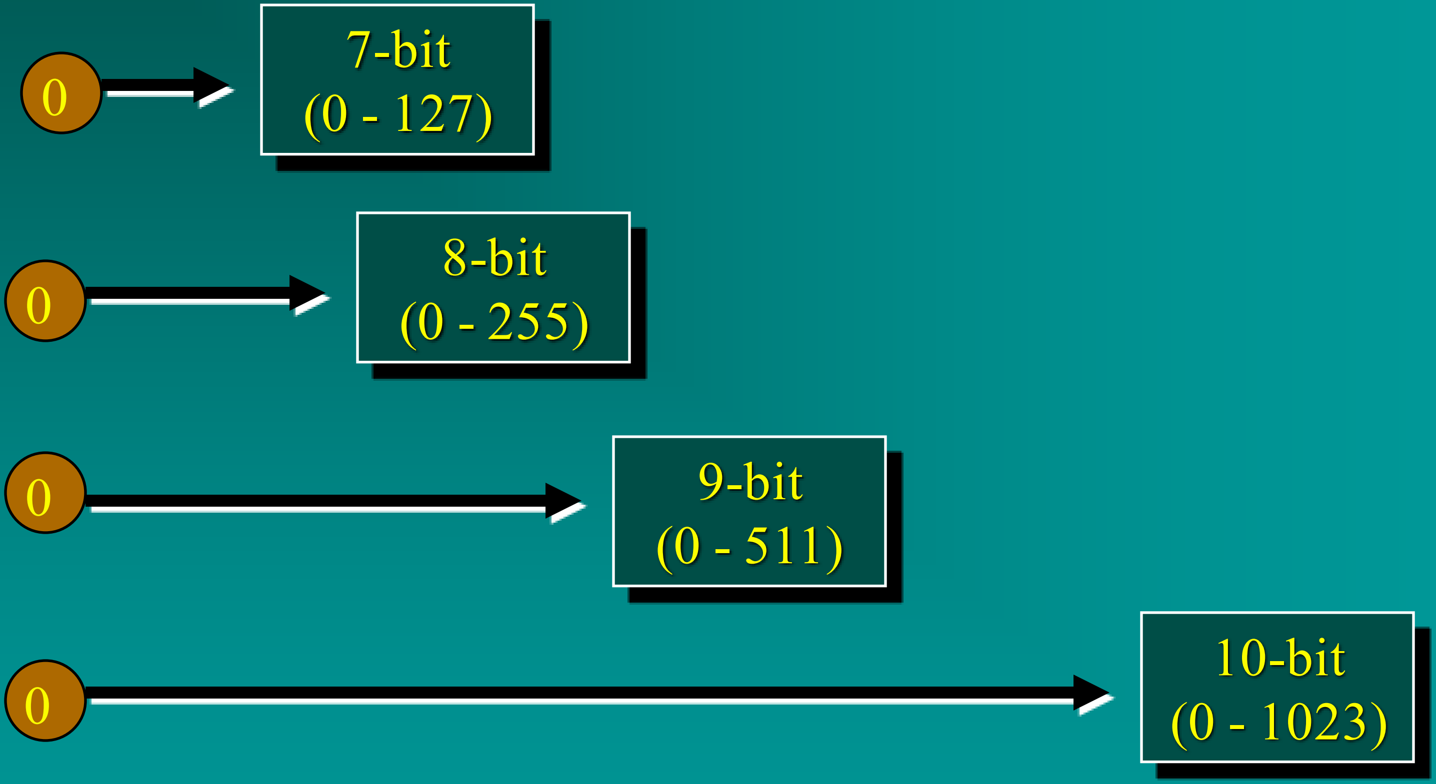
MODIS FPAR

(Fraction of Photosynthetically Active Radiation)

Composite March 24 - April 8, 2000

University of Montana
Science Compute Facility

Radiometric Resolution

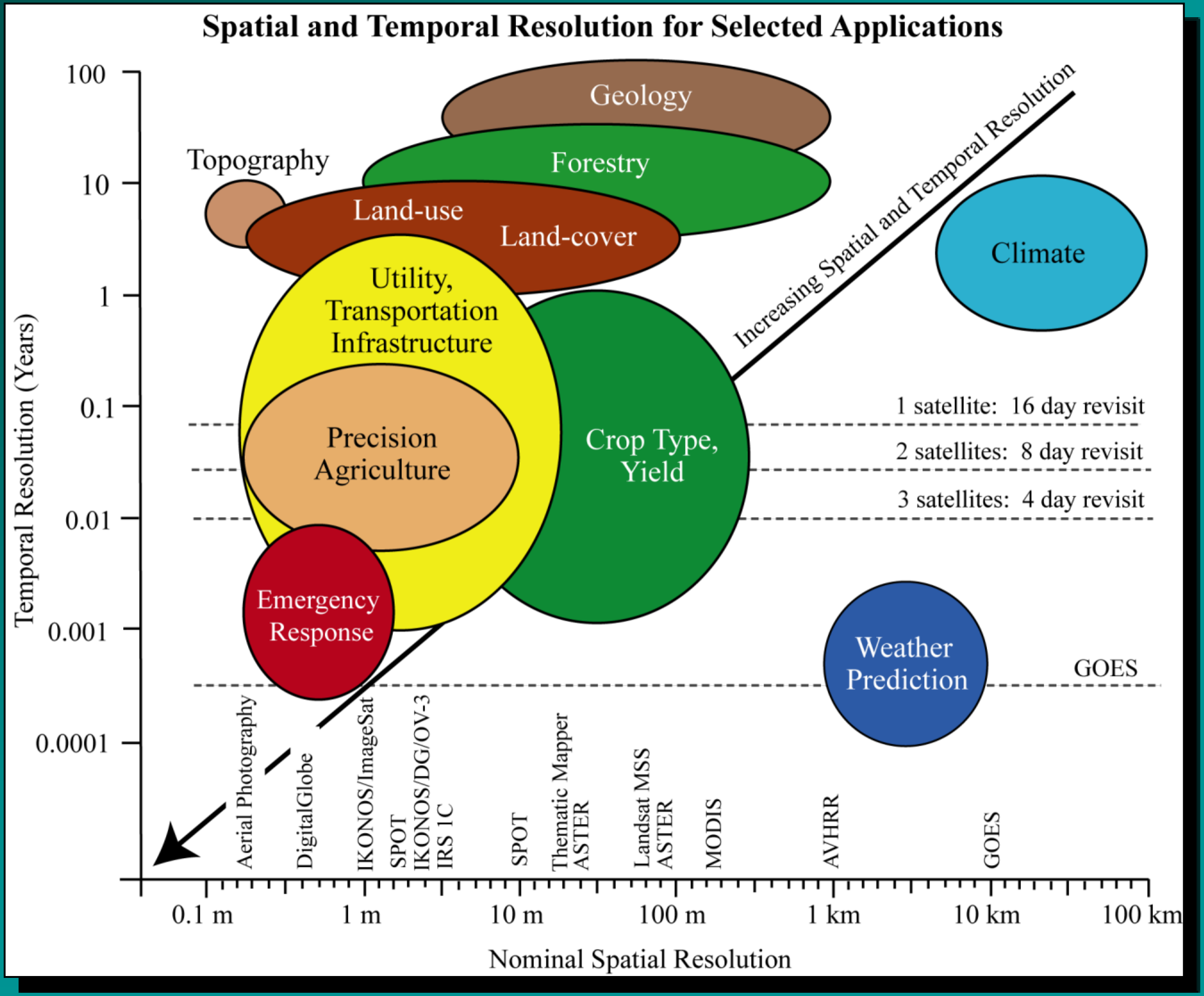


Jensen, 2007

Digital Orthophotos of an Area near Atlanta, GA

a. 1993 orthophoto.

b. 1999 orthophoto.

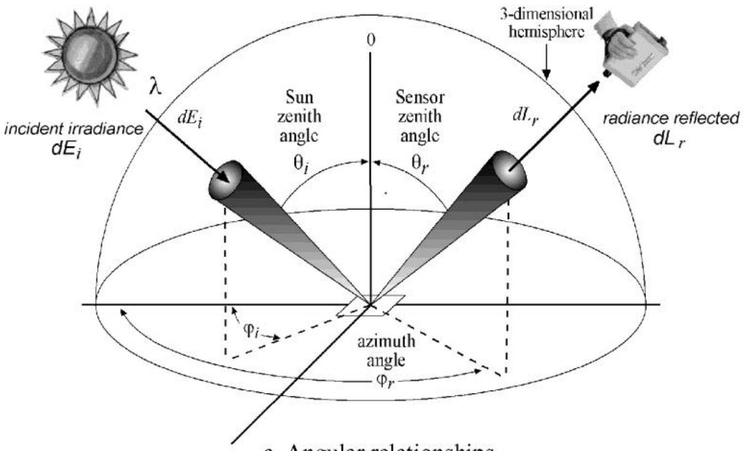


There are spatial and temporal resolution considerations that must be made for certain remote sensing applications.

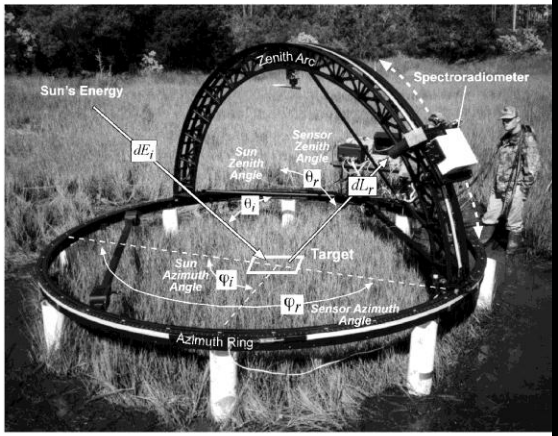
Angular Information

There is always an angle of incidence associated with the incoming energy that illuminates the terrain and an angle of exitance from the terrain to the sensor system. This *bidirectional* nature of remote sensing data collection is known to influence the spectral and polarization characteristics of the at-sensor radiance, *L*, recorded by the remote sensing system.

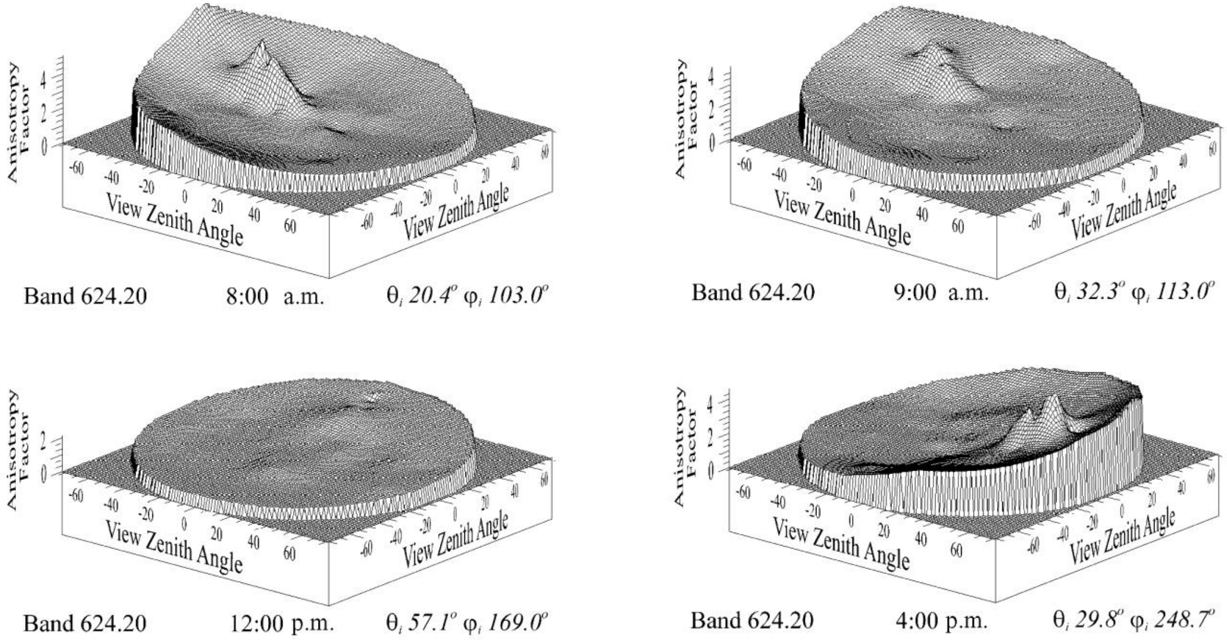
Bidirectional Reflectance Distribution Function



a. Angular relationships.



b. Sandmeier Field Goniometer.



c. Comparison of hourly three-dimensional plots of BRDF for smooth cordgrass (*Spartina alterniflora*) data collected at 8 a.m., 9 a.m., 12 p.m., and 4 p.m. at the boardwalk site on March 21 – 22, 2000, for band 624.20 nm.

Angular Information

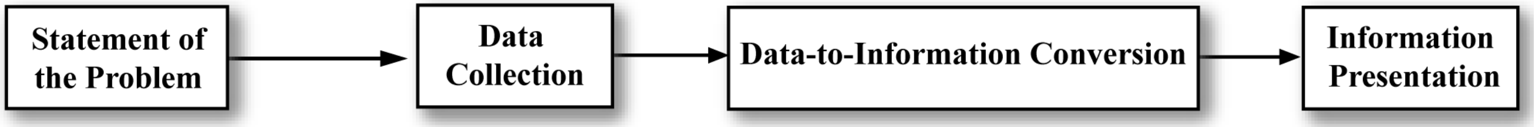
Remote sensing systems record very specific *angular characteristics* associated with each exposed silver halide crystal or pixel. The angular characteristics are a function of:

- location in a three-dimensional sphere of the illumination source (e.g., the Sun for a passive system or the sensor itself in the case of RADAR, LIDAR, and SONAR) and its associated azimuth and zenith angles,
- orientation of the terrain facet (pixel) or terrain cover (e.g., vegetation) under investigation, and
- location of the suborbital or orbital remote sensing system and its associated azimuth and zenith angles.

The Remote Sensing Process

- *In situ* and remotely sensed data are processed using a) analog image processing, b) digital image processing, c) modeling, and d) *n*-dimensional visualization.
- Metadata, processing lineage, and the accuracy of the information are provided and the results communicated using images, graphs, statistical tables, GIS databases, Spatial Decision Support Systems (SDSS), etc.

The Remote Sensing Process



Statement of the Problem → **Data Collection** → **Data-to-Information Conversion** → **Information Presentation**

- **Formulate Hypothesis** (if appropriate)
- **Select Appropriate Logic**
  - Inductive and/or
  - Deductive
  - Technological
- **Select Appropriate Model**
  - Deterministic
    - Empirical
    - Knowledge-based
    - Process-based
  - Stochastic

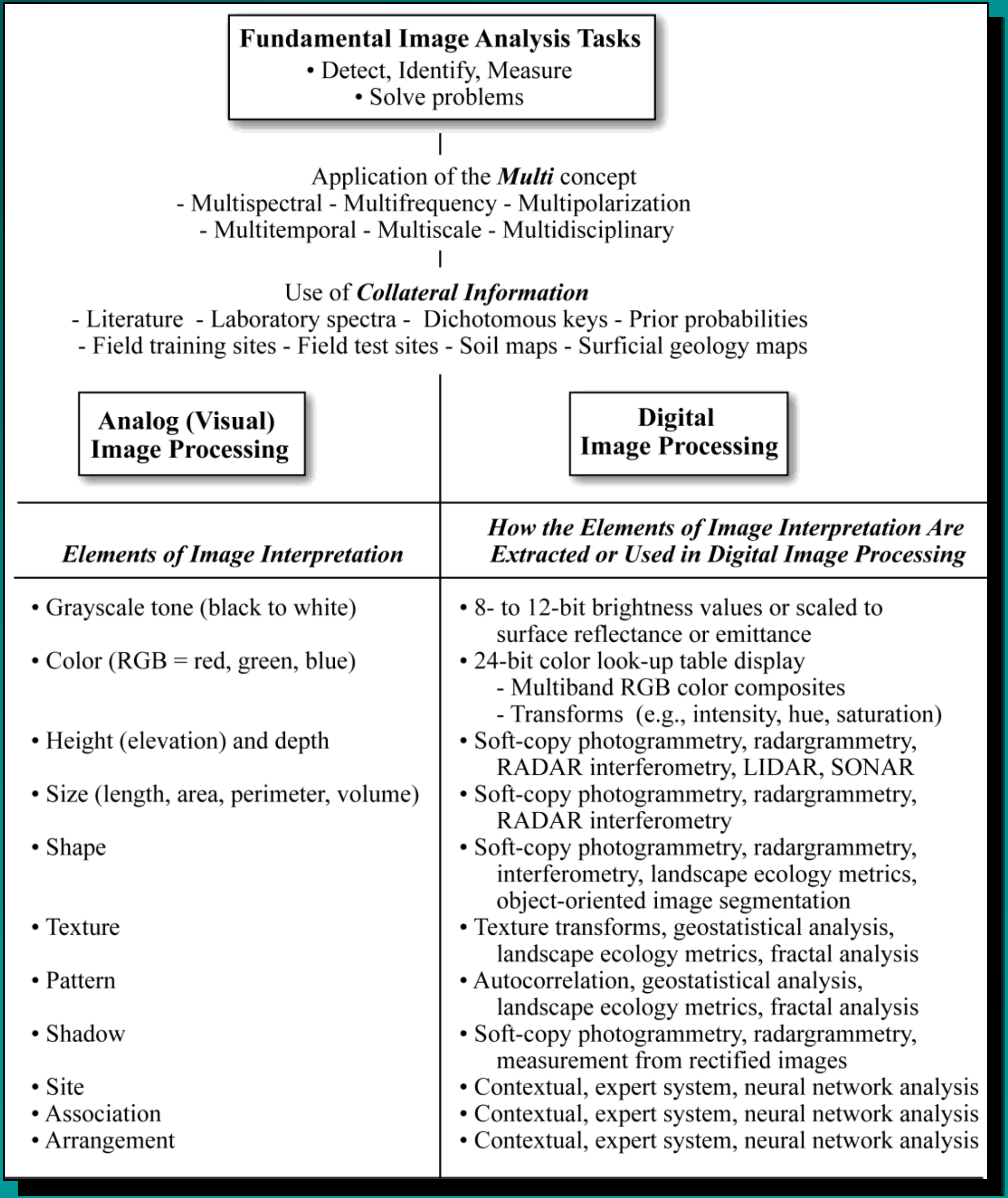
- ***In Situ* Measurements**
  - Field (e.g., *x,y,z* from GPS, biomass, reflectance)
  - Laboratory (e.g., reflectance, leaf area index)
- **Collateral Data**
  - Digital elevation models
  - Soil maps
  - Surficial geology maps
  - Population density, etc.
- **Remote Sensing**
  - Passive analog
    - Frame camera
    - Videography
  - Passive digital
    - Frame camera
    - Scanners
      - Multispectral
      - Hyperspectral
    - Linear and area arrays
      - Multispectral
      - Hyperspectral
  - Active
    - Microwave (RADAR)
    - Laser (LIDAR)
    - Acoustic (SONAR)

- **Analog (Visual) Image Processing**
  - Using the *Elements of Image Interpretation*
- **Digital Image Processing**
  - Preprocessing
    - Radiometric Correction
    - Geometric Correction
  - Enhancement
  - Photogrammetric analysis
  - Parametric, such as
    - Maximum likelihood
  - Nonparametric, such as
    - Artificial neural networks
  - Nonmetric, such as
    - Expert systems
    - Decision-tree classifiers
    - Machine learning
  - Hyperspectral analysis
  - Change detection
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling
  - Scientific geovisualization
    - 1, 2, 3, and *n* dimensions
- **Hypothesis Testing**
  - Accept or reject hypothesis

- **Image Metadata**
  - Sources
  - Processing lineage
- **Accuracy Assessment**
  - Geometric
  - Radiometric
  - Thematic
  - Change detection
- **Analog and Digital**
  - Images
    - Unrectified
    - Orthoimages
  - Orthophotomaps
  - Thematic maps
  - GIS databases
  - Animations
  - Simulations
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3 dimensions

Jensen, 2007

Analog (Visual) and Digital Image Processing of Remote Sensor Data



Fundamental Image Analysis Tasks
- Detect, Identify, Measure
- Solve problems

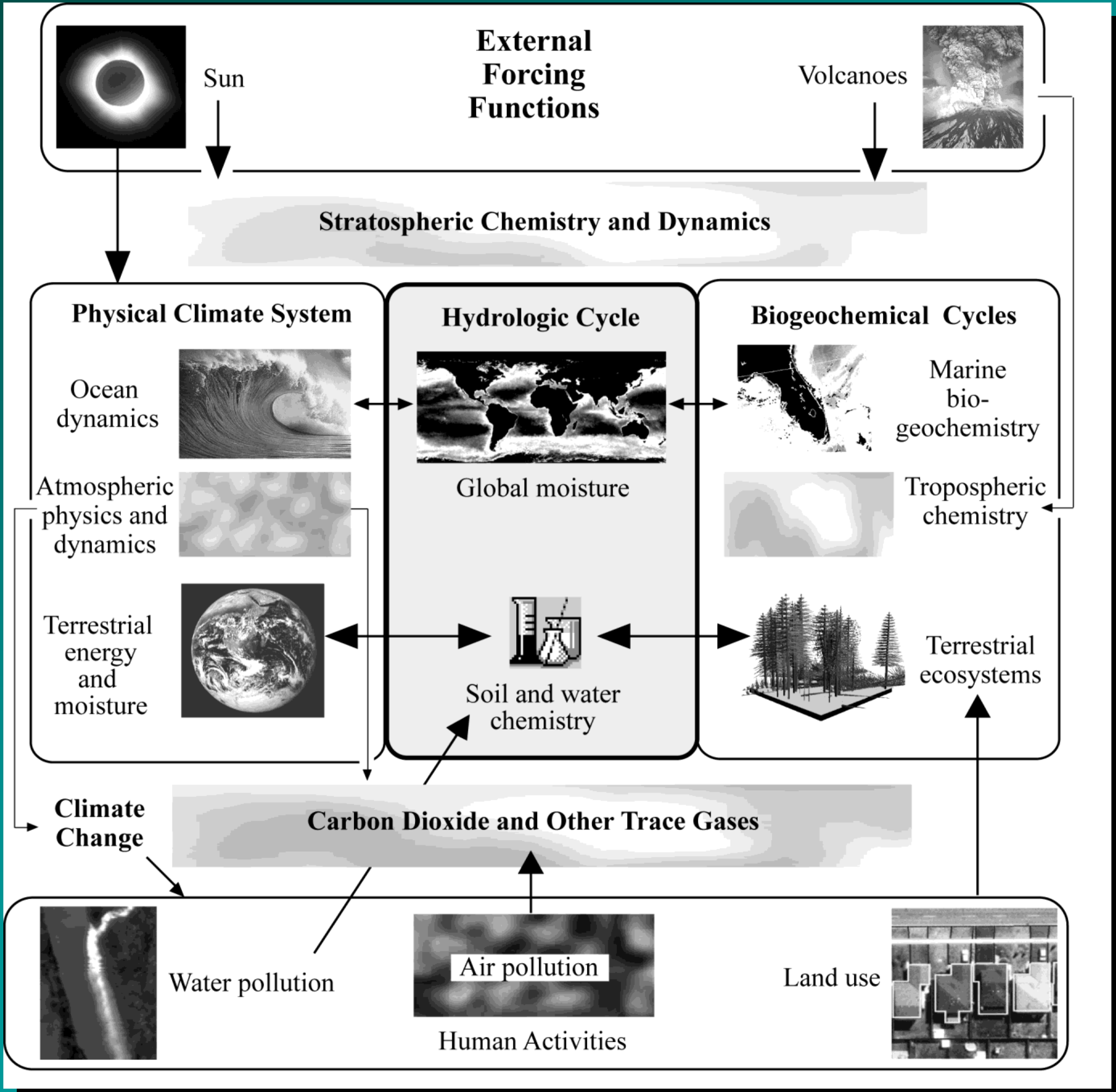
Application of the ***Multi*** concept
- Multispectral - Multifrequency - Multipolarization
- Multitemporal - Multiscale - Multidisciplinary

Use of ***Collateral Information***
- Literature - Laboratory spectra - Dichotomous keys - Prior probabilities
- Field training sites - Field test sites - Soil maps - Surficial geology maps

Analog (Visual) Image Processing	**Digital Image Processing**
Elements of Image Interpretation	***How the Elements of Image Interpretation Are Extracted or Used in Digital Image Processing***
• Grayscale tone (black to white)	• 8- to 12-bit brightness values or scaled to surface reflectance or emittance
• Color (RGB = red, green, blue)	• 24-bit color look-up table display - Multiband RGB color composites - Transforms (e.g., intensity, hue, saturation)
• Height (elevation) and depth	• Soft-copy photogrammetry, radargrammetry, RADAR interferometry, LIDAR, SONAR
• Size (length, area, perimeter, volume)	• Soft-copy photogrammetry, radargrammetry, RADAR interferometry
• Shape	• Soft-copy photogrammetry, radargrammetry, interferometry, landscape ecology metrics, object-oriented image segmentation
• Texture	• Texture transforms, geostatistical analysis, landscape ecology metrics, fractal analysis
• Pattern	• Autocorrelation, geostatistical analysis, landscape ecology metrics, fractal analysis
• Shadow	• Soft-copy photogrammetry, radargrammetry, measurement from rectified images
• Site	• Contextual, expert system, neural network analysis
• Association	• Contextual, expert system, neural network analysis
• Arrangement	• Contextual, expert system, neural network analysis

Jensen, 2007

Remote Sensing Earth System Science



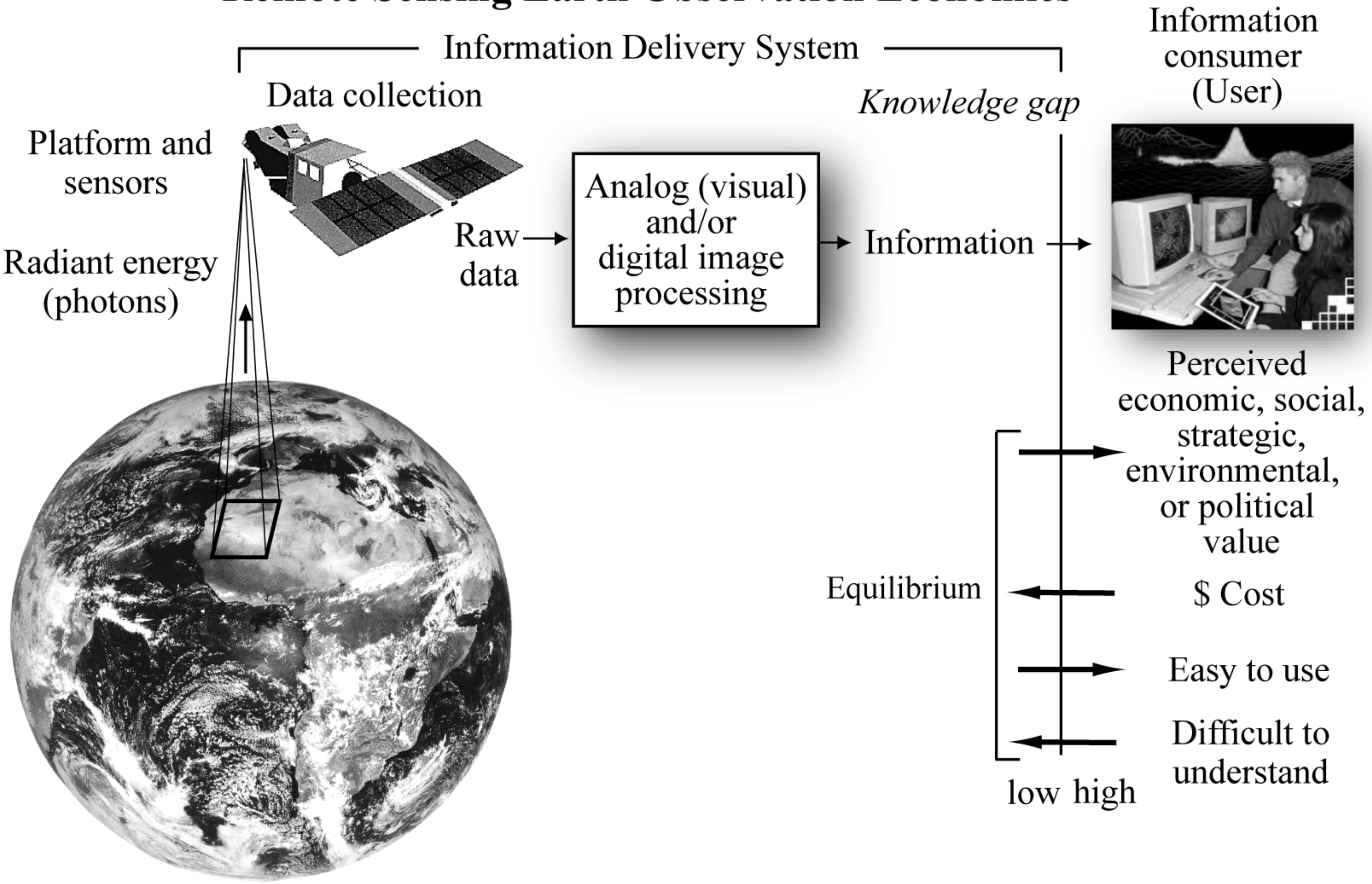
Jensen, 2007

Earth Resource Analysis Perspective

Such information may be useful for modeling:

- the global carbon cycle,
- biology and biochemistry of ecosystems,
- aspects of the global water and energy cycle,
- climate variability and prediction,
- atmospheric chemistry,
- characteristics of the solid Earth,
- population estimation, and
- monitoring land-use change and natural hazards.

Remote Sensing Earth Observation Economics



Information Delivery System

Data collection

Platform and sensors

Radiant energy (photons)

Raw data → Analog (visual) and/or digital image processing → Information → Information consumer (User)

Knowledge gap

Perceived economic, social, strategic, environmental, or political value

Equilibrium

$ Cost

Easy to use

Difficult to understand

low high

Organization of
Remote Sensing of the Environment

Chapter 1.
Remote Sensing of the Environment
- *In Situ* Data Collection
- Remote Sensing Data Collection
- The Remote Sensing Process

Chapter 2.
Electromagnetic Radiation Principles
- Conduction, Convection, and Radiation
- Energy-Matter Interactions in the Atmosphere
- Energy-Matter Interactions with the Terrain

Chapter 3.
History of Aerial Photography and Aerial Platforms
- History of Photography
- Photography from Aerial Platforms
- Photo-Reconnaissance in WWI and WWII
- Cold War Photo-Reconnaissance
- Celestial Satellilte Sentinels
- Unmanned Aerial Vehicles

Chapter 4.
Aerial Photography
- Vertical and Oblique Vantage Points
- Aerial Cameras
- Filtration and Films
- Planning Aerial Photography Missions

Chapter 5.
Elements of Visual Image Interpretation
- Elements of Image Interpretation
- Methods of Search

Chapter 6.
Photogrammetry
- Flightlines of Aerial Photography
- Image Nomenclature
- Scale/Height Measurement on Single Photos
- Stereoscopic Measurement
- Orthophotos and Digital Elevation Models
- Area Measurement

Chapter 7.
Multispectral Remote Sensing
- Multispectral Data Collection
- Discrete Detectors and Sanning Mirrors
- Multispectral Imaging Using Linear Arrays
- Imaging Spectroscopy
- Digital Frame Cameras
- Satellite Photographic Systems

Chapter 8.
Thermal Infrared Remote Sensing
- History
- Thermal Infrared Radiation Properties
- Atmospheric Windows
- Thermal Radiation Laws
- Thermal Properties of Terrain
- Thermal Infrared Data Collection
- TIR Environmental Considerations

Chapter 9.
Active and Passive Microwave
- History
- Active Microwave System Components
- RADAR Environmental Considerations
- SAR Remote Sensing from Space
- RADAR Interferometry
- Passive Microwave Remote Sensing

Chapter 10.
LIDAR Remote Sensing
- Principles (returns, density, intensity)
- Processing to Create DEM, DSM, DTM
- Accuracy of LIDAR-derived products

Chapter 11.
Remote Sensing of Vegetation
- Photosynthesis Fundamentals
- Spectral Characteristics of Vegetation
- Temporal Characteristics of Vegetation
- Vegetation Indices
- Landscape Ecology Metrics
- Biodiversity and GAP Analysis
- Vegetation Change Detection

Organization of
Remote Sensing of the Environment **-** *continued*

Chapter 12.
Remote Sensing of Water

- Surface Water Biophysical Characteristics
- Precipitation
- Aerosols and Clouds
- Water Vapor and Snow
- Water-quality Modeling

Chapter 13.
Remote Sensing the Urban Landscape

- Urban/Suburban Resolution Considerations
- Remote Sensing Land Use/Land Cover
- Residential
- Commercial and Services
- Industrial and Transportation
- Communications and Utilities
- Urban Meteorological Data
- Critical Environmental Area Assessment
- Disaster Emergency Response

Chapter 14.
Remote Sensing Soils, Minerals, and Geomorphology

- Soil Characteristics and Taxonomy
- Remote Sensing Soil Properties
- Remote Sensing Rocks and Minerals
- Geology and Geomorphology

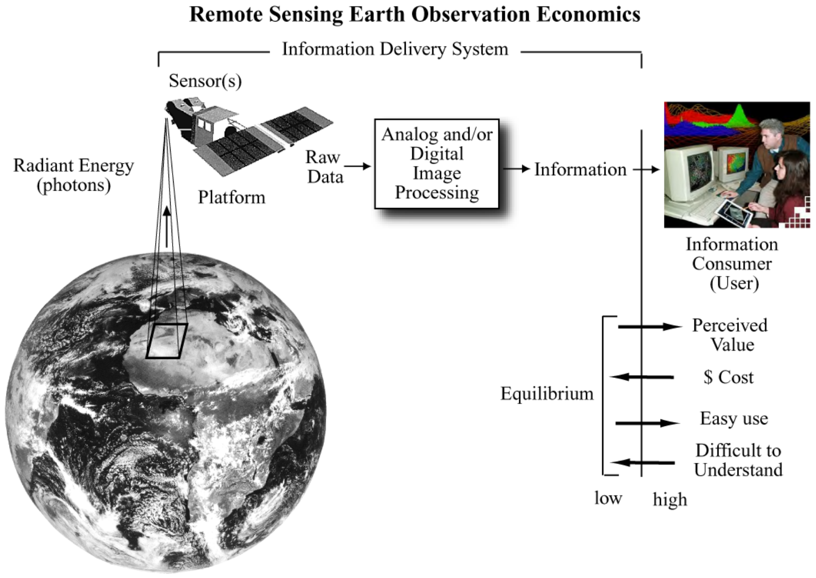
Chapter 15.
In Situ Spectral Reflectance Measurement

- Spectral Reflectance of a Material
- Illumination Considerations
- Radiometer Considerations

REMOTE SENSING AND DIGITAL IMAGE PROCESSING TO EXTRACT INFORMATION OF VALUE

Principle: The general process of creating information from remote sensing earth observation is shown below. Radiant energy is collected by the remote sensing system and processed using analog and/or digital image processing techniques to extract information. Remote sensing data alone are not a panacea for Earth resource management problems. Remote sensing derived information are usually only of significant value when used inconjunction with other information in a well-conceived application.

It is important to remember that the user is a *consumer* who requires information of perceived economic, social, strategic, environmental and/or political value. In addition, the information must be relatively easy to use and understand, and should not be prohibitively expensive.



Remote Sensing Earth Observation Economics

MacDonald, 1999; Jensen, 2001

The Remote Sensing Process

- The hypothesis to be tested is defined using a specific type of *logic* (e.g., inductive, deductive) and an appropriate processing *model* (e.g., deterministic, stochastic).

- *In situ* and collateral data necessary to calibrate the remote sensor data and/or judge its geometric, radiometric, and thematic characteristics are collected.

- Remote sensor data are collected passively or actively using analog or digital remote sensing instruments, ideally at the same time as the *in situ* data.