Geography 551: Principles of Remote Sensing

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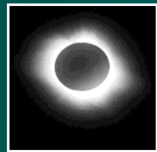
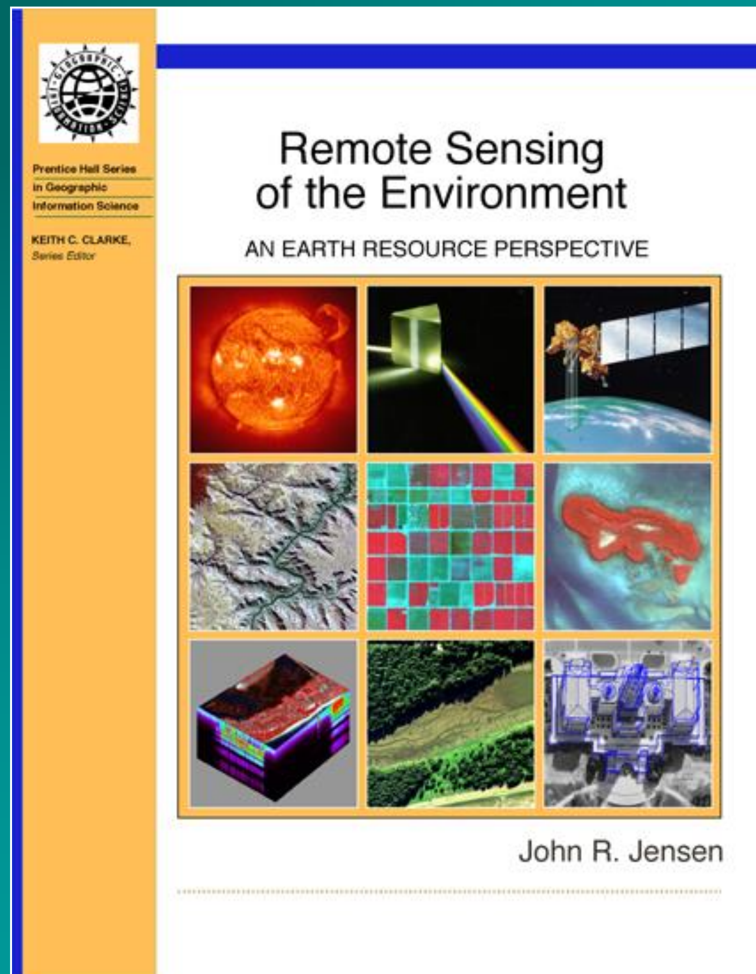
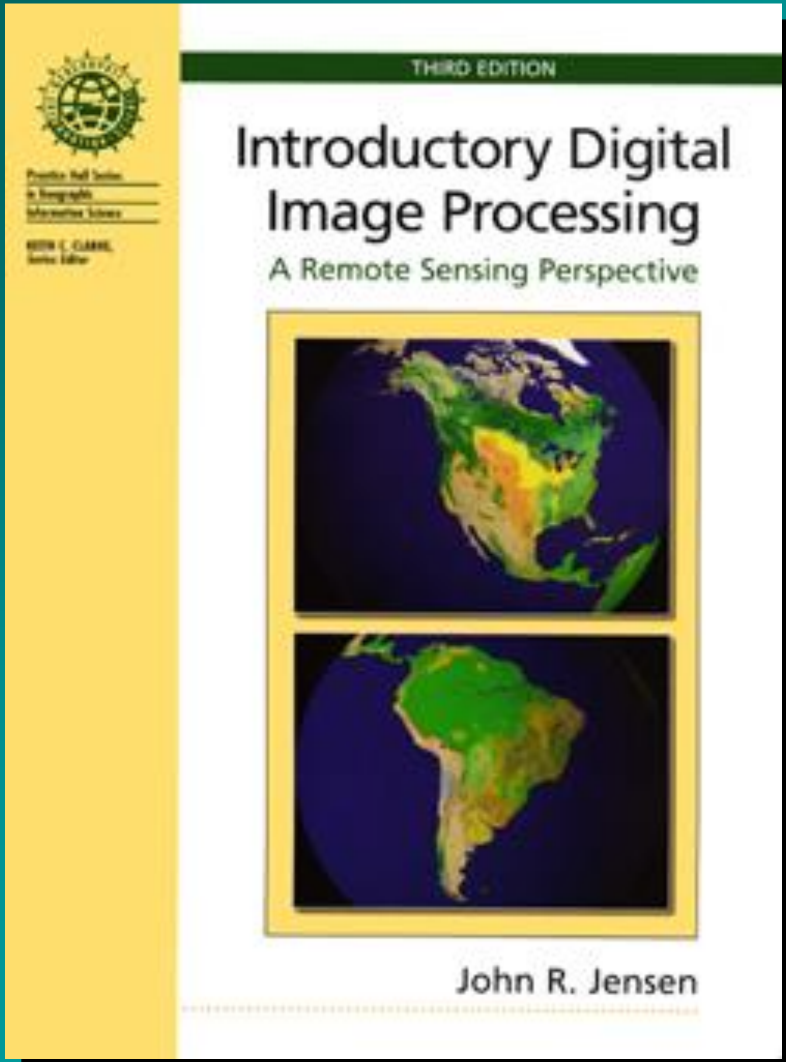


Geography 551: Principles of Remote Sensing



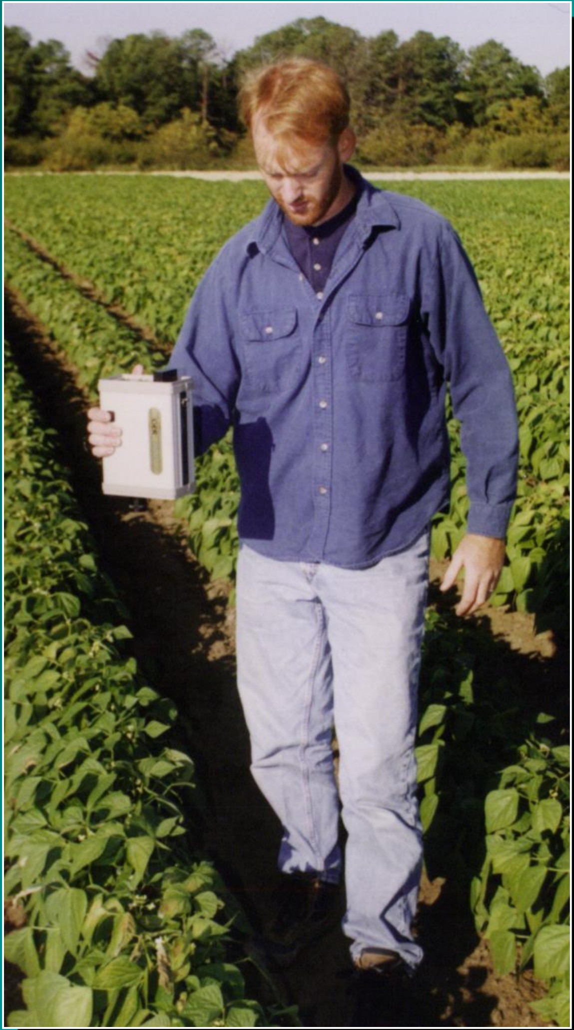
Required text:

Text used in Geography 751: Digital Image Processing



In situ Measurement in Support of Remote Sensing Measurement

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



In situ spectroradiometer measurement of soybeans

Jensen, 2000

In Situ Data Collection

a. Spectroradiometer measurement.

b. Global positioning system (GPS) measurement.

Jensen, 2004

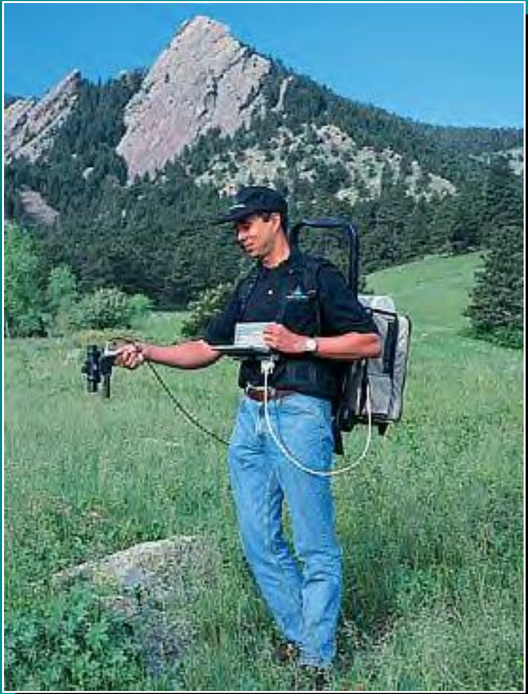
In situ Measurement in Support of Remote Sensing Measurement

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

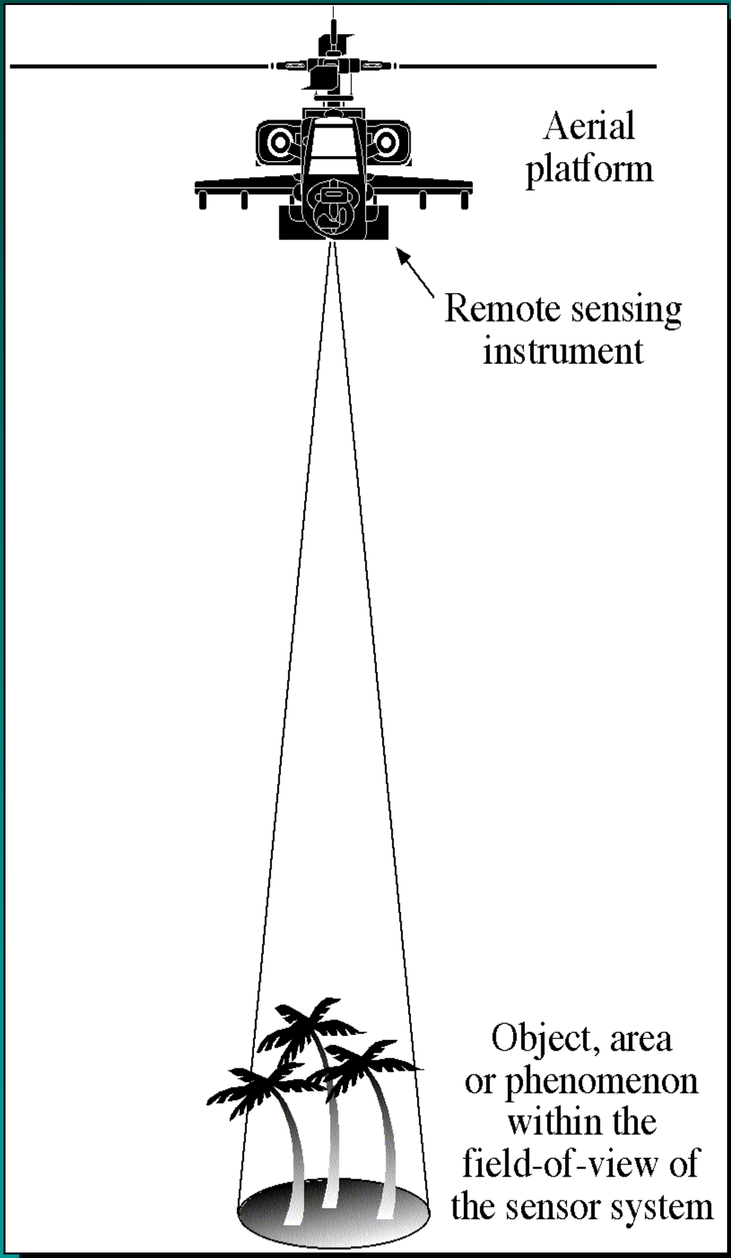
It is a misnomer to refer to *in situ* data as *ground truth data*. Instead, we should refer to it simply as *in situ ground reference data*, and acknowledge that it also contains error.

Jensen, 2000

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.



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).

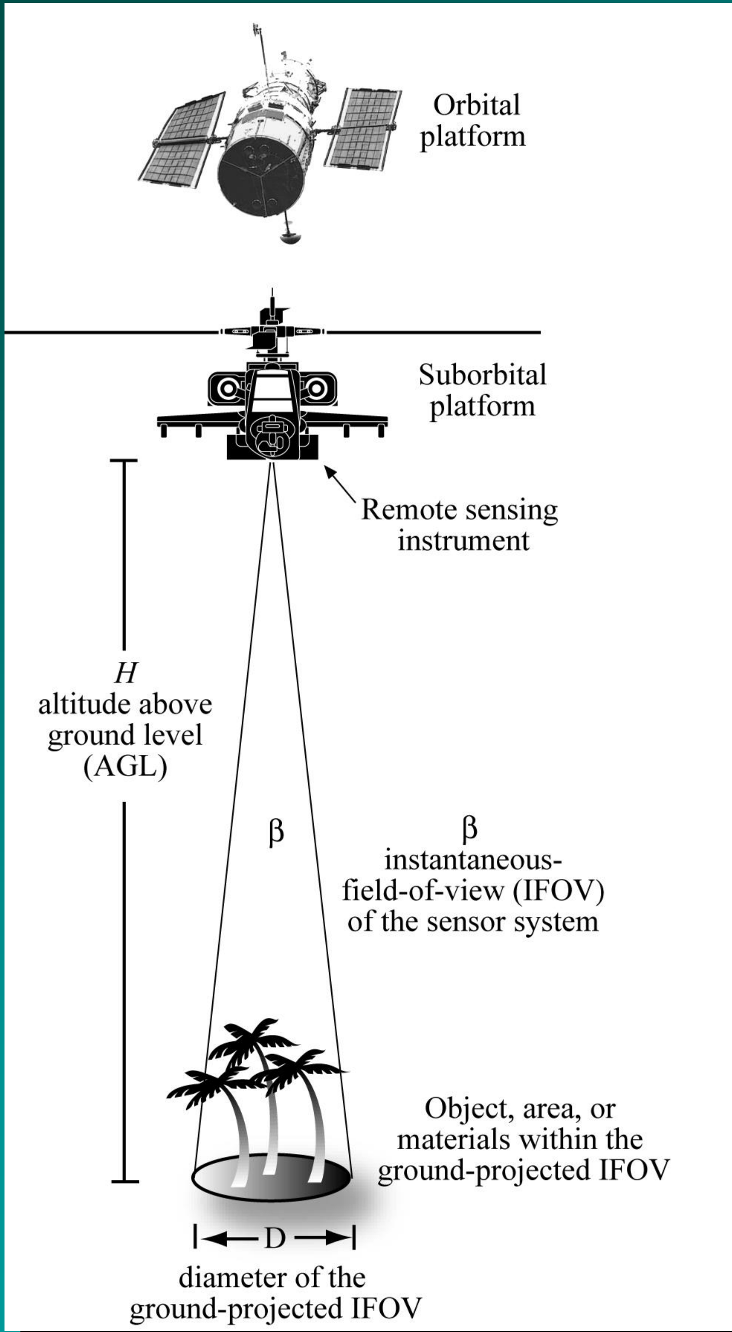
Jensen, 2000

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, 2000



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.

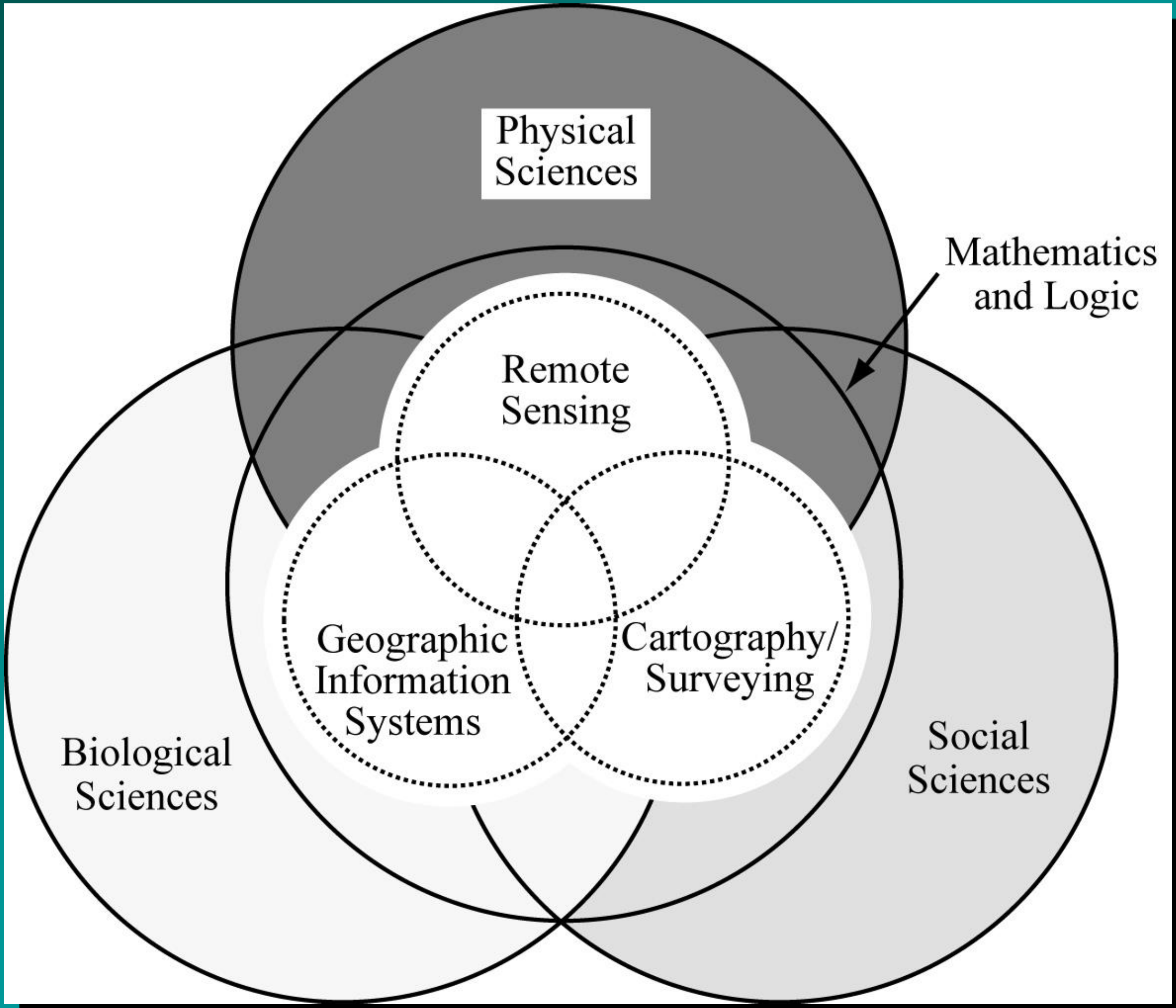
Jensen, 2000; 2004

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, 2000; 2004

Developmental Stages of a Scientific Discipline

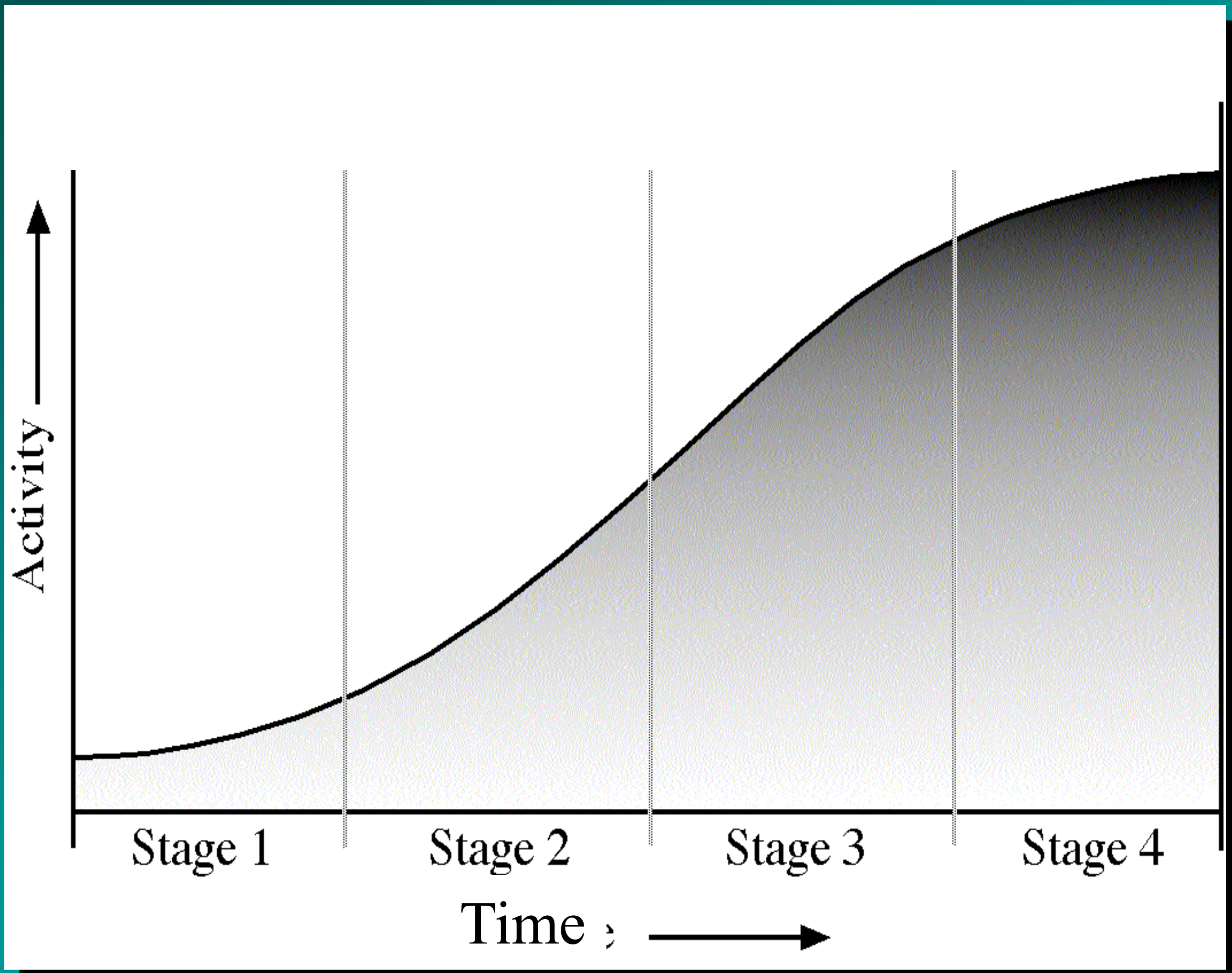


Table 1-1 Identifies the Major Milestones in Remote Sensing

Jensen, 2000

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*.

Remote Sensing Process

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

Statement of the Problem

- **Select Appropriate Logic**
  - Inductive
  - Deductive
  - Technological
- **Formulate Hypothesis**

Data Collection

- ***In Situ***
  - Field (e.g., GPS, biomass, spectroradiometer)
  - Laboratory measurements
  - Collateral data (e.g., maps)
- **Remote Sensing**
  - Passive analog
    - Frame Camera
    - Videography
  - Passive digital
    - Frame Camera
    - Multispectral scanners
    - Linear and area arrays
      - Hyperspectral
  - Active
    - Microwave (RADAR)
    - Laser (LIDAR)
    - Acoustic (SONAR)

Data-to-Information Conversion

- **Analog (Visual) Image Processing**
  - Using "Elements of Image Interpretation"
- **Digital Image Processing**
  - Photogrammetric analysis
  - Pattern recognition
    - inferential statistics
  - Hyperspectral analysis
  - Artificial Intelligence Analysis
    - Expert system
    - Neural network
    - Decision Tree
      - machine learning
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling based on physics of energy/matter interactions
- **Scientific Visualization**
  - 1, 2, 3, and *n*-dimensional

Information Presentation

- **Analog and Digital**
  - Images
    - Unrectified
    - Orthophotos
  - Orthophotomaps
  - Thematic maps
  - GIS databases
- **Accuracy Assessment**
  - Geometric/radiometric
  - Thematic
- **Image Metadata**
  - Genealogy
  - Processing history
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3-dimensions

Jensen, 2000

The Remote Sensing Process

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

Statement of the Problem

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

Data Collection

- ***In Situ* Measurements**
  - Field (e.g., *x,y,z* from GPS, biomass, spectroradiometer)
  - 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
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Data-to-Information Conversion

- **Analog (Visual) Image Processing**
  - Using the *Elements of Image Interpretation*
- **Digital Image Processing**
  - Preprocessing
    - Radiometric Correction
    - Geometric Correction
  - Enhancement
  - Photogrammetric analysis
  - Parametric, such as
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  - Scientific geovisualization
    - 1, 2, 3, and *n* dimensions
- **Hypothesis Testing**
  - Accept or reject hypothesis

Information Presentation

- **Image Metadata**
  - Sources
  - Processing lineage
- **Accuracy Assessment**
  - Geometric
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- **Analog and Digital**
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  - Univariate
  - Multivariate
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  - 1, 2, and 3 dimensions

Jensen, 2004

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, 2004

Remote Sensing Data Collection

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

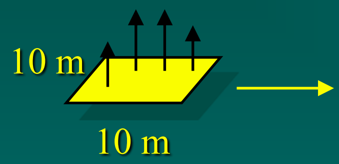
t = temporal information, i.e., when and how often the information was acquired

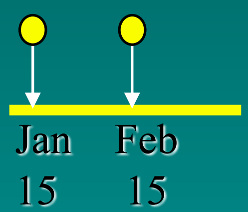
θ = set of angles that describe the geometric relationships among the radiation source (e.g., the Sun), the terrain target of interest (e.g., a corn field), and the remote sensing system

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

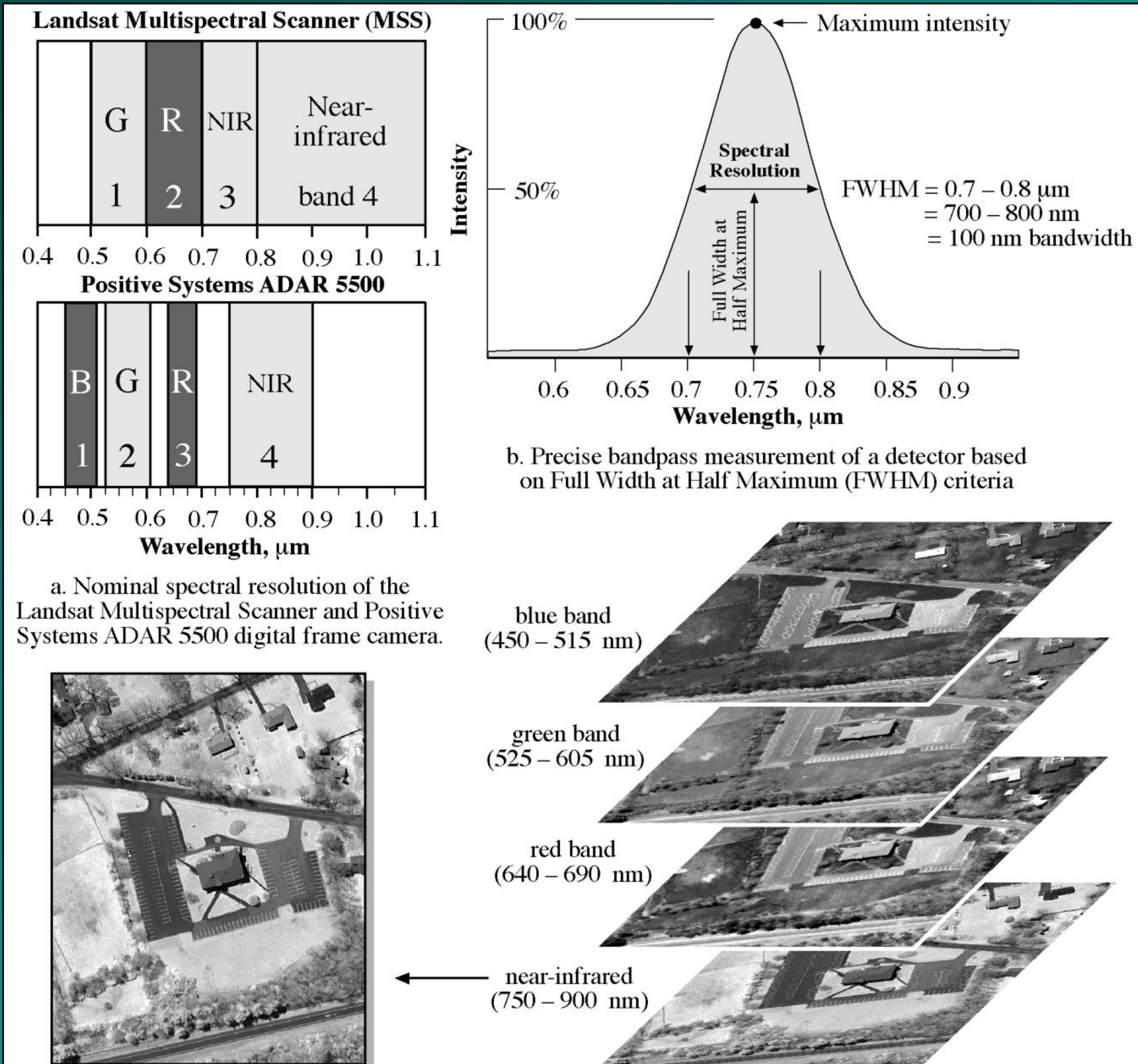




- Spatial - the size of the field-of-view, e.g. 10 x 10 m.
- Spectral - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared thermal infrared, microwave (radar).
- Temporal - how often the sensor acquires data, e.g. every 30 days.
- Radiometric - the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

Jensen, 2000

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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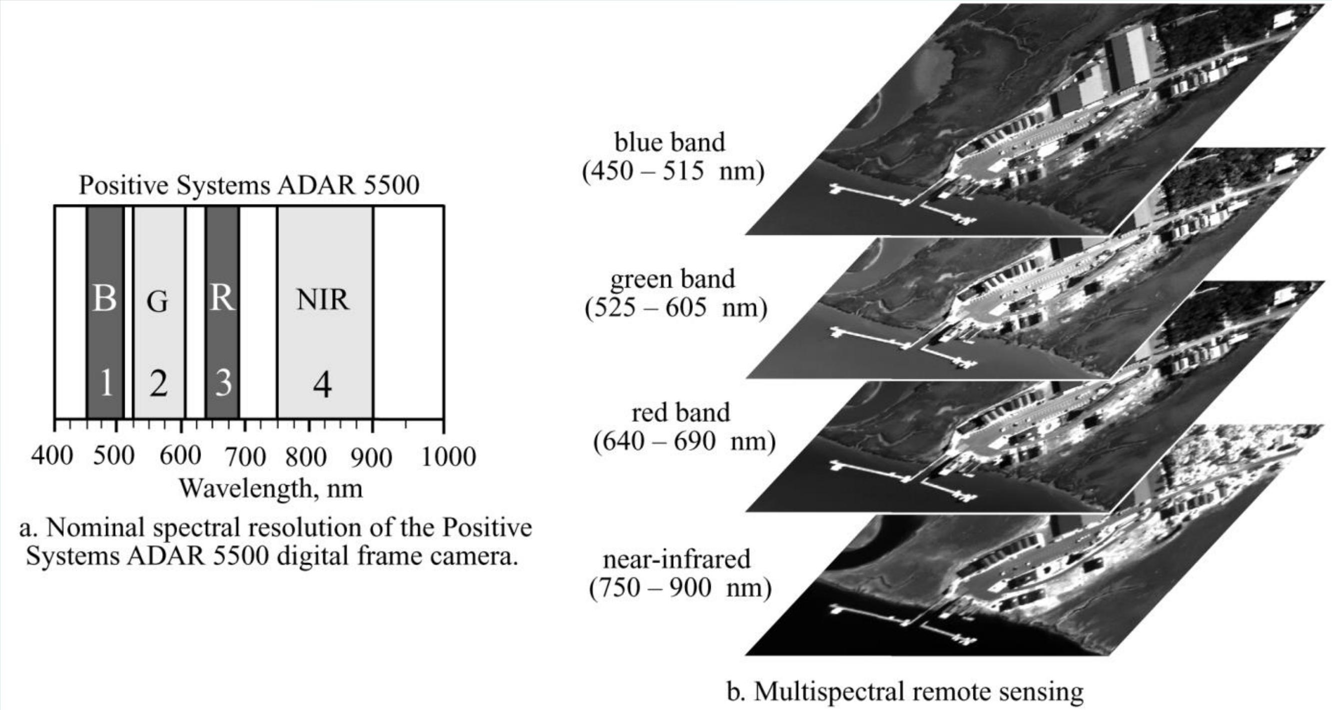
Marina in the Ace Basin, South Carolina

Spectral Resolution



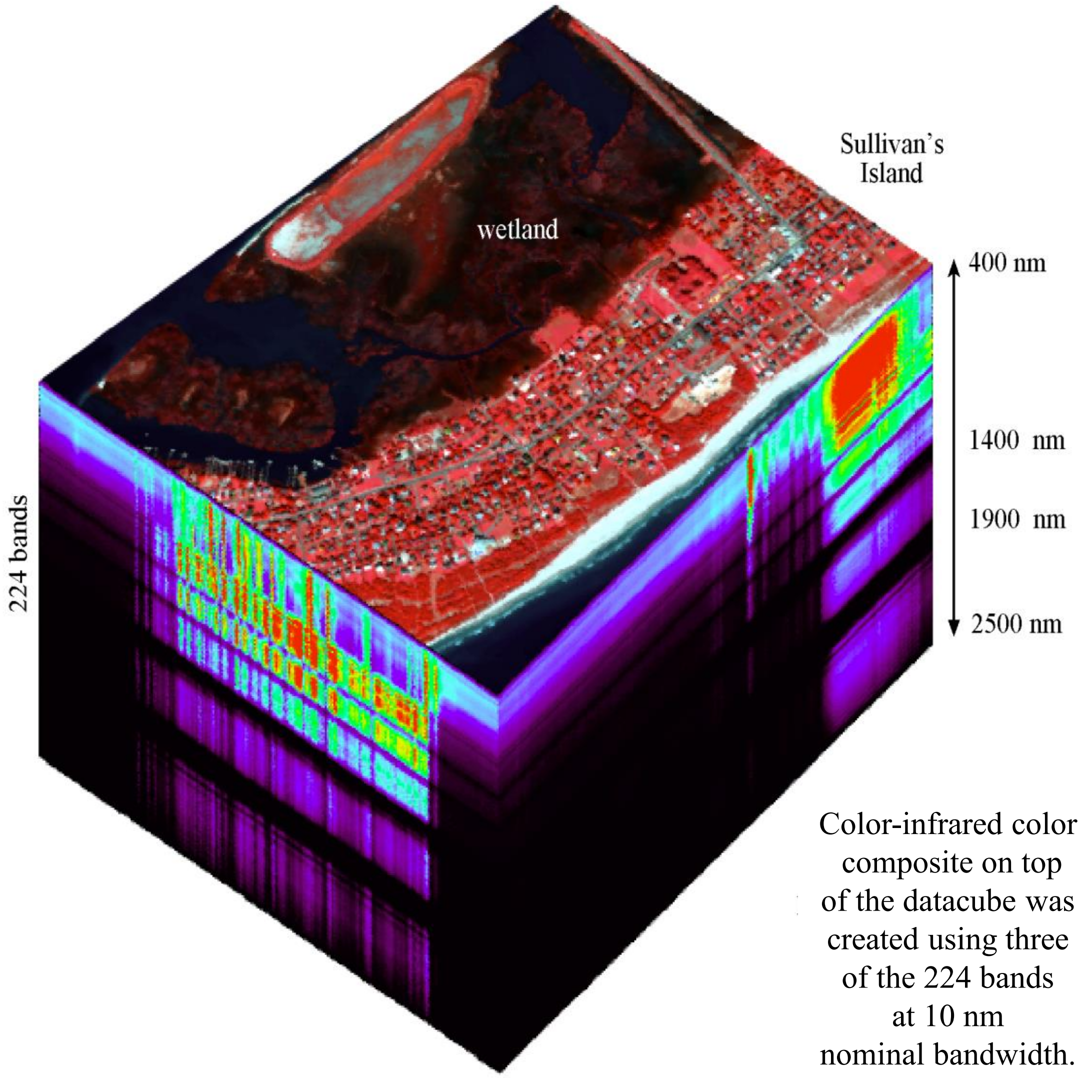
a. Nominal spectral resolution of the Positive Systems ADAR 5500 digital frame camera.

b. Multispectral remote sensing

Spectral Resolution

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

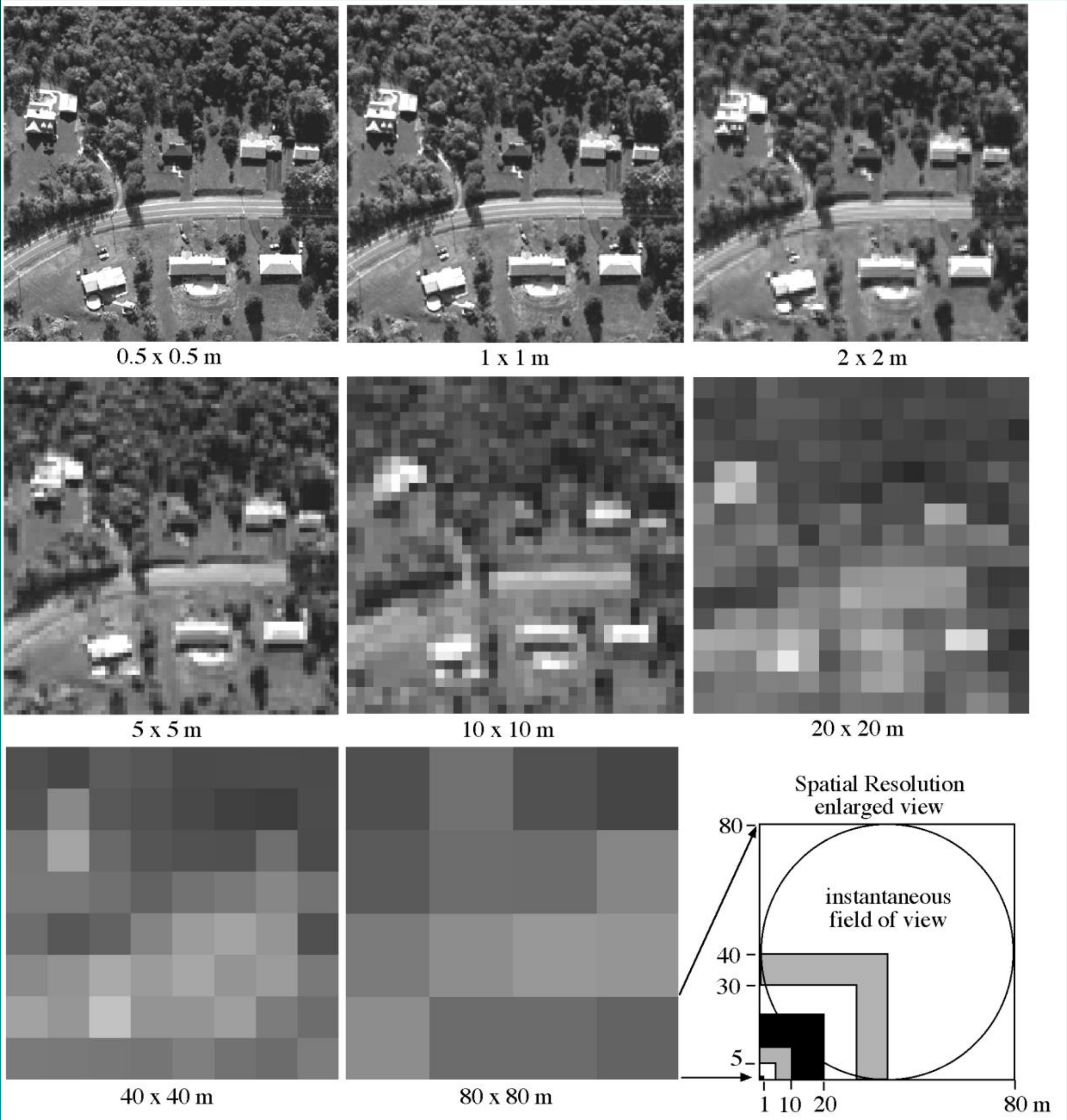
Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island Obtained on October 26, 1998



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

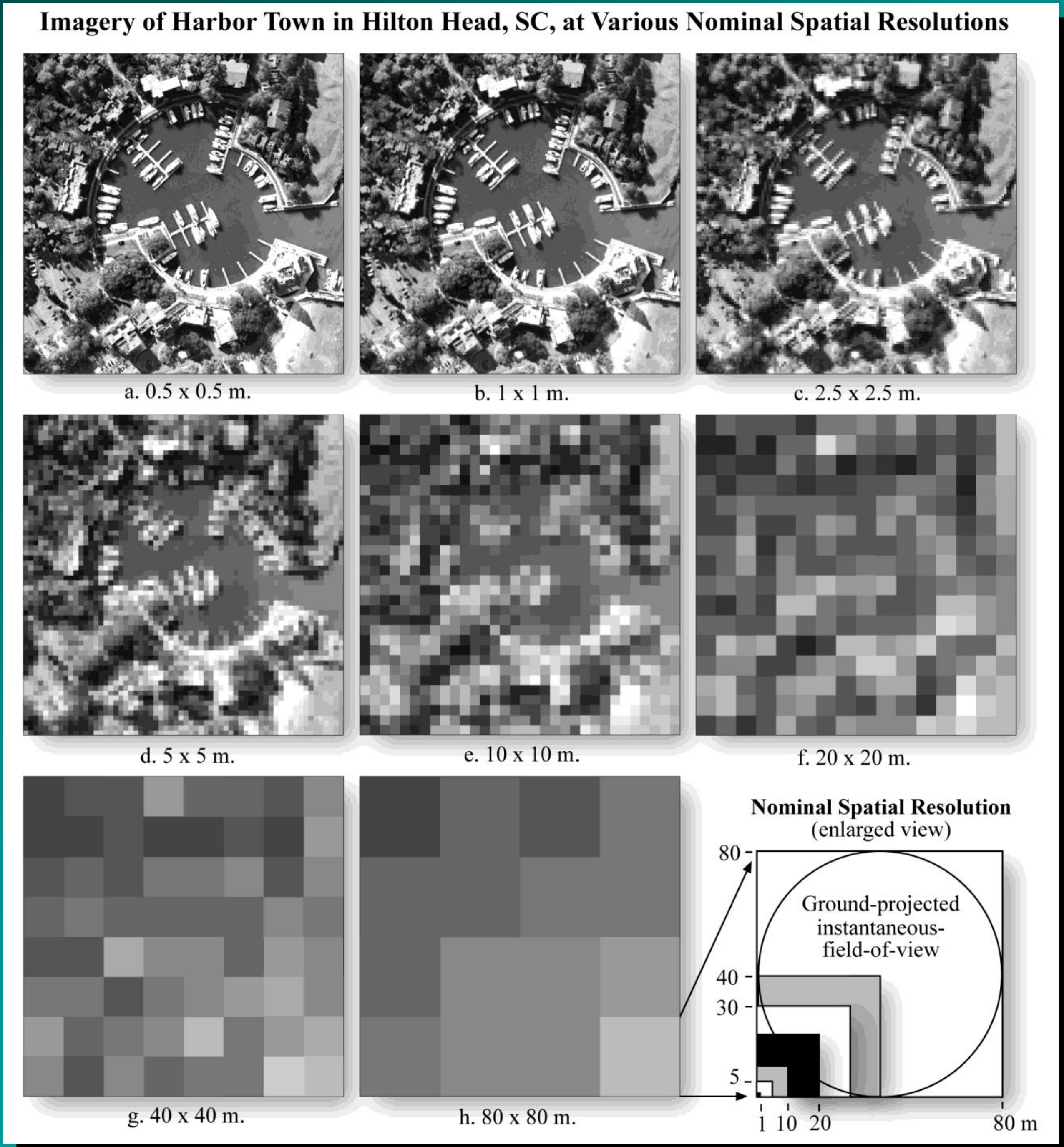
Jensen, 2000

Spatial Resolution



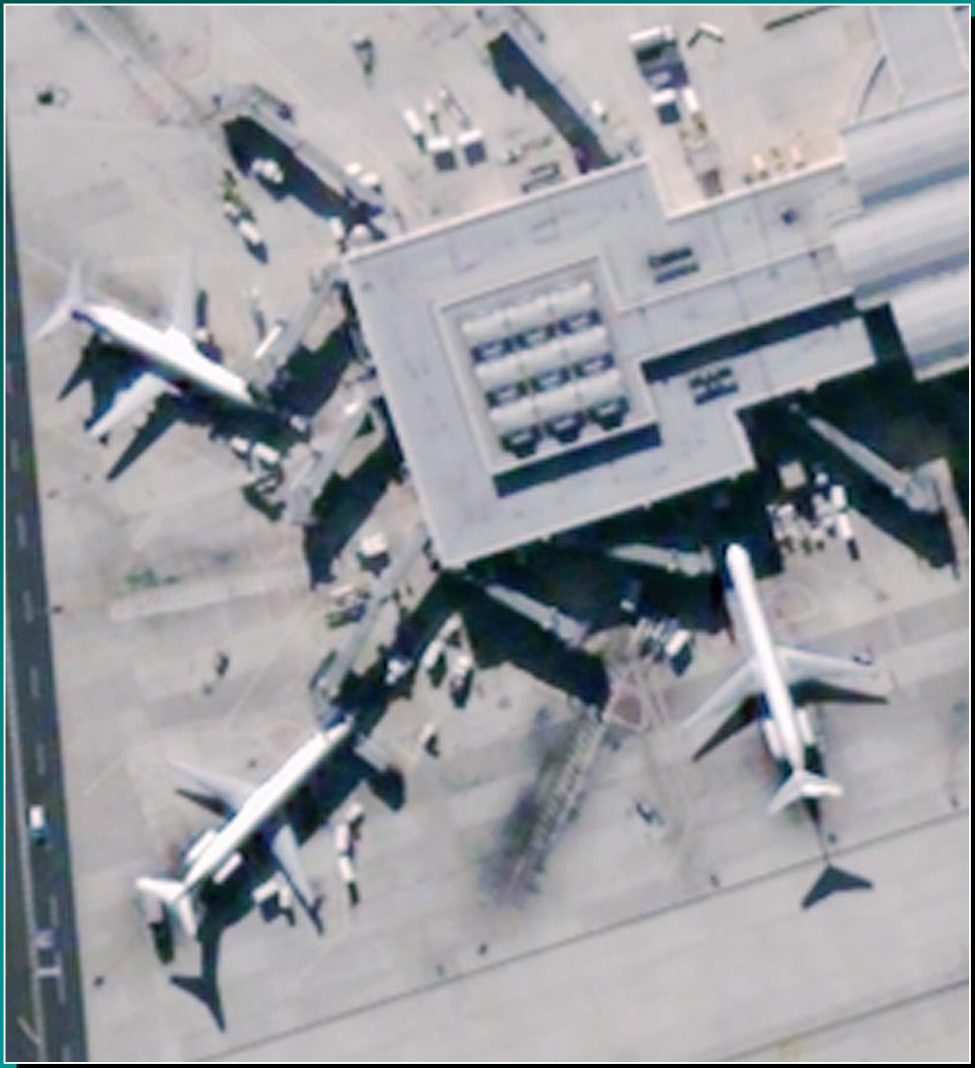
Jensen, 2000

Spatial Resolution



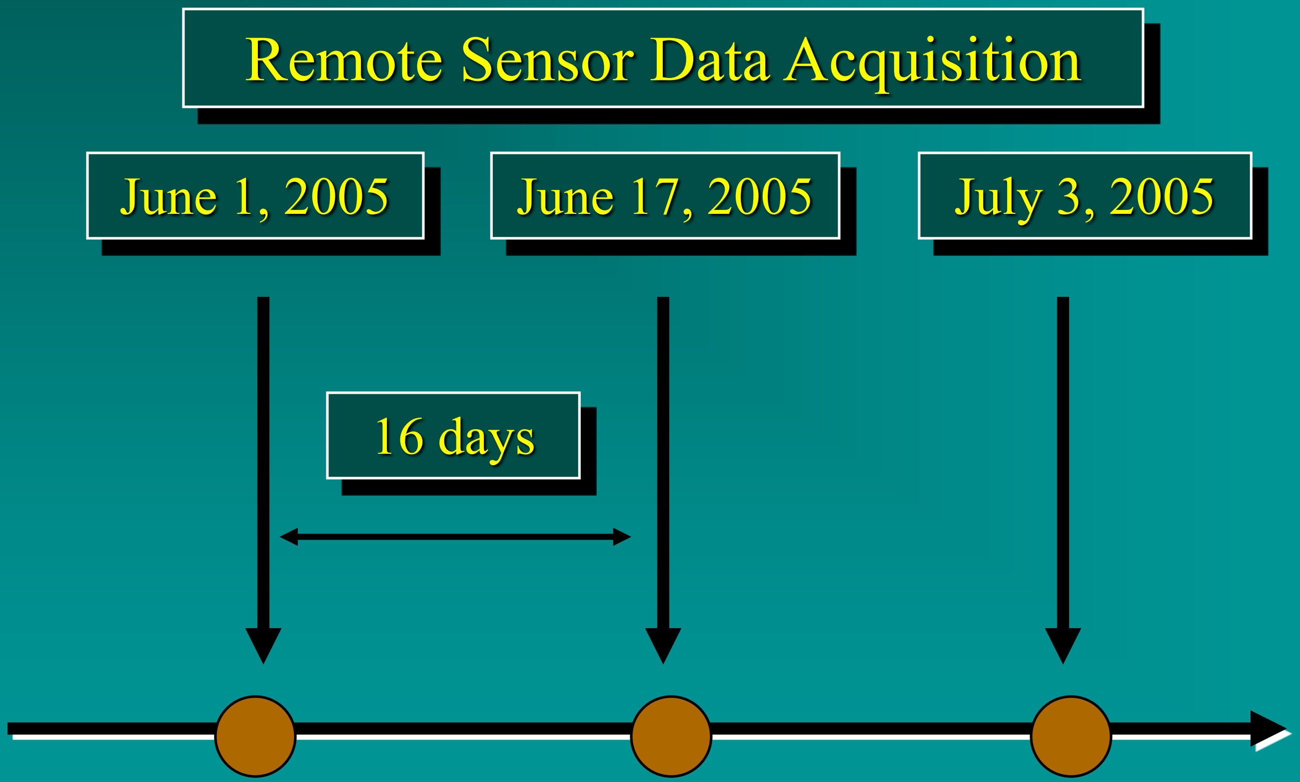
Jensen, 2004

Spatial Resolution

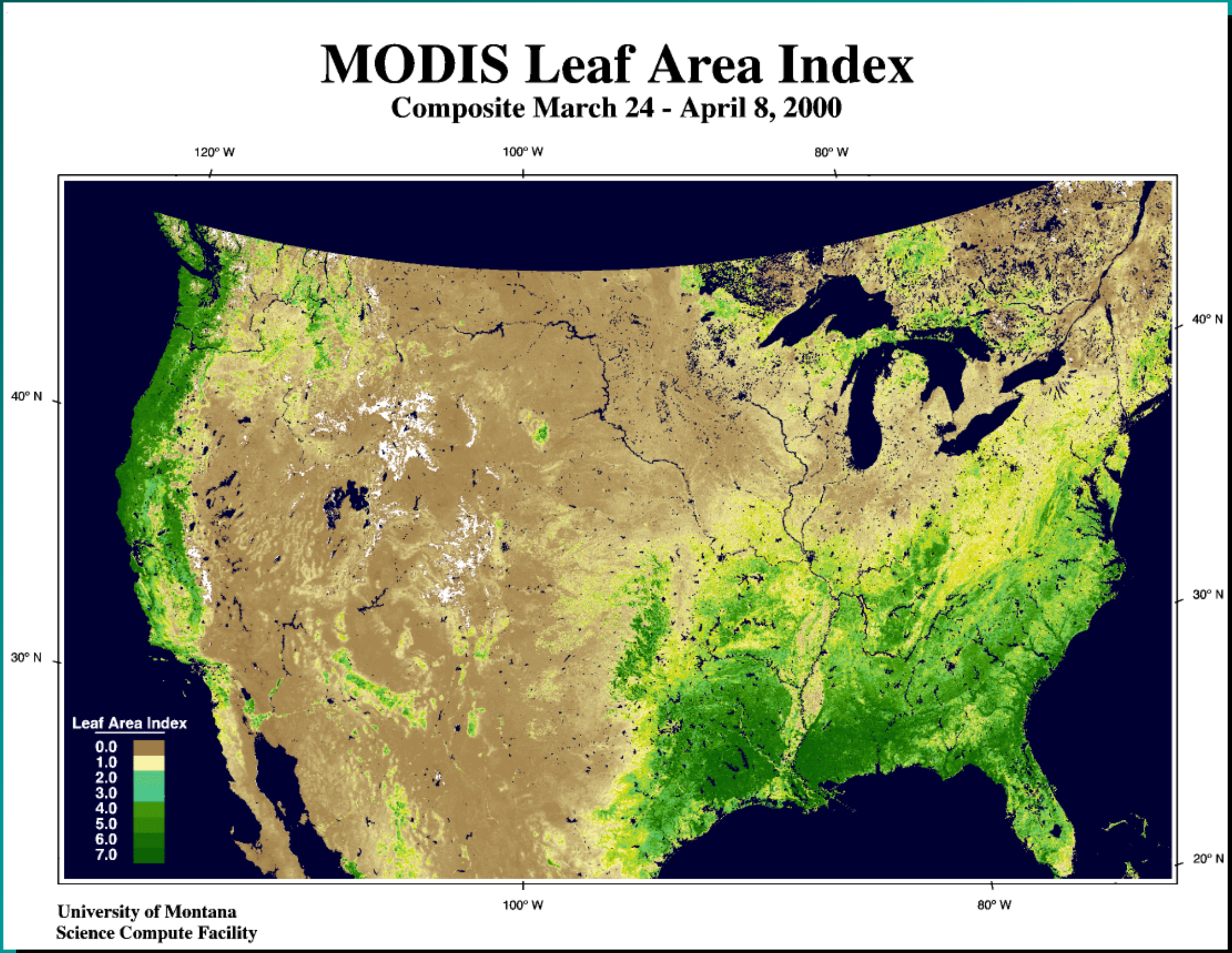


1 x 1 m of Ronald Reagan International Airport in Washington, DC by Digital Globe, Inc.

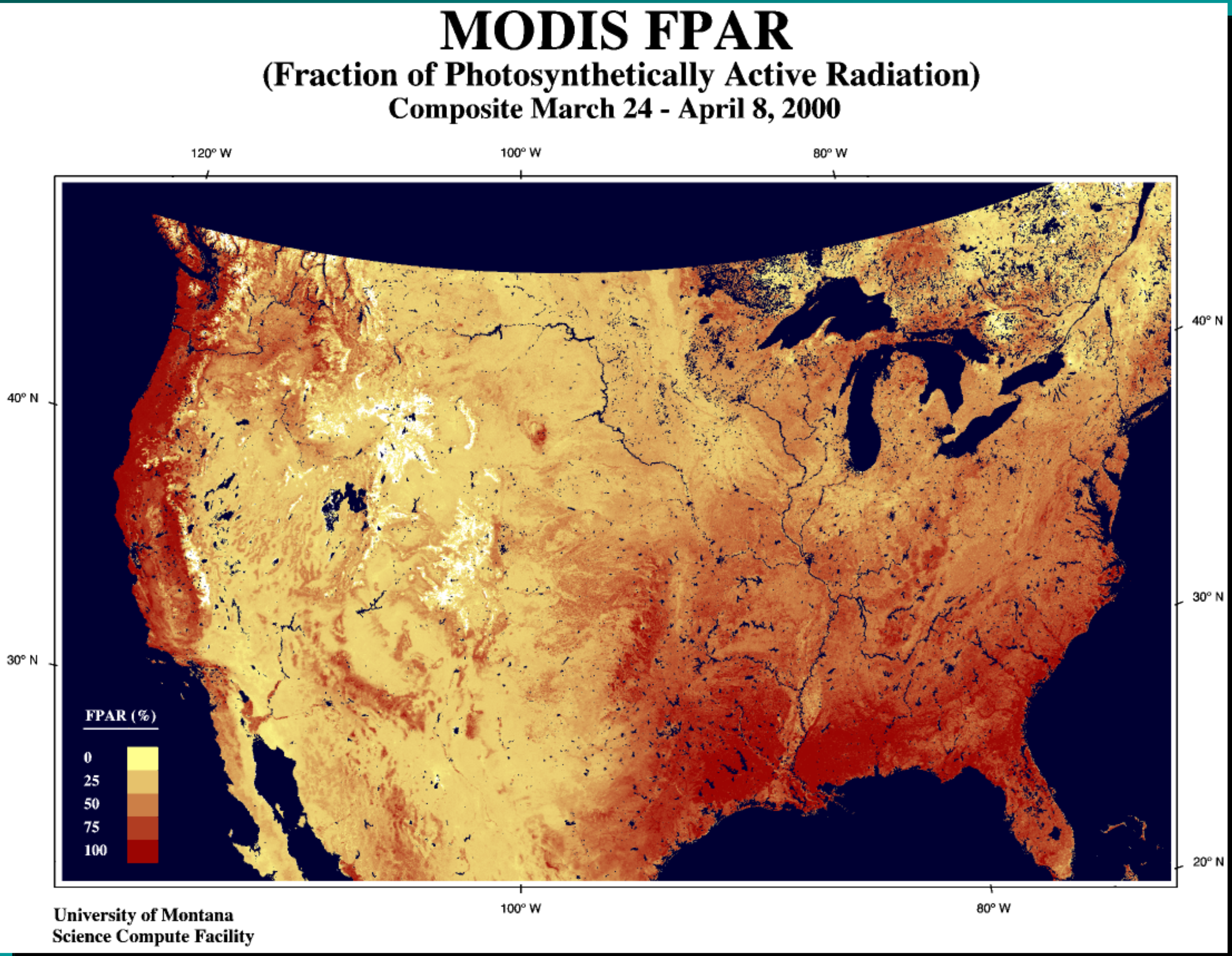
Temporal Resolution



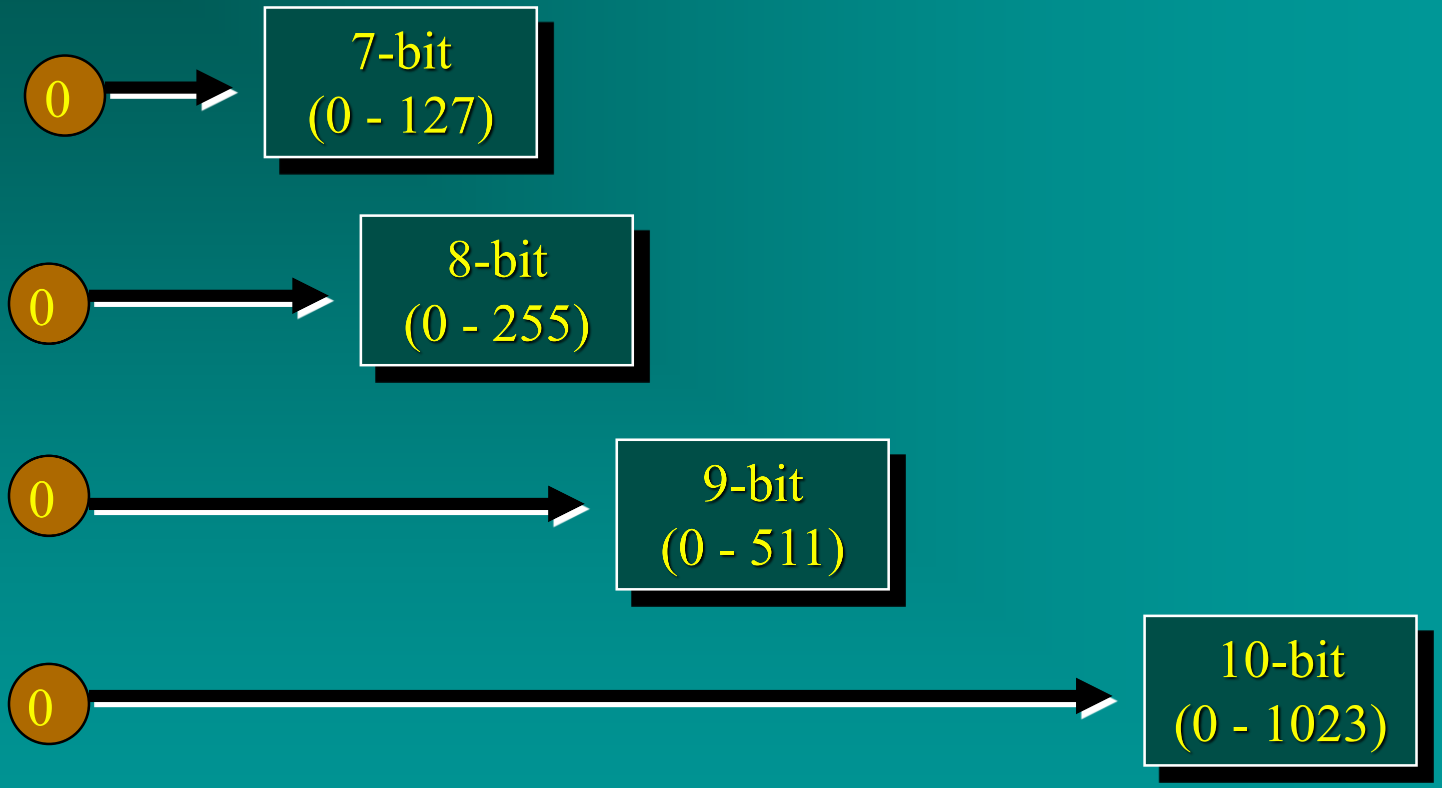
Temporal Resolution



Temporal Resolution



Radiometric Resolution

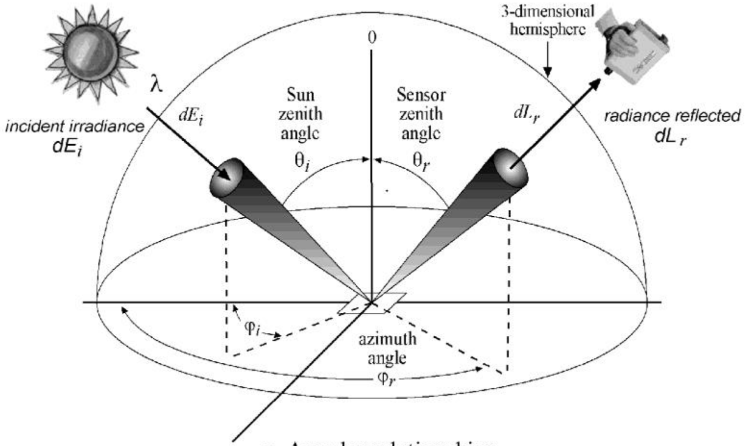


Jensen, 2000; 2004

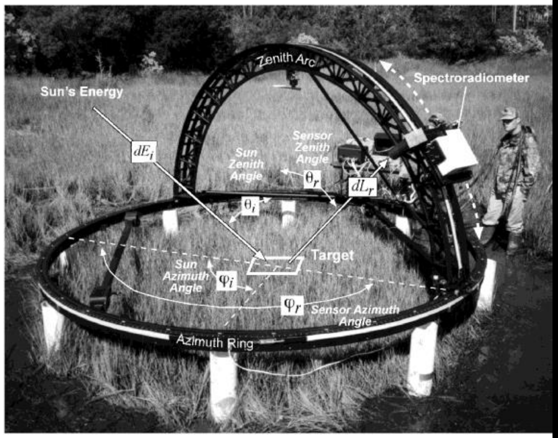
Angular Information

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.

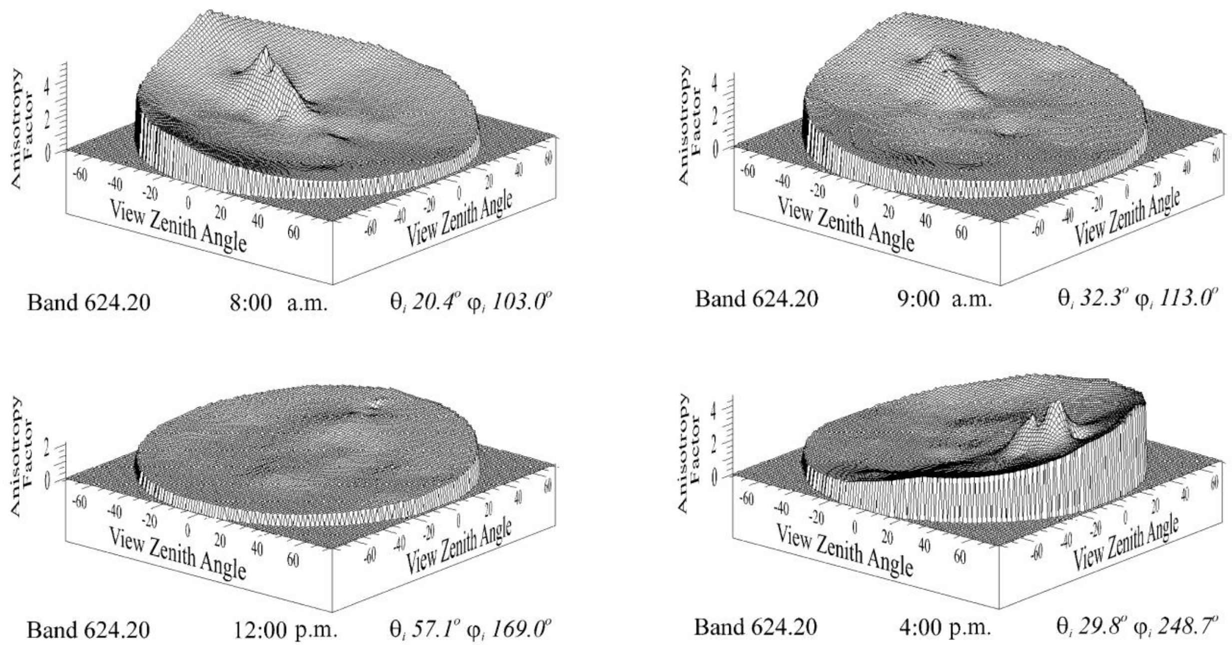
Bidirectional Reflectance Distribution Function



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.

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  - Digital elevation models
  - Soil maps
  - Surficial geology maps
  - Population density, etc.
- **Remote Sensing**
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    - Videography
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Data-to-Information Conversion

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    - 1, 2, 3, and *n* dimensions
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  - Animations
  - Simulations
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3 dimensions

Jensen, 2004

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.

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

Fundamental Image Analysis Tasks
?Detect, identify, measure
?Solve problems

Analog (Visual) Image Processing → **Elements of Image Interpretation** ← **Digital Image Processing**

Analog (Visual) Image Processing

- ?**Application of the Multi-concept**
  - Multitemporal
  - Multispectral
  - Multiscale
  - Multidisciplinary
- ?**Intuitive Convergence of Evidence**
- ? **Scientific Visualization**
- ? **Analog Monoscopic Analysis**
- ?**Analog Stereoscopic Analysis**
- ?**Collateral Information**
  - Literature
  - Dichotomous keys
  - Field training sites
  - Field test sites
  - Other GIS data

Elements of Image Interpretation

? **B&W tone** ?**Color** ?**Stereoscopic Parallax**	Primary elements
?**Size** ?**Shape** ?**Texture** ?**Pattern** ?**Fractal dimension**	Spatial arrangements of tone and color
?**Height** ?**Shadow**	Based on analysis of primary elements
?**Site** ?**Association**	Contextual elements

Digital Image Processing

- ? **Application of the Multi-concept**
  - Multitemporal
  - Multispectral
  - Multiscale
  - Multidisciplinary
- ? **Statistical and Syntactical Pattern Recognition**
- ?**Expert Systems and Neural Networks**
- ?**Scientific Visualization**
- ? **Monoscopic Photogrammetric Analysis**
- ? **Stereoscopic Photogrammetric Analysis**
  - Digital elevation model
  - Orthophotographs
- ? **Collateral Information**
  - Literature
  - Lab spectra
  - Signature library
  - Prior probabilities
  - Field training sites
  - Field test sites
  - Other GIS data
- ? **Modeling and Simulation**

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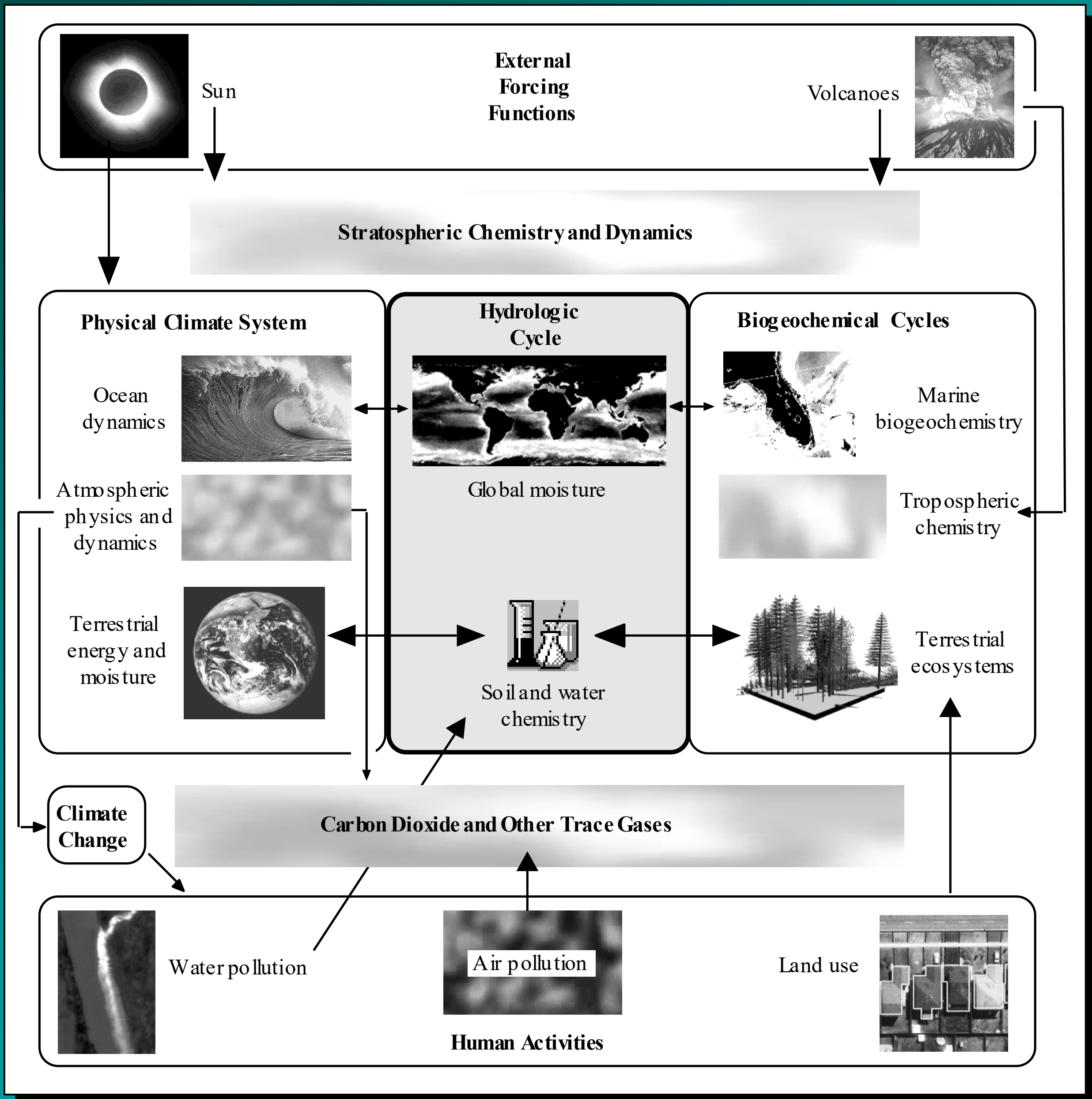
Remote Sensing Earth System Science



Jensen, 2000

Earth Resource Analysis Perspective

Such information may be useful for modeling:

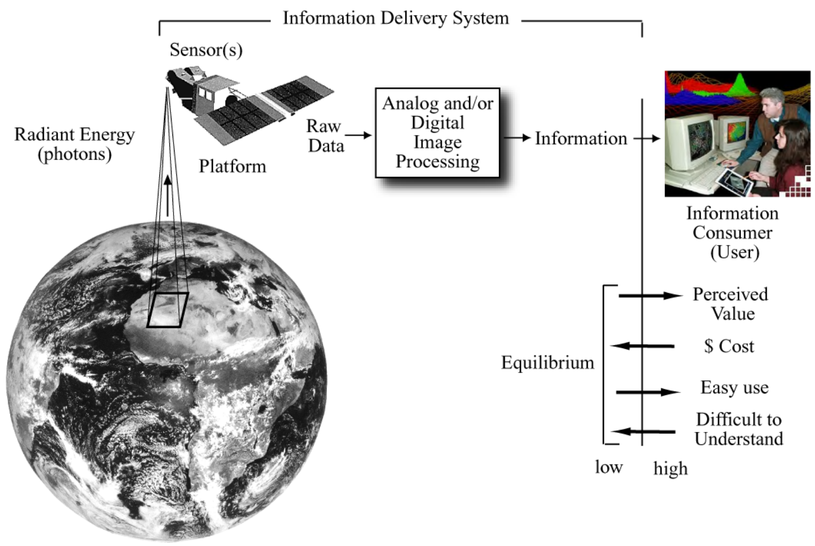
- the global carbon cycle,
- biology and biochemistry of ecosystems,
- aspects of the global water and energy cycle,
- climate variability and prediction,
- atmospheric chemistry,
- characteristics of the solid Earth,
- population estimation, and
- monitoring land-use change and natural hazards.

REMOTE SENSING 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

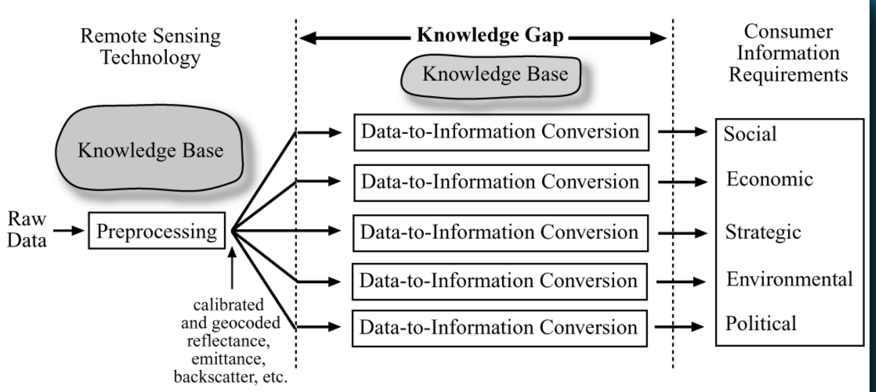
THE KNOWLEDGE GAP ASSOCIATED WITH TURNING REMOTELY SENSED DATA INTO USEFUL INFORMATION

The general process of converting remotely sensed data to useful information is shown below. It can be divided into two steps that must function in harmony:

1) ***remote sensor data pre-processing***, and

2) the calibrated ***data-to-information conversion***.

The first step involves relatively sophisticated digital (or analog) image processing to convert the raw remote sensor data into calibrated, geocoded (accurate x,y,z location), reflectance, emittance, or backscattered data. The knowledge base associated with pre-processing remotely sensed data is relatively well developed with many robust algorithms that actually work. Thus, the pre-processingknowledge base symbolization is relatively large. Unfortunately, it is not always used wisely.



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.

A Taxonomy of Models used in Remote Sensing, GIS, and Environmental Science Research

Models Based on the Method of Processing		Models Based on the Type of Logic Used: **Inductive**	Models Based on the Type of Logic Used: **Deductive**
		• Dominate spatial data handling (GIS, remote sensing) in environmental science • *Steps:* - define hypothesis - collect data and derive conclusion from facts - statistical analysis used to accept or reject research hypothesis - state probability of conclusion	• Develop a specific conclusion from a set of general propositions (premises) • *Steps:* - proceed from general truths (premises) to a conclusion - if the premises are accepted, then one must accept the conclusion
Deterministic • Fixed output(s) for specific input(s)	**Empirical** • May be inductive or deductive • Often developed from empirically derived field measurements although rules may be encapsulated in an expert system • Can be difficult to extend through space and time	• Statistical models (e.g., bi-variate regression relationship between NDVI and biomass) • *Training* supervised classifiers • Threshold models • Rule induction • Geostatistical models	• For example, the computation of NDVI • *Classification* by supervised classification algorithms (e.g., maximum likelihood via model inversion) • Modified inductive models • Process models
	Knowledge-driven • Use rules to define relationships between dependent and independent variables	• May generate rules from training data (e.g., using C5.0) • Bayesian inference algorithm states that the conditional probability of a hypothesis occurring is a function of the evidence • Fuzzy systems	• Expert system based on - knowledge base of rules extracted from an expert - analysis by inference engine
	Process-driven • Use mathematics to describe factors controlling a process • Usually deductive • May be limited to small, simple areas • Temporally static or dynamic • May be *distributed* or *lumped*	• Modification of inductive model coefficients for local conditions using field or laboratory data	• Hydrological models • Ecological models • Atmospheric models
Stochastic • Input is randomly varied • Output is variable		• Neural network classification - trained based on induction - random weights may be assigned prior to first epoch (processing) • Monte Carlo simulation	• Monte Carlo simulation

Jensen, 2004