A Remote Sensing Overview: Principles and Fundamentals

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Outline

- **Remote Sensing**
  - **Introduction: Need, History, Advantages**
  - **How it works**
    - Physical basis
    - Sensors, data acquisition and analysis
- **Applications**
  - **Examples of mapping and monitoring Minnesota land and water resources**
- **Future Perspectives**

Challenges….

- Feeding the world's population
  - Now 6 billion plus
  - Urbanization, soil erosion and salinization,… have reduced the amount of cropland
- Tropical deforestation
- Global warming and climate change
- Ozone depletion
- Toxic chemicals in the environment
- Loss of biodiversity and habitat
-
-

Environmental and Natural Resources Issues in Minnesota

- Forest fragmentation
- Loss of wetlands
- Loss of farmland
- Soil erosion
- Ground water contamination
- Lake water quality
- Flooding
- Urban sprawl
- Climate change
-
-
-

- Demand for **accurate, timely** information on environment and natural resources, including **spatial relationships** and **temporal changes and trends**, is increasing at all levels, **local to global**.

…provides opportunity and need for remote sensing and geospatial analysis

"Man must rise above the Earth to the top of the universe and beyond, for only then will fully understand the world in which he lives."

- Socrates, 500 BC

Advantages of Remote Sensing

1. Improved vantage point, synoptic view

Advantages of Remote Sensing

1. Improved vantage point, synoptic view
2. Broadened spectral sensitivity
3. Increased spatial resolution
4. 3-D perspective
5. Capability to stop action
6. Historical record
7. Comparability of data
8. Rapid data collection
9. Quantitative analysis
10. Ability to extend ground observations
11. Cost savings

Uses of Remotely Sensed Images

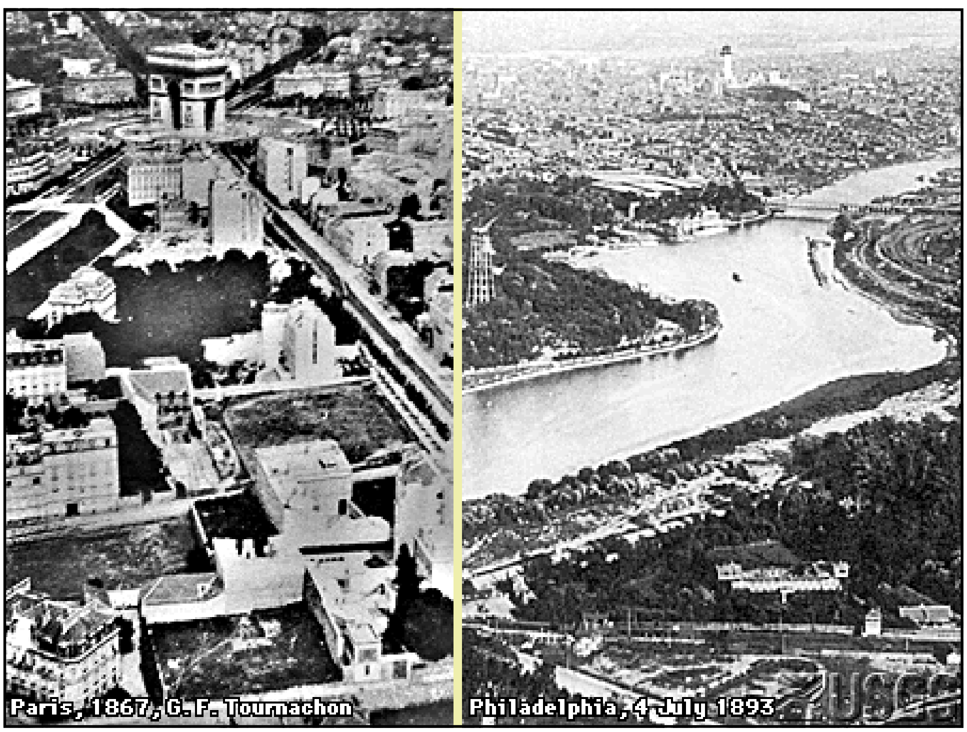
- Base on which other information can be portrayed
- Delineate patterns
- Determine extent and areas of different cover types and conditions
- Quantitative measurement of landscape properties

Applications of Remote Sensing
a few of many…

- **Agriculture, Forestry and Range**
  - Identify crop, forest and rangeland types
  - Measure area
  - Assess condition and estimate yields
  - Monitor changes
- **Water Resources**
  - Lake water quality monitoring
  - Inventory and mapping of wetlands
- Urban Dynamics
  - Monitor land use and change

History of Remote Sensing

- 1839 Photographic image formed
- 1850's Photography from balloons
- 1909 First photography from airplane
- 1920's Initial development of photogrammetry and applications of aerial photography
- 1940's Initial development of infrared and radar sensing
- 1956 Research on crop disease detection with infrared photography

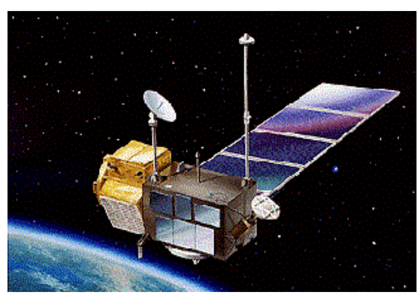


History of Remote Sensing, cont.

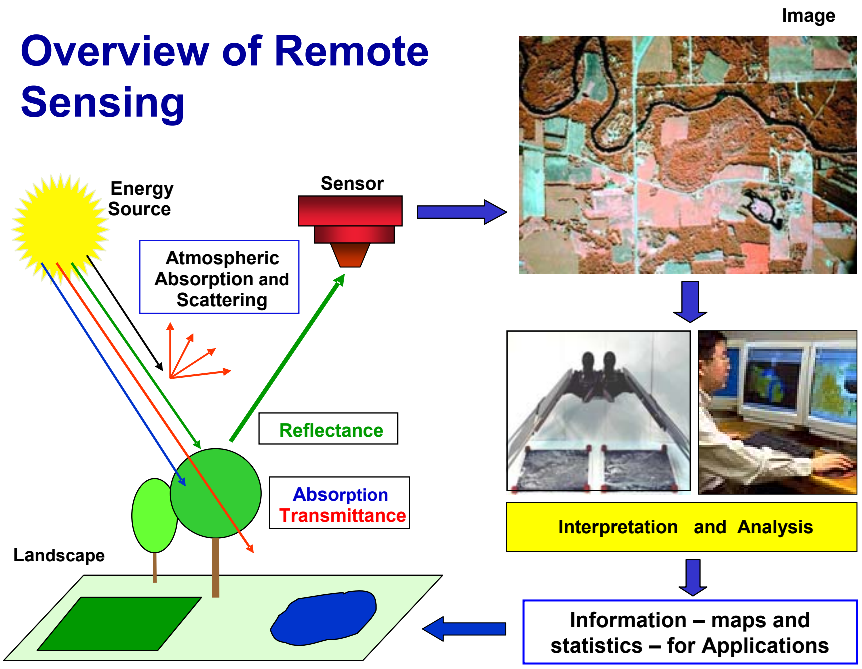
- 1960 "Remote Sensing" term first used
- 1960 TIROS weather satellite launched
- 1965 Airborne multispectral scanner data becomes available for civilian research
- 1972 Launch of Landsat 1
- 1982 Landsat-4 w/ Thematic Mapper launched
- 1986 SPOT satellite launched
- 1999 First U.S. high resolution commercial satellite successfully launched
- 1999 Launches of Landsat-7 and Earth Observing System (Terra satellite)

Definition of Remote Sensing

- **Obtaining information about Earth's surface from measurements by aircraft or satellite sensors of radiated energy**

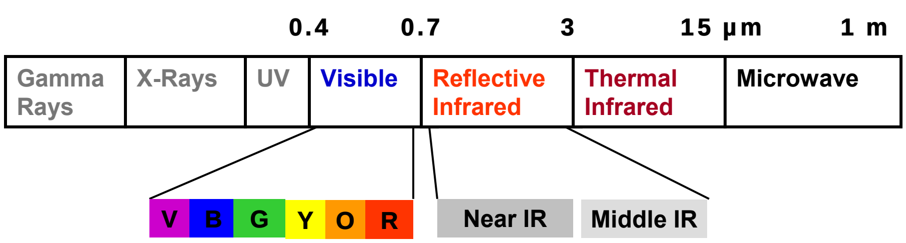


Overview of Remote Sensing



Major Objective of Remote Sensing

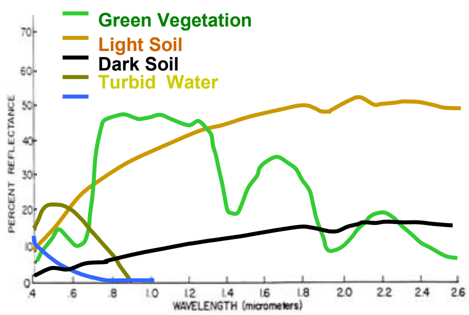
Detect, measure, record and analyze
energy radiated
in selected wavelengths of the
electromagnetic spectrum



Physical Basis of Remote Sensing

The distinctive character of electromagnetic radiation reflected or emitted from natural and human-made objects and scenes.

Spectral Reflectance of Basic Cover Types



What Information Can Be Remotely Sensed?

Fundamental Variables

- Planimetric (x,y) location and dimensions
- Topographic (z) location
- Color (spectral reflectance)
- Surface temperature
- Texture
- Surface roughness
- Moisture content
- Vegetation biomass

Sources of Information

Variations in electromagnetic fields that can be used to identify and characterize objects:

- Spectral-radiometric (color, temperature)
- Spatial (pattern, size, shape, texture, ...)
- Temporal (time 1, time 2, …)

Active and Passive Sensors

- Passive Sensors
  depend on external energy source, i.e. Sun
  - **Photographic** } *this presentation*
  - **Multispectral**
  - Thermal infrared
  - Hyperspectral
  - Passive microwave
- Active Sensors
  energy is transmitted from sensor system to object or surface
  - Radar
  - Lidar

Major Types of Sensor Systems

Orientation	Typical Sensor, Analysis	Advantages	Disadvantages
Pictorial	Camera, Photo Interpreter	Resolution Familiarity Cost	Spectral range Data volume
Numerical	Multispectral Scanner, Computer-aided	Spectral range Radiometric resolution Digital analysis GIS compatible	Complexity Familiarity Cost

Cameras and Films

- 9-inch metric camera

- Small format cameras

Film Types

Black and white

- **Panchromatic**
- **Black and white infrared**

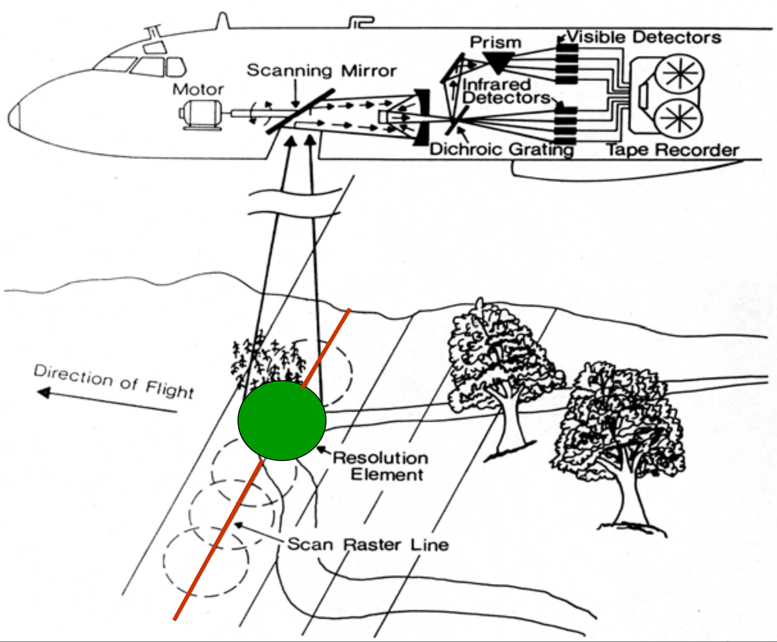
Color

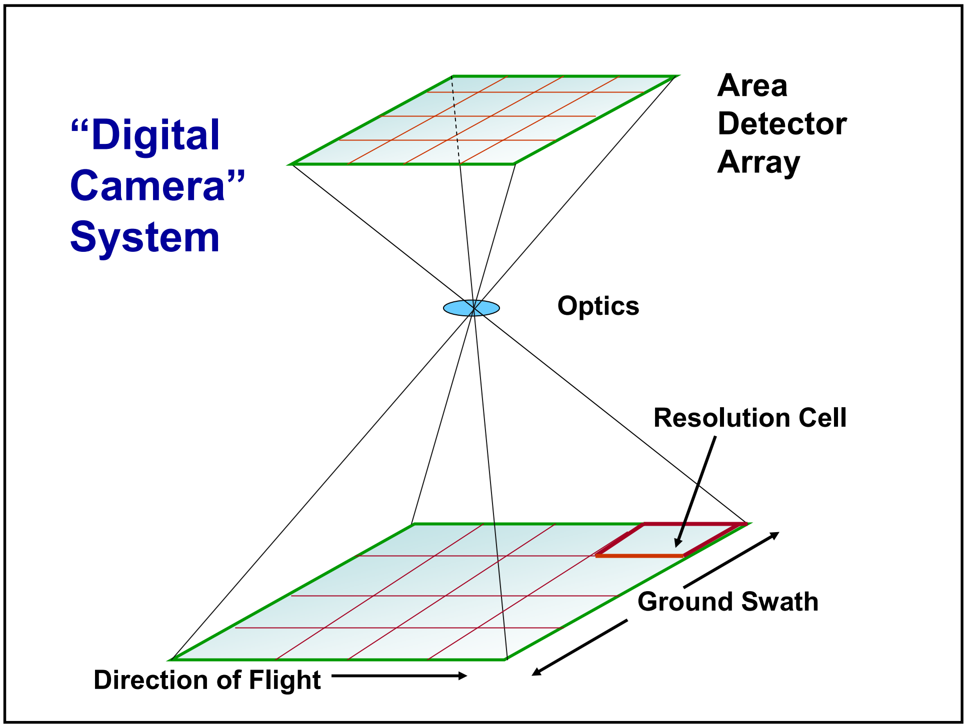
- **Color**
- **Color infrared**

Color Infrared Aerial Photo

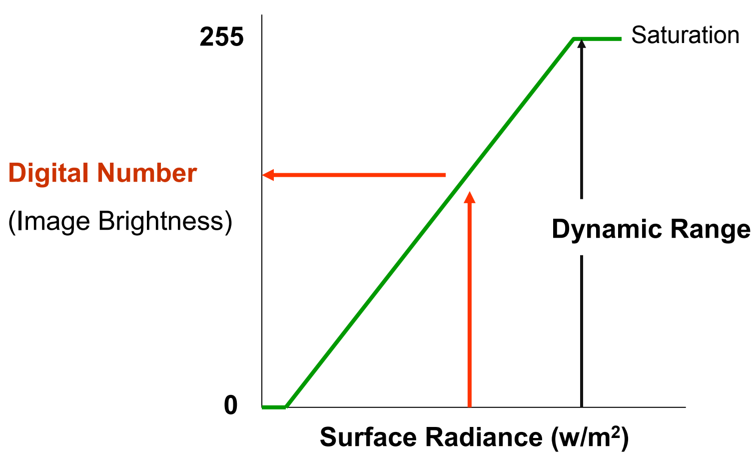
Illustrating photo interpretation elements: color, texture, shape, …

How a Multispectral Scanner Works



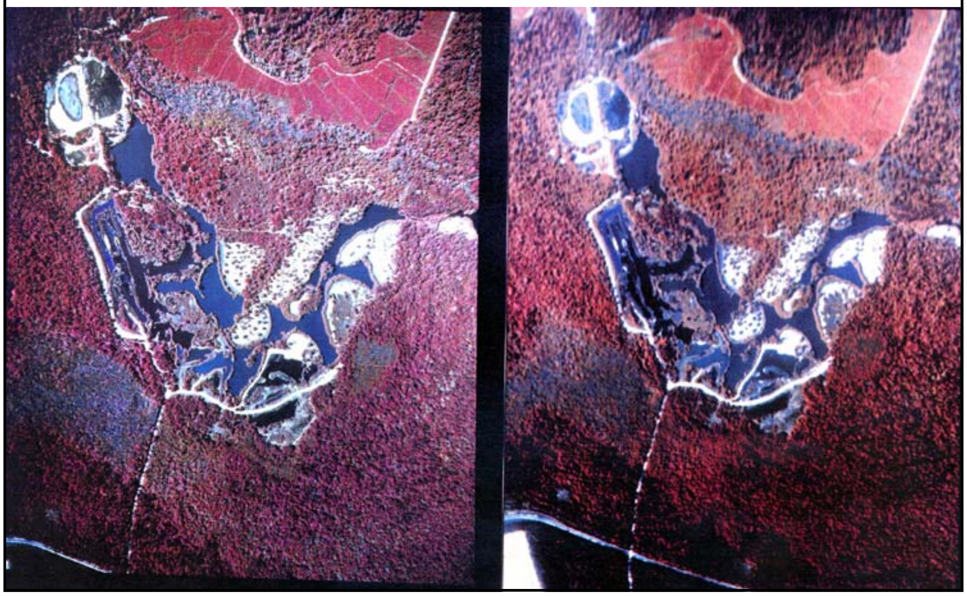


Sensor Input and Output

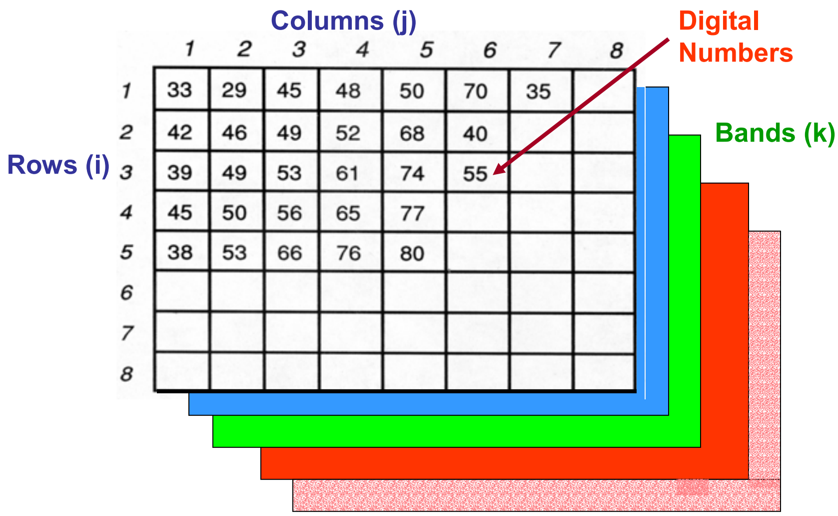


Surface Radiance, $L = 1/\pi\ \rho\ E\ T + L_P$

Comparison of Color IR Photo and Multispectral Scanner Image



Components of Digital Images



	1	2	3	4	5	6	7	8
1	33	29	45	48	50	70	35	
2	42	46	49	52	68	40		
3	39	49	53	61	74	55		
4	45	50	56	65	77			
5	38	53	66	76	80			
6								
7								
8								

Advantages and Disadvantages of Electronic/Digital Sensors

- **Advantages**

  Spectral range

  Radiometric resolution

  Digital analysis

  GIS compatible

Advantages and Disadvantages of Electronic/Digital Sensors

- **Advantages**

  Spectral range

  Radiometric resolution

  Digital analysis

  GIS compatible

- **Disadvantages**

  Complexity, maybe but becoming less complex and more user friendly

  Familiarity, perhaps, but this, too, is changing

  Cost, maybe higher, but depends on the sensor system, and all are decreasing

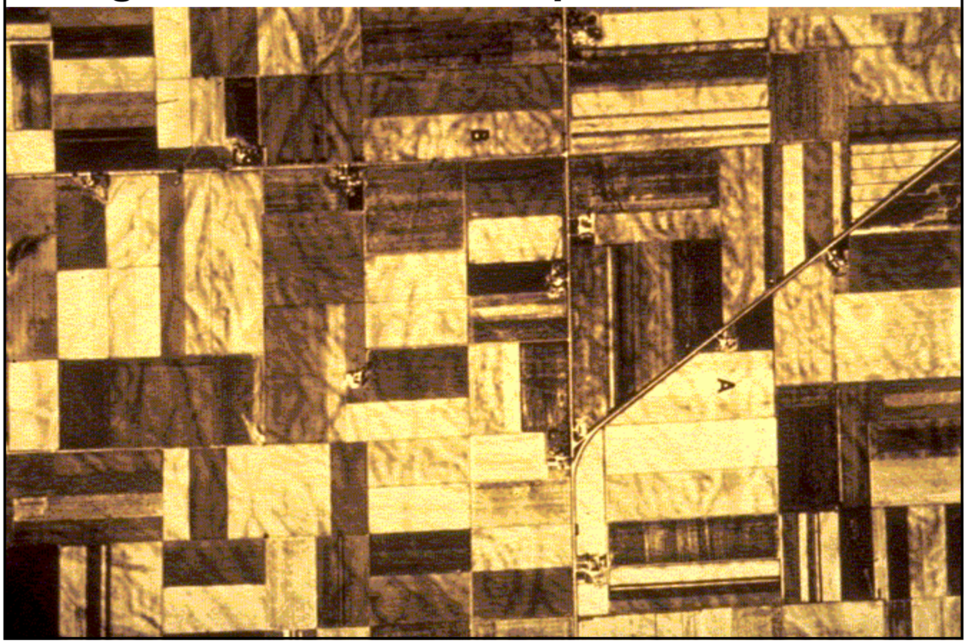
The two types of systems should not be viewed as being in competition with one another; each has different capabilities and is useful in different circumstances

- Photographic systems, typically aerial, have been best suited for intensive mapping or monitoring where high spatial detail is needed.
- Digital systems, typically satellite-borne, have been more appropriate for large area (extensive) surveys.
- **However, recently high-resolution multispectral satellite imagery has become available, AND aerial photography (imagery) is increasingly digital.**

Examples of Remote Sensing Imagery

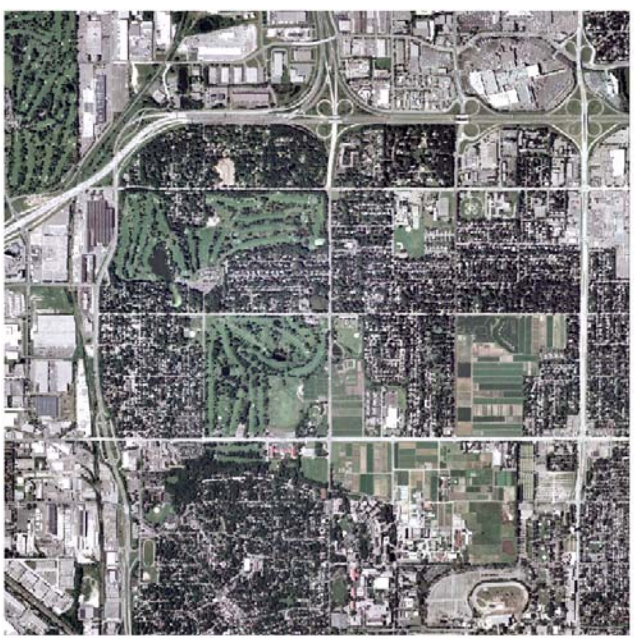
- **Aerial photography**
- **Digital imagery**
  - **Satellite**
  - **Aerial**

Large scale B&W aerial photo



Color Infrared Aerial Photo

High Altitude Color Infrared Aerial Photo



National Agricultural Imagery Program (NAIP) Digital Orthorectified Images

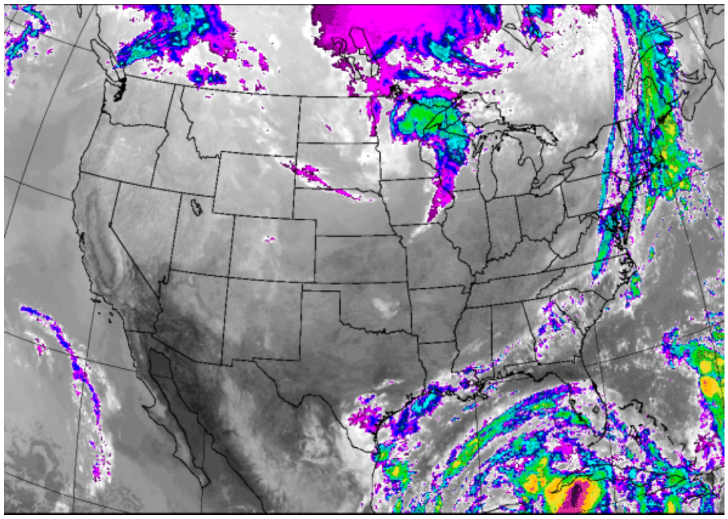
1-meter resolution

Color images

Summer 2003

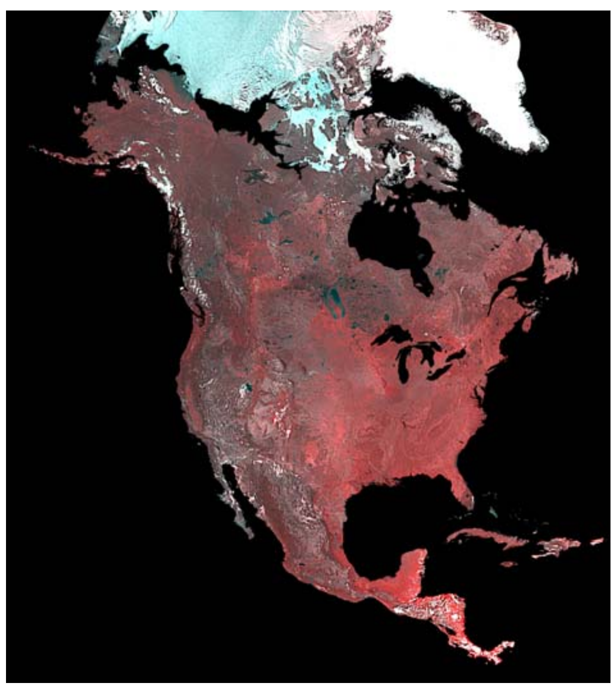
Cost -- **Free**

Perhaps the most familiar satellite remote sensing: GOES imagery of weather systems



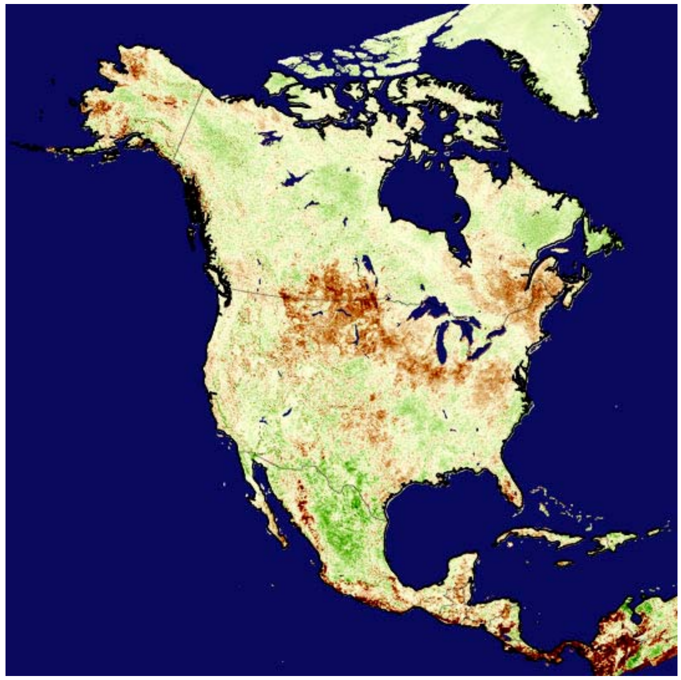
NOAA AVHRR Imagery

– another weather satellite

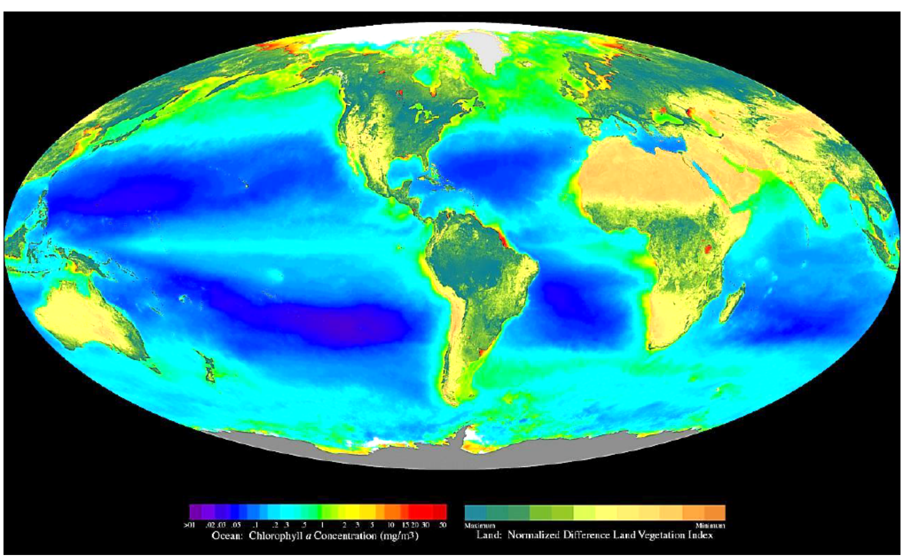


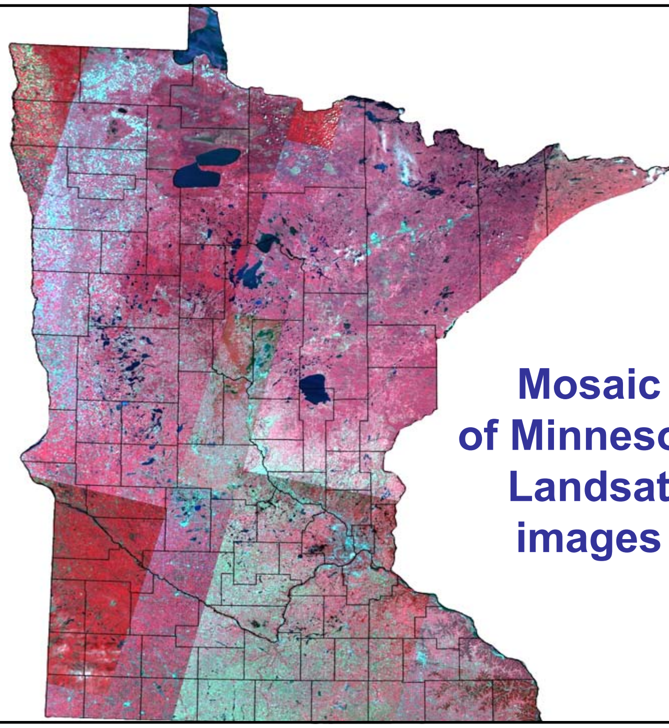
NOAA AVHRR NDVI Image

Midwest Drought, 1988

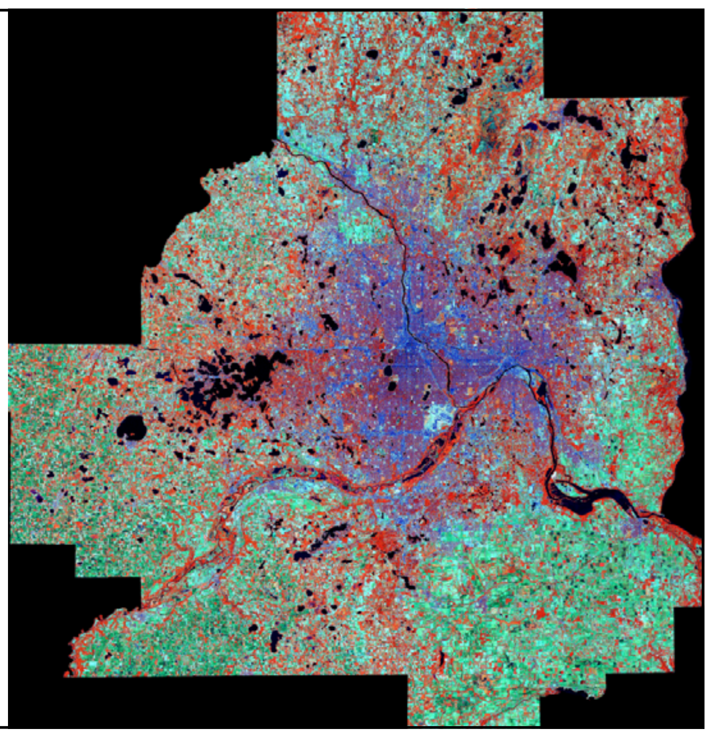


Global Biosphere: Land, Ocean Productivity



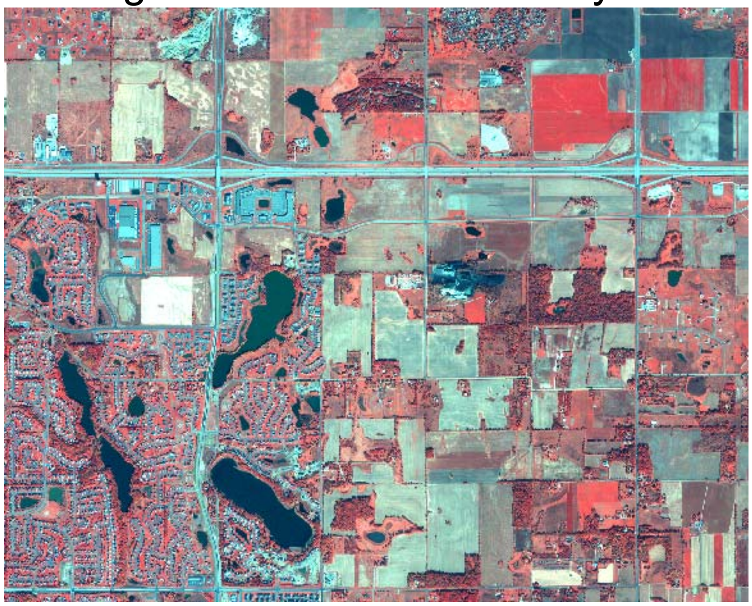


Mosaic of Minnesota Landsat images



Landsat TM Image of 7-County Twin Cities Metropolitan Area

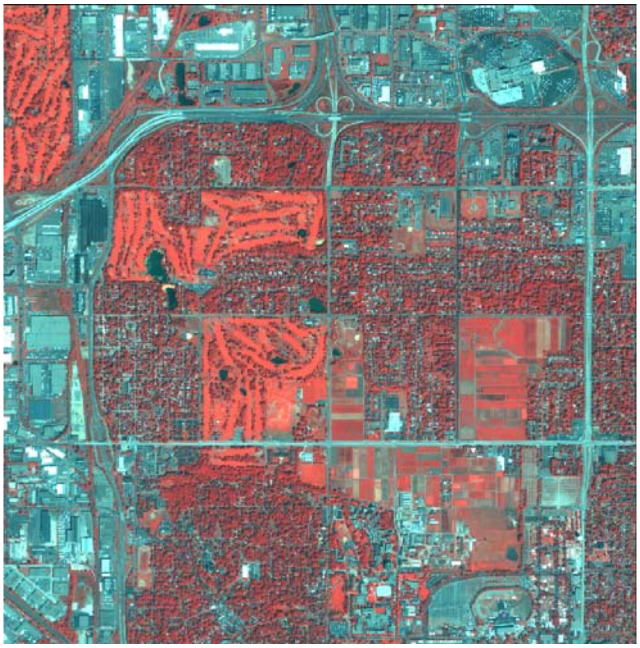
IKONOS, high-resolution (4-meter) false color image of northeast Woodbury



Imagery© Space Imaging L.P.

IKONOS, high-resolution (4-meter) color image of northeast Woodbury

Imagery© Space Imaging L.P.



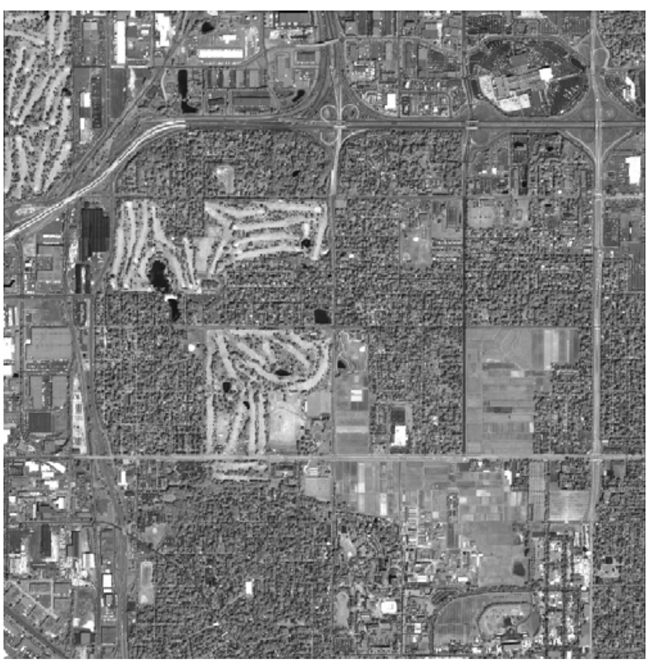
Imagery© Digital Globe

QuickBird Image

2.4 meter resolution

Band 4,3,2 false color composite

August 18, 2003



Imagery© Digital Globe

QuickBird Panchromatic Image

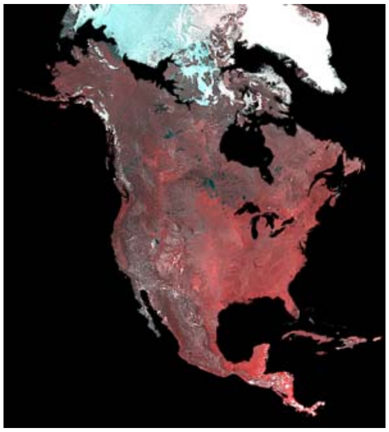
0.6 meter resolution

August 18, 2003

Scale

- Refers to the geographic coverage of an image
  ratio of image distance to ground distance

Large scale image

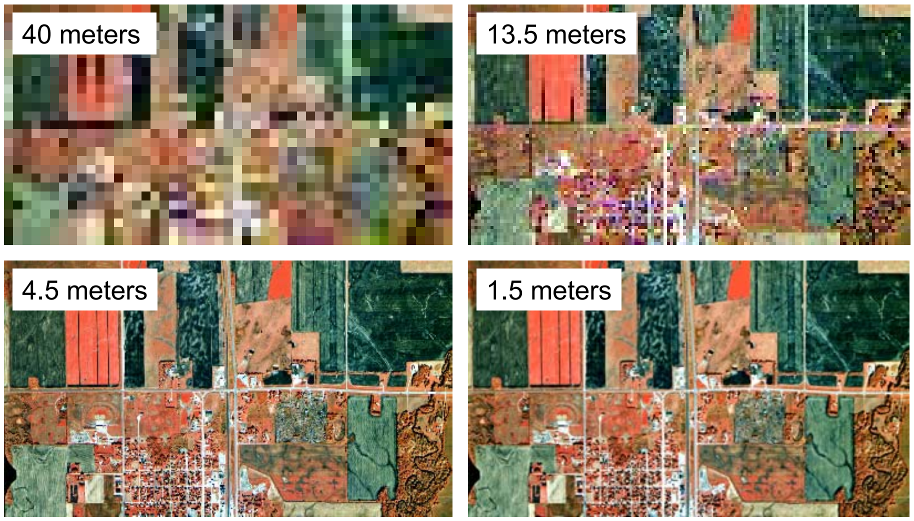


Very small scale imagery

Resolution

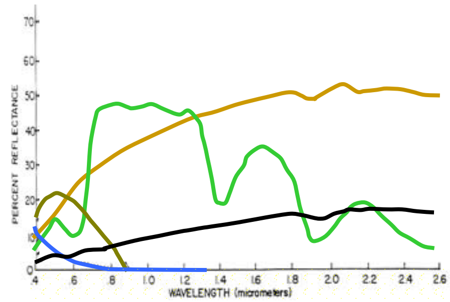
- **Spatial** -- measure of smallest angular or linear separation between two objects that can be resolved
- **Spectral** -- number and width of wavelength intervals (spectral bands)
- **Radiometric** -- sensitivity to differences in radiance; number of brightness levels
- **Temporal** -- time interval between data acquisitions

Comparison of Spatial Resolutions

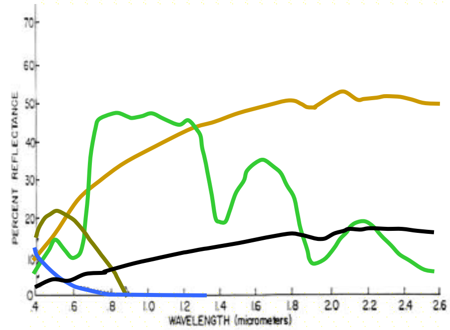


Spectral Resolution

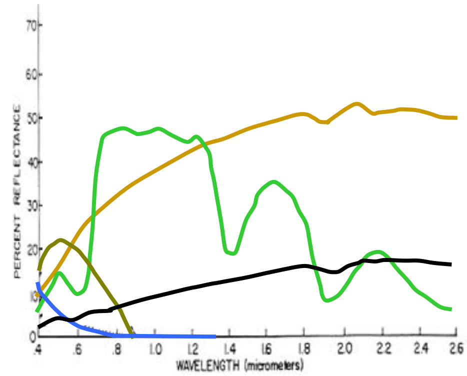
- Low



- High

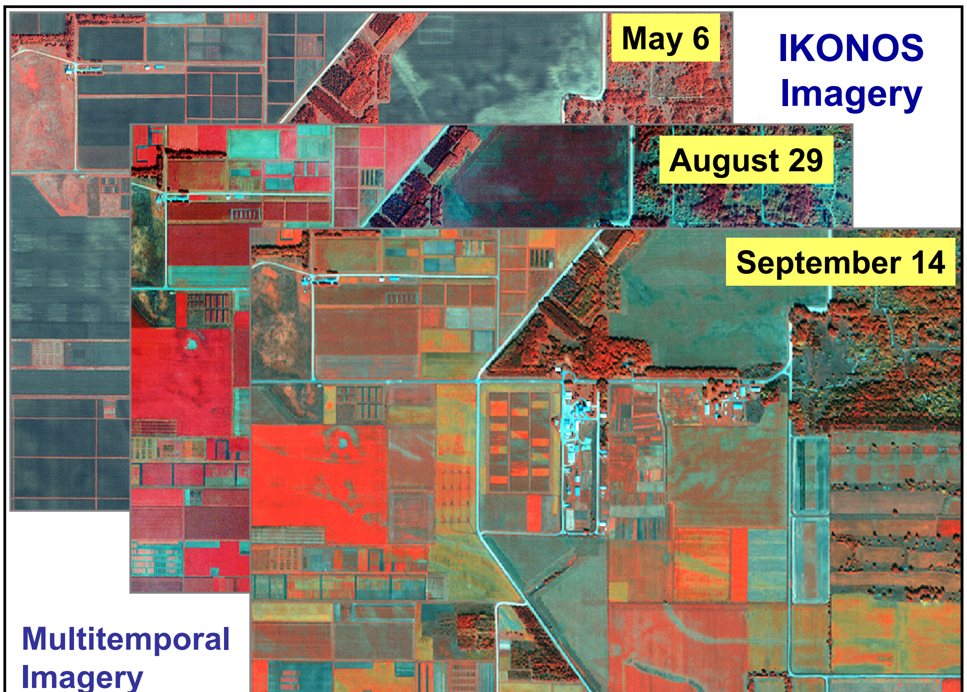


Radiometric Resolution



- Measured in “bits”
- 6-bit = 64 gray levels
- 8-bit = 256 levels, or approx. 0.25% reflectance
- 10-bit = 1024 levels, or approx. 0.10% reflectance

IKONOS Imagery

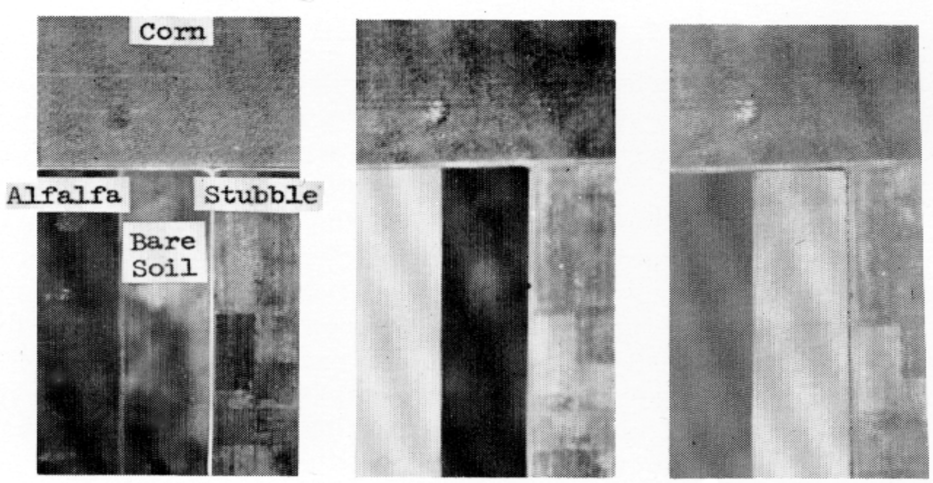


Multitemporal Imagery

Some further thoughts on sensors…

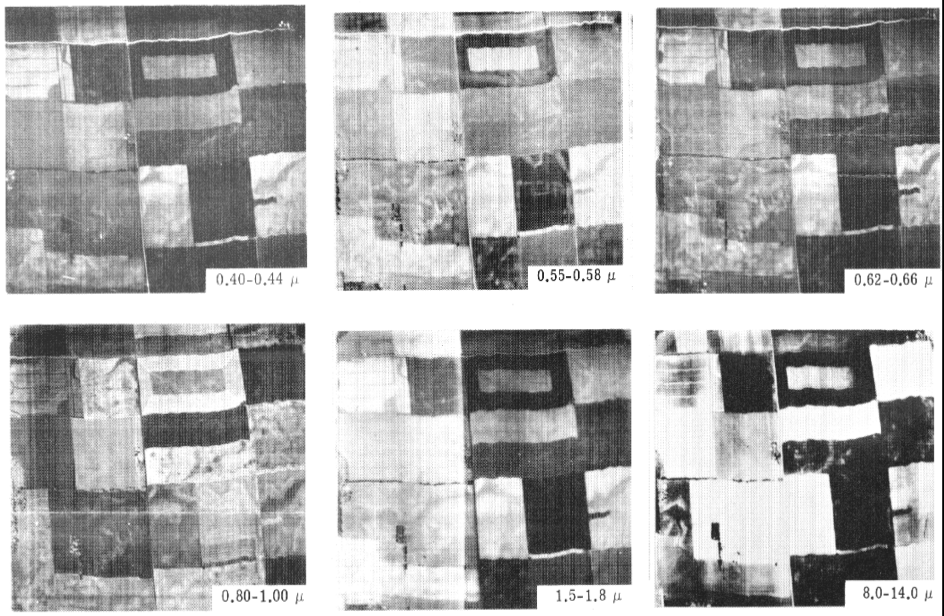
- Until recently, digital systems, typically satellite-borne, have been thought of as more appropriate for large area (extensive) surveys.
- But, today we have **high-resolution satellite** data
  - As high as 0.6 meters
- Meanwhile, **aerial digital** remote sensing systems are becoming common
- There are a wide variety (and growing number) of data acquisition and analysis approaches available
- Successful remote sensing matches information requirements to sensor characteristics
  - no single sensor or analysis procedure is appropriate for all applications

Multispectral Concept

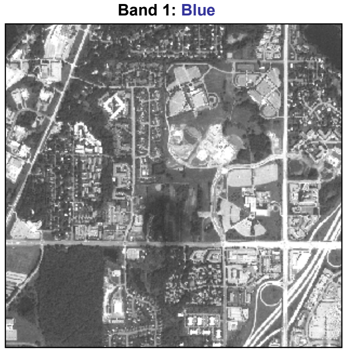


Visible 0.4 – 0.7 μm | **Near Infrared** 0.7 – 0.9 μm | **Thermal Infrared** 4.5 – 5.5 μm

Example of Multispectral Imagery

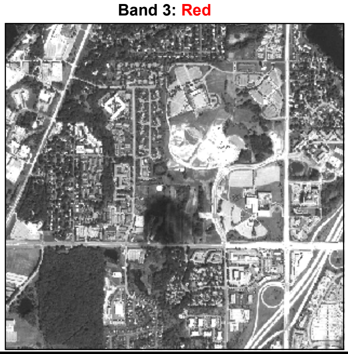


Band 1: Blue

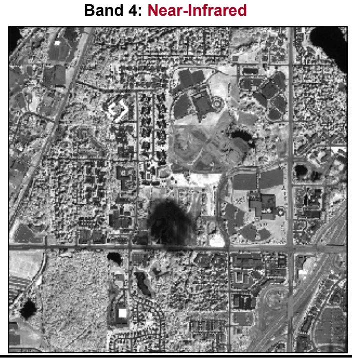


Band 2: Green

Band 3: Red



Band 4: Near-Infrared



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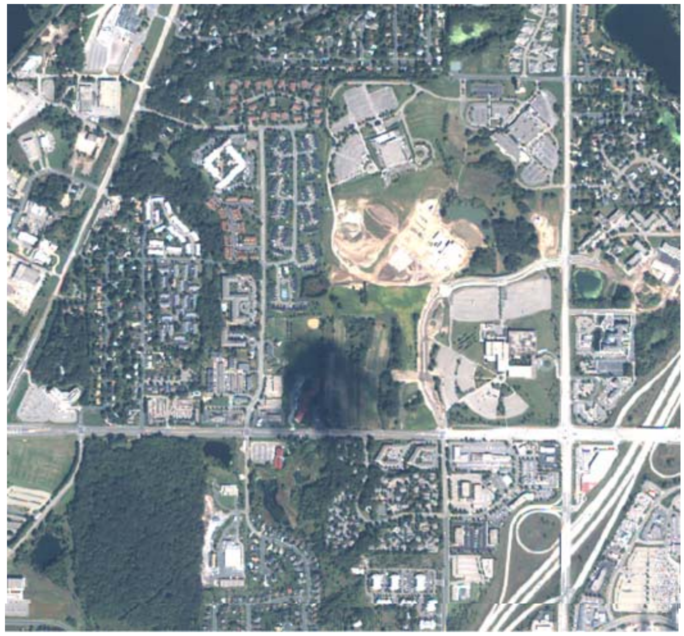
Color: bands 3, 2,1   4-meter



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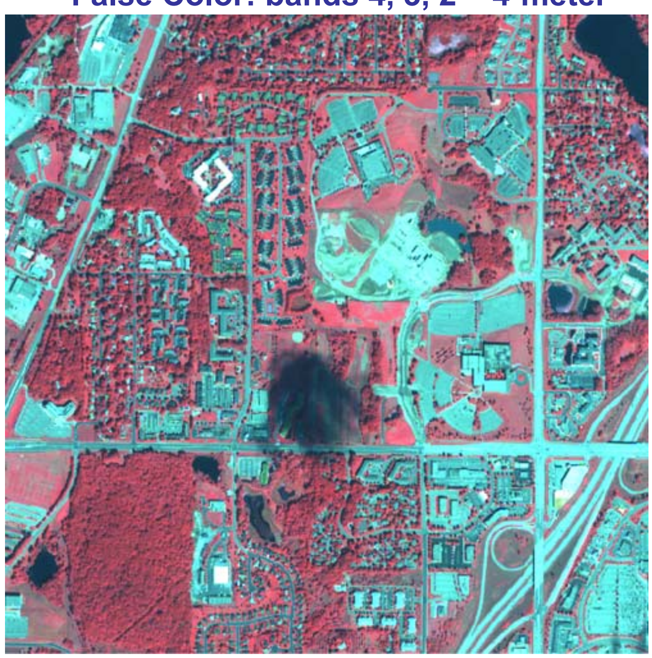
False Color: bands 4, 3, 2   4-meter



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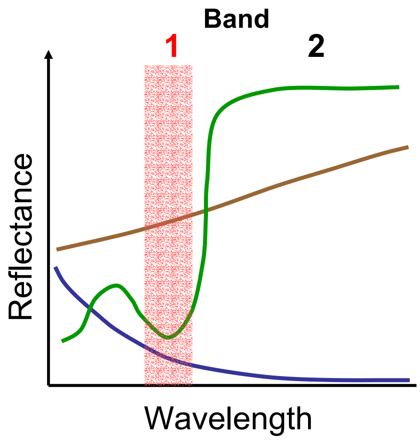
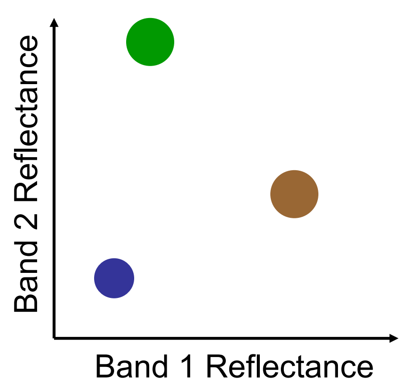
NDVI Transformation: bands 4 - 2 / 4 + 2

Multispectral Analysis

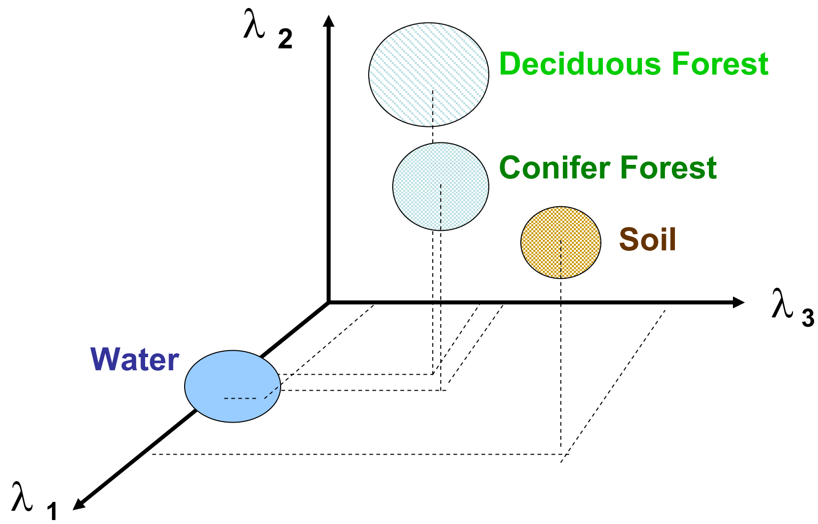
Spectral Response



Feature Space

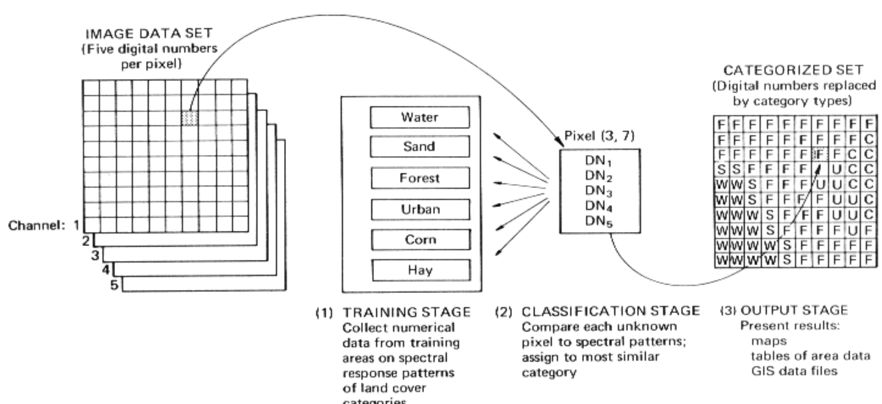


Spectral - Radiometric Response Patterns in 3-Dimensional Feature Space



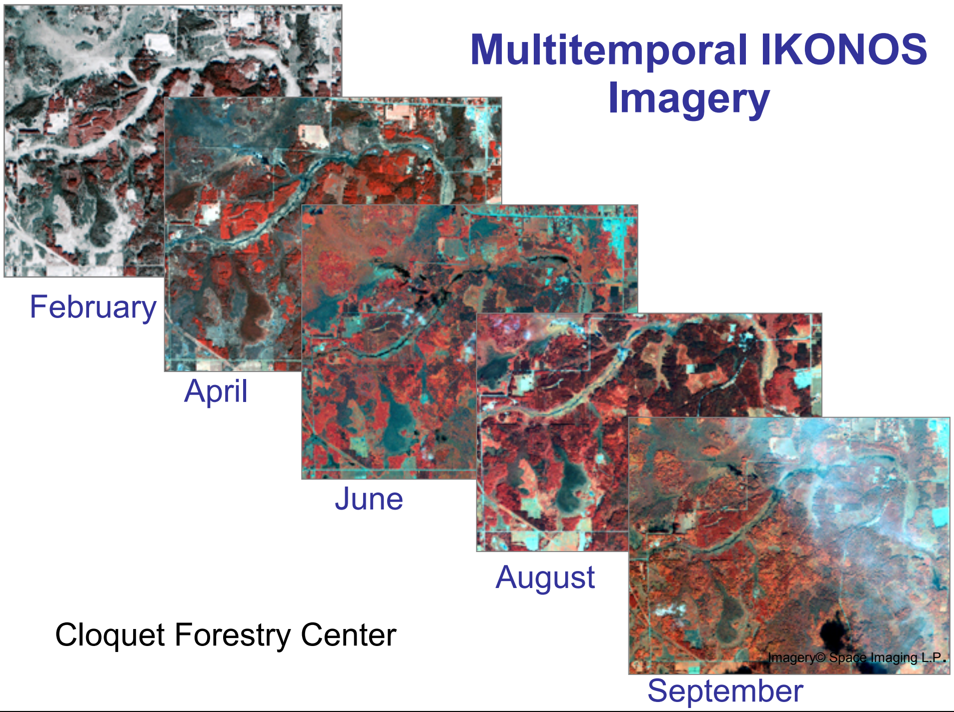
A typical approach to training and classification will take one of two forms:

- Supervised training
- Unsupervised training



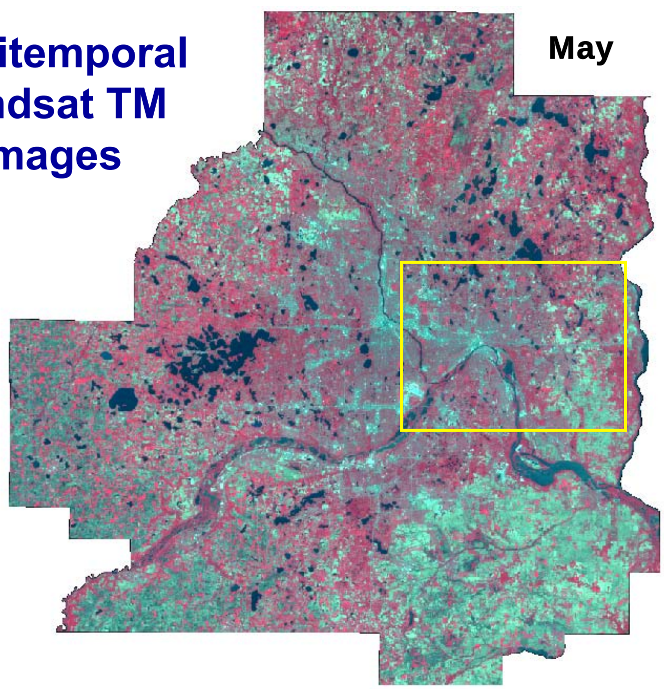
from Lillesand & Kiefer

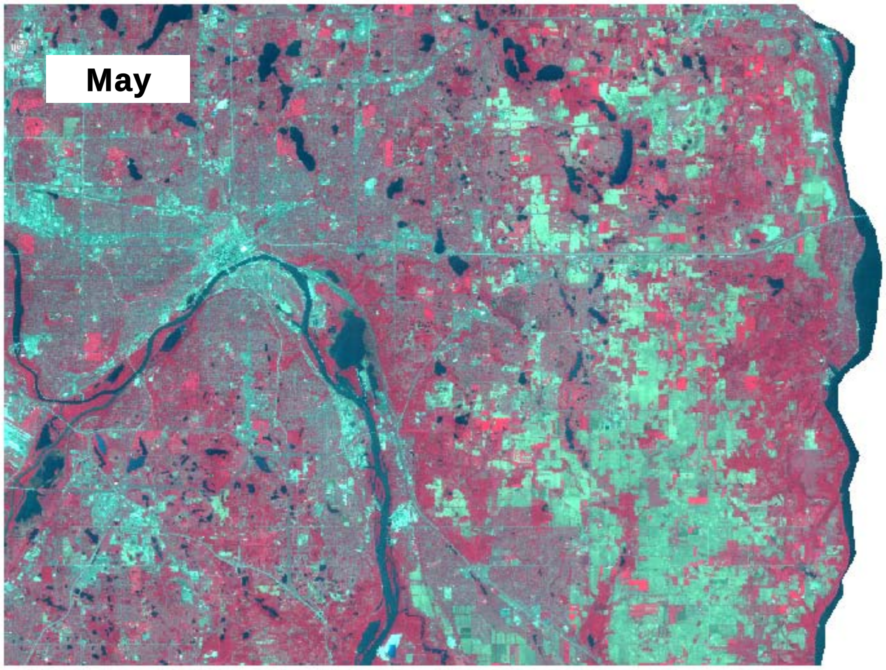
Multitemporal IKONOS Imagery

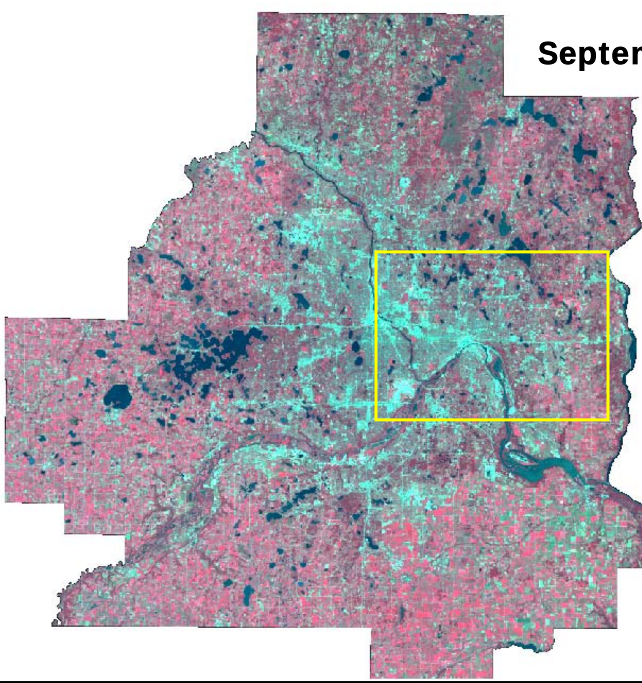


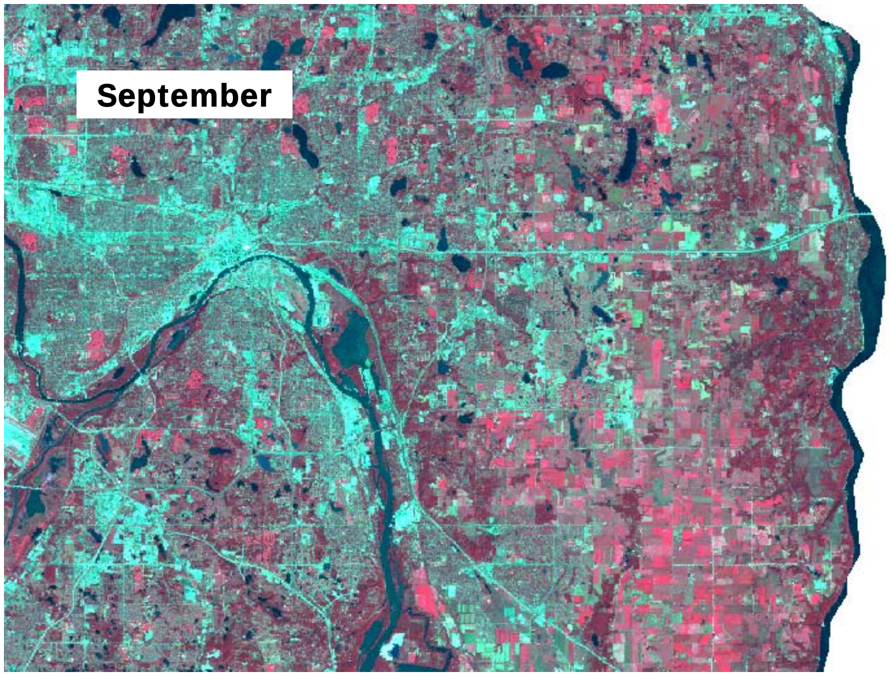
Cloquet Forestry Center

Multitemporal Landsat TM Images




May

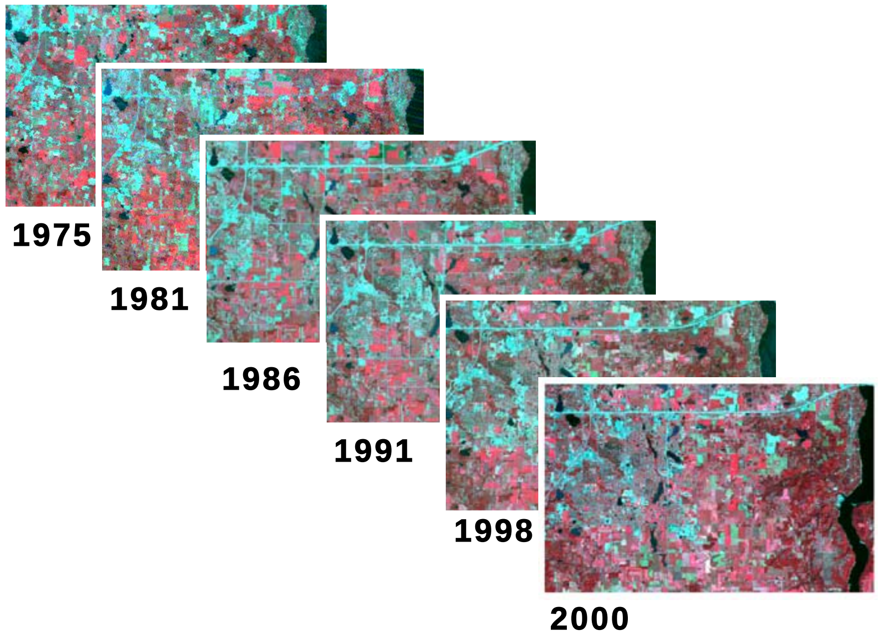

September



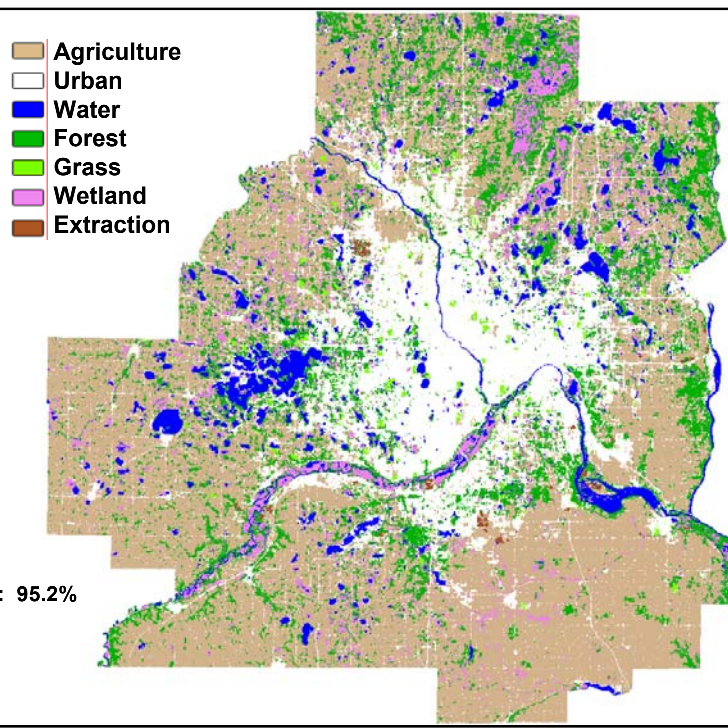
Applications of Remote Sensing

1. Land Cover Classification and Change Detection

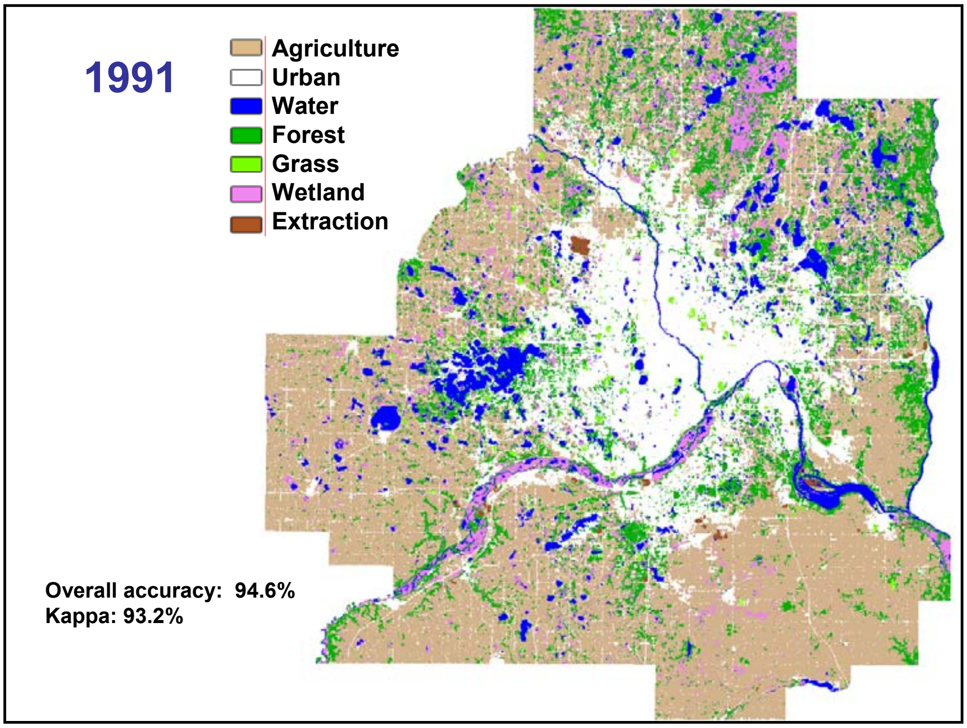
Twin Cities Landsat Imagery

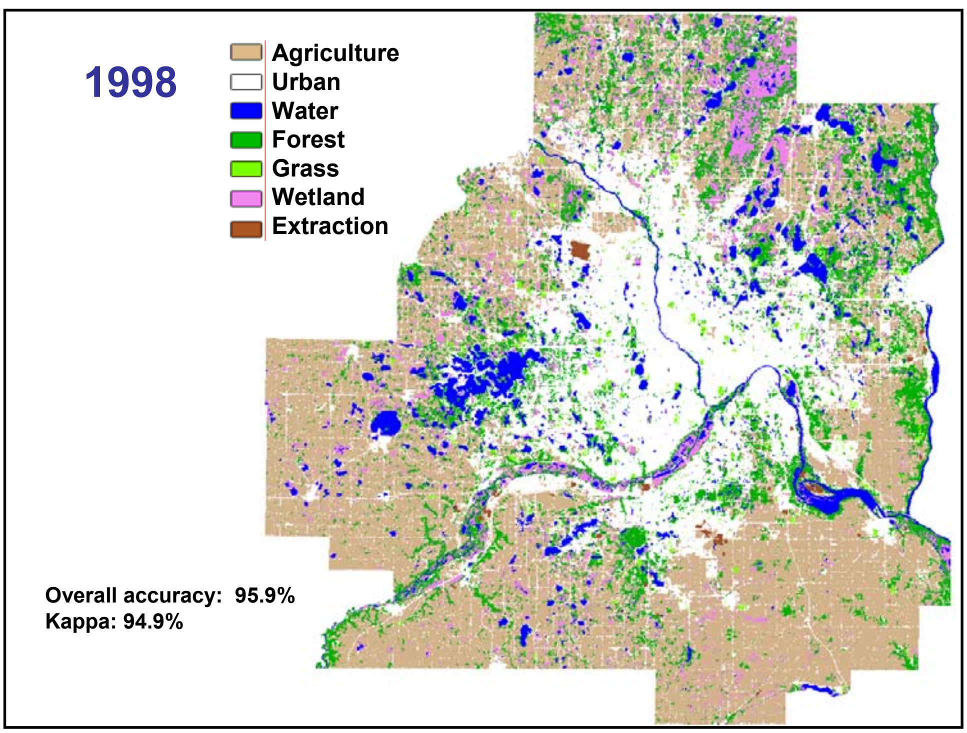


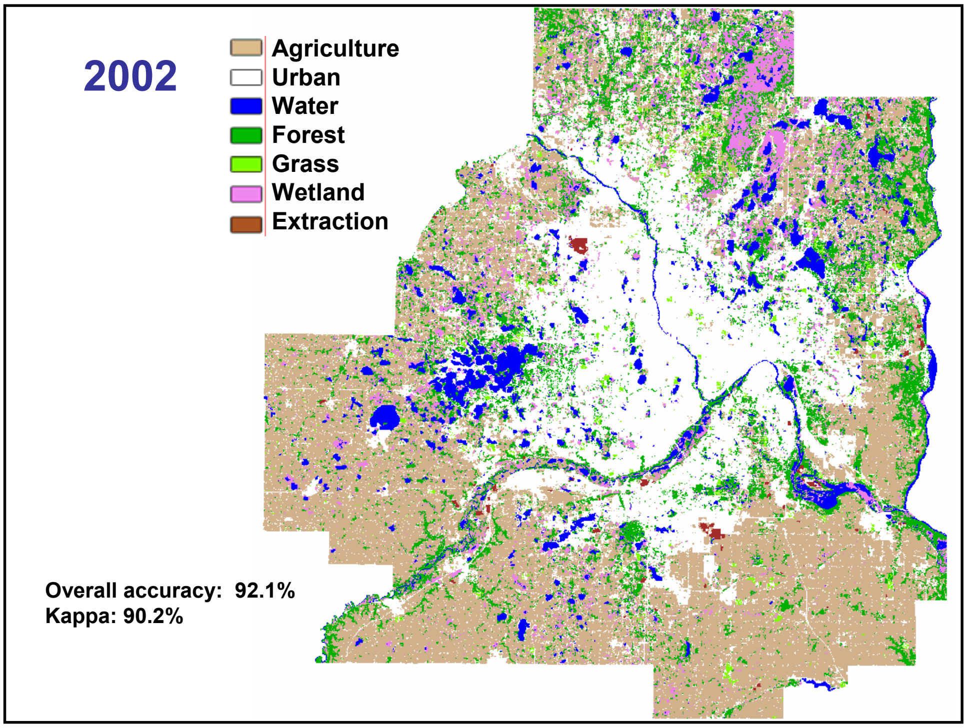
1986

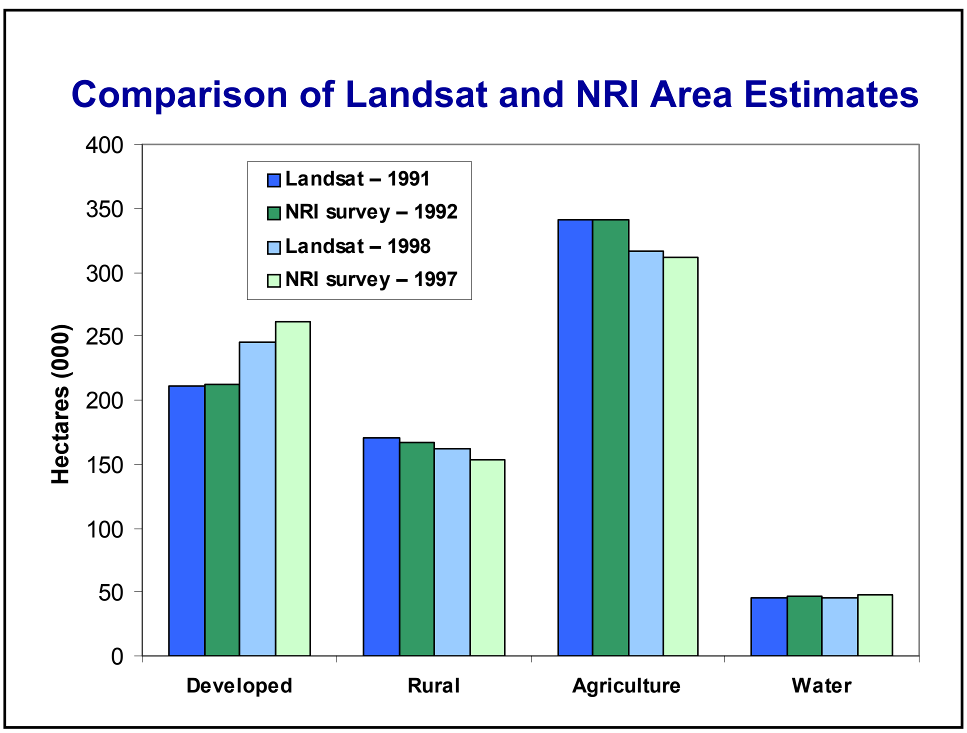


Overall accuracy: 95.2%
Kappa: 94%


1991
Agriculture
Urban
Water
Forest
Grass
Wetland
Extraction
Overall accuracy: 94.6%
Kappa: 93.2%

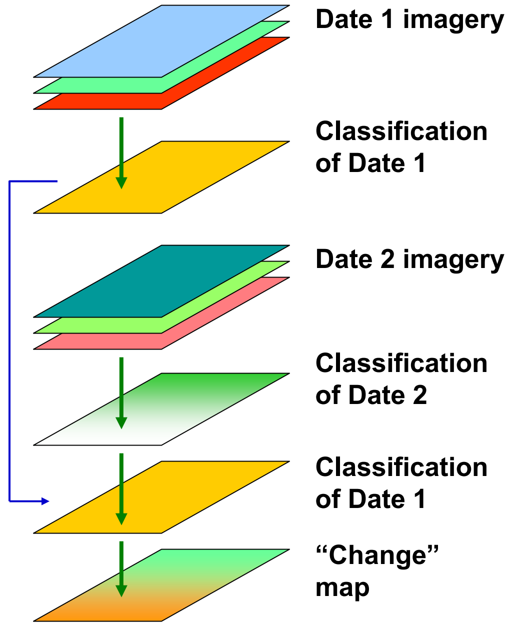

1998
Agriculture
Urban
Water
Forest
Grass
Wetland
Extraction
Overall accuracy: 95.9%
Kappa: 94.9%


2002
Agriculture
Urban
Water
Forest
Grass
Wetland
Extraction
Overall accuracy: 92.1%
Kappa: 90.2%

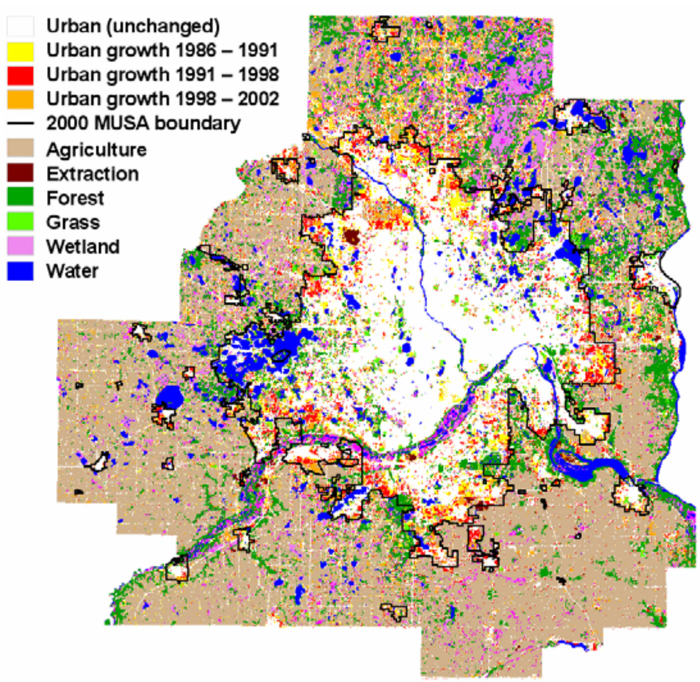

Comparison of Landsat and NRI Area Estimates
Landsat – 1991
NRI survey – 1992
Landsat – 1998
NRI survey – 1997
Hectares (000)
0
50
100
150
200
250
300
350
400
Developed
Rural
Agriculture
Water

Comparison of Classifications

- Two dates are classified separately
- Classification map of Date 2 is then subtracted from the map of Date 1



Change Map



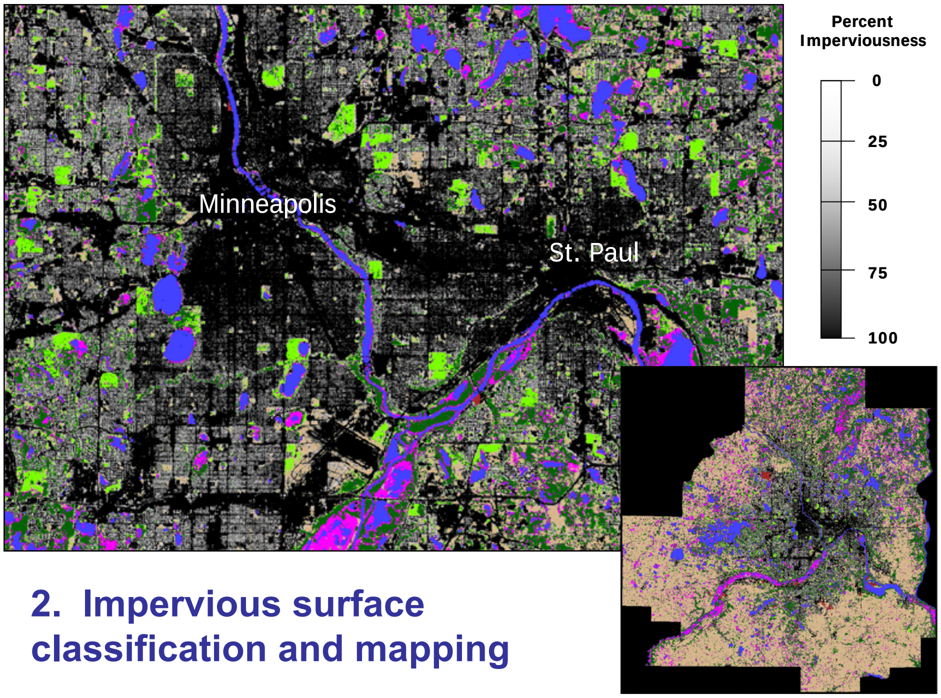
Land Cover Changes from 1991 to 2002

Land Cover Class	1986		1991		1998		2002		Relative Change, 1986 – 2002 (%)
	Area (000 ha)	%	Area (000 ha)	%	Area (000 ha)	%	Area (000 ha)	%	
Agriculture	365	47.5	342	44.4	316	41.1	305	39.9	-16.4
Urban	183	23.8	202	26.3	235	30.6	257	33.4	40.4
Forest	112	14.6	111	14.4	106	13.8	102	13.3	-8.9
Wetland	58	7.5	60	7.8	56	7.3	50	6.5	-13.8
Water	42	5.5	46	6.0	46	5.9	43	5.6	2.4
Cult. Grass	7.2	0.9	6.4	0.8	7.7	1.0	6.7	0.9	-6.9
Extraction	1.9	0.2	2.4	0.3	2.7	0.4	2.7	0.3	42.1

- Multitemporal data, typically at different times of the year, can be used to increase classification accuracy and specificity

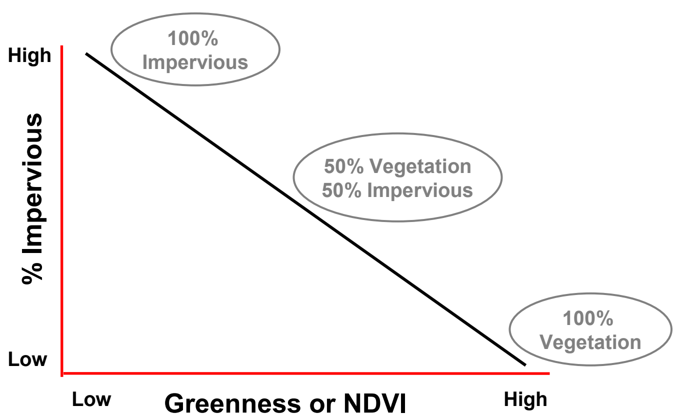
  but does require acquiring and processing additional dates of data

- Data acquired over different years can be used to detect and classify changes in land cover and use



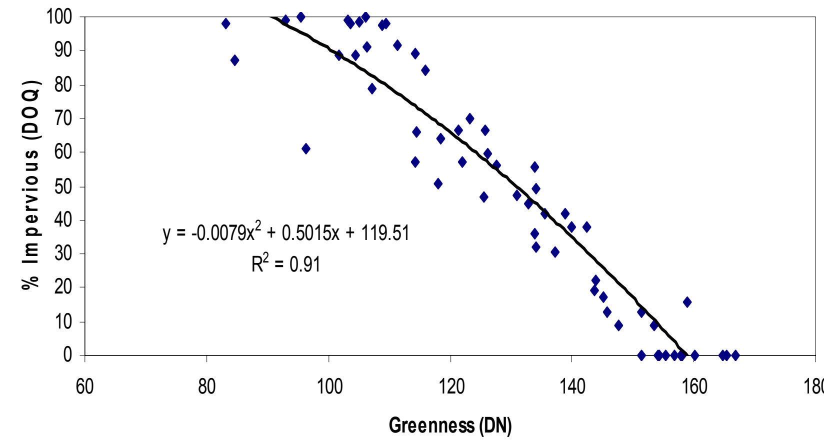
2. Impervious surface classification and mapping

Basic Theory for Satellite Mapping of ISA

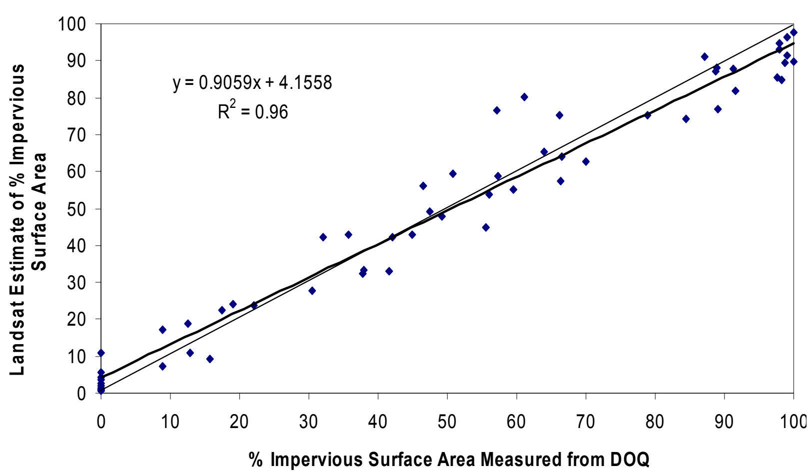


Greenness is sensitive to amount of green vegetation and inversely related to amount of impervious surface

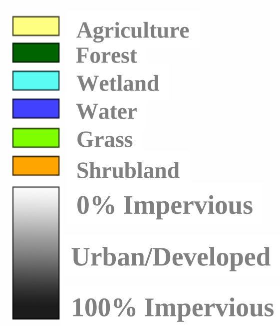
Relationship of Landsat TM Greenness and Percent Impervious Surface Area

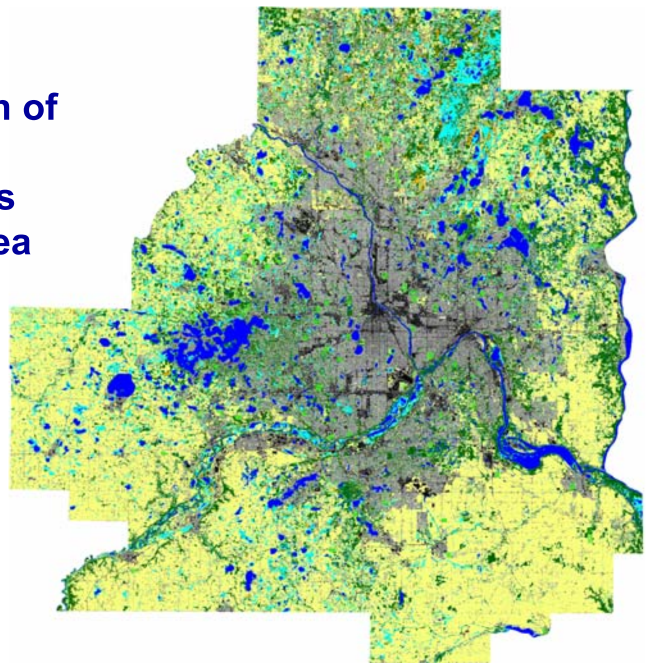


Comparison of measured and Landsat estimates of impervious surface area

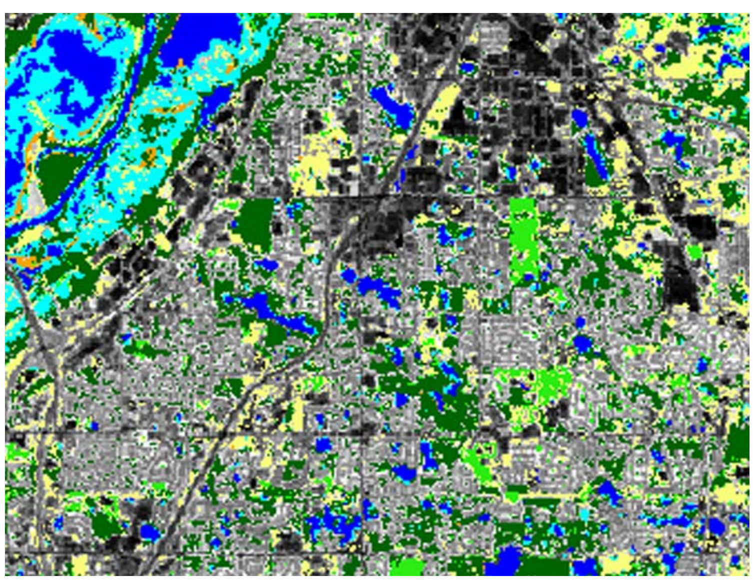


Landsat classification of TCMA Impervious Surface Area

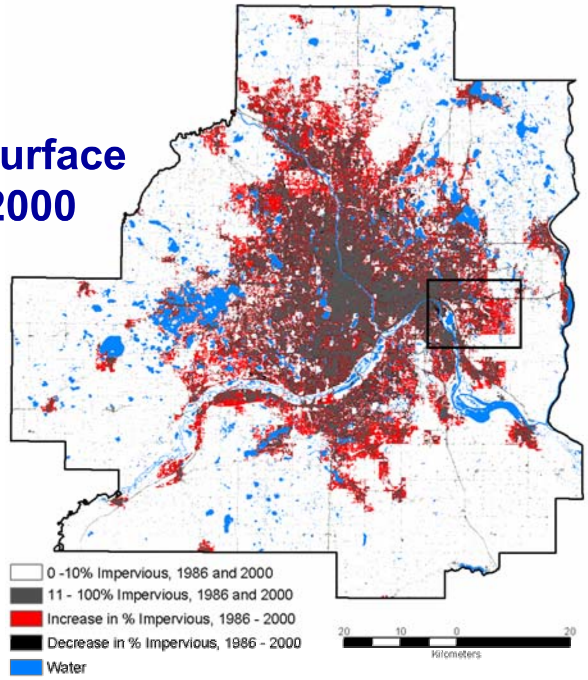




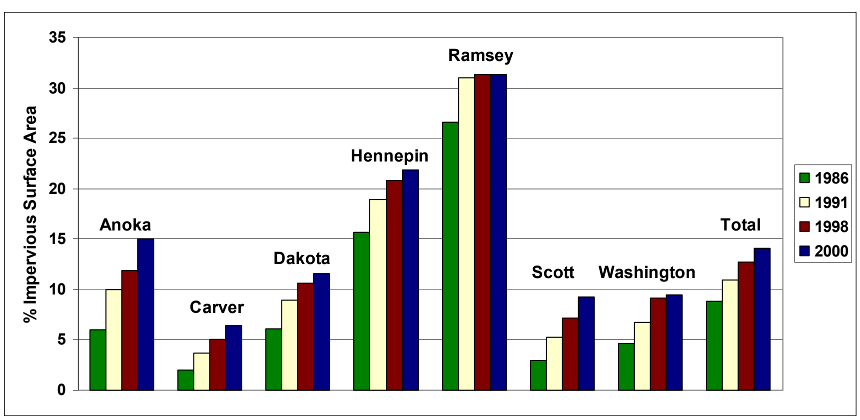
Landsat classification of Eagan land cover and % impervious surface area



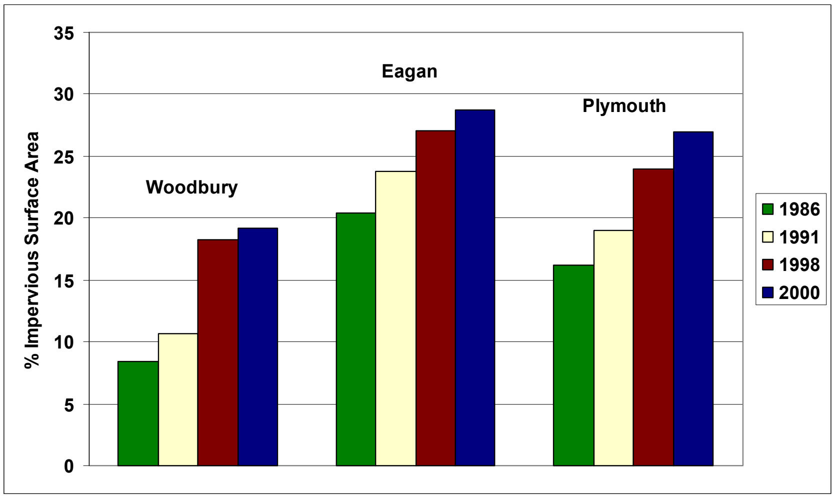
Change in Impervious Surface Area, 1986 - 2000



Change in Percent Impervious Surface Area, 1986 – 2000, by County

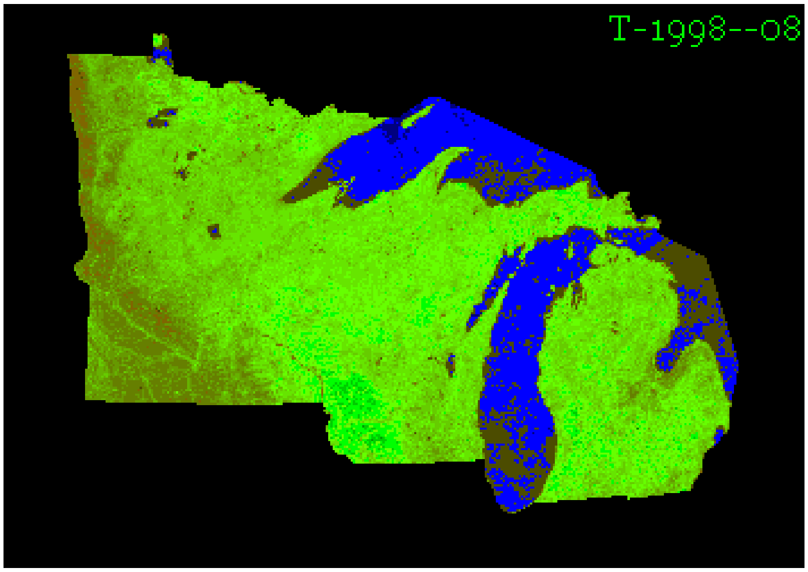


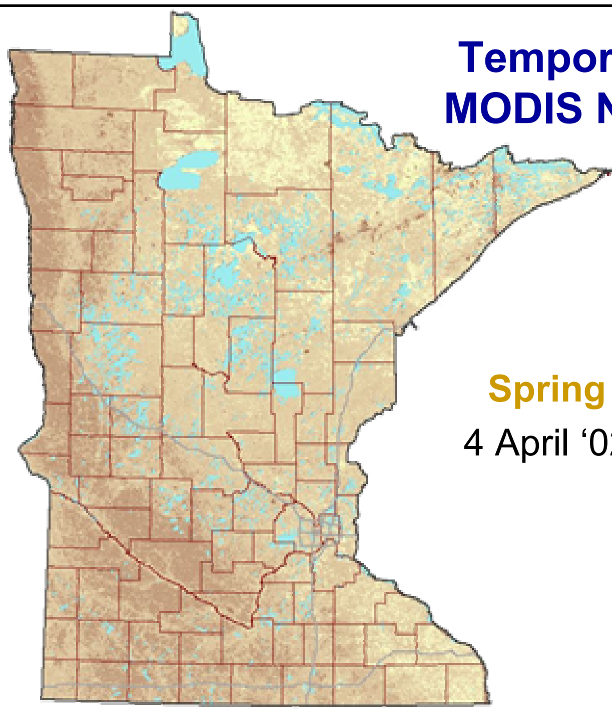
Change in Percent Impervious Surface Area, 1986 – 2000, for Three Cities



- A strong relationship between impervious area and Landsat greenness enables percent impervious surface area to mapped at the pixel level.
- Landsat classification provides GIS-ready, accurate and consistent maps and estimates at 30-meter resolution over city to county to regional size areas.

3. Vegetation Condition Assessment



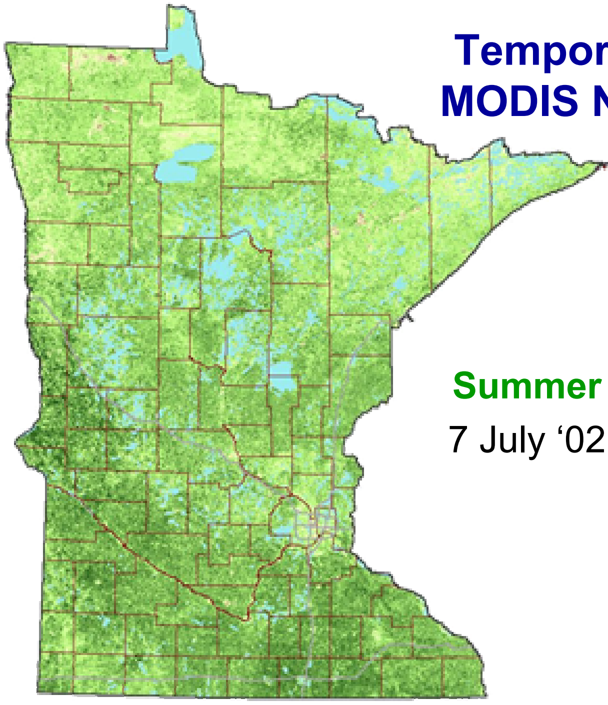


Temporal Series of MODIS NDVI Images

Spring

4 April '02

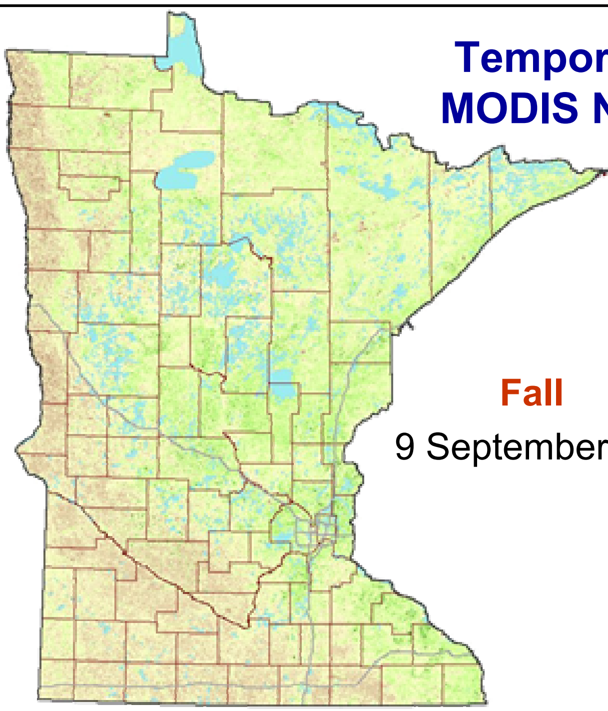
Temporal Series of MODIS NDVI Images



Summer

7 July ‘02

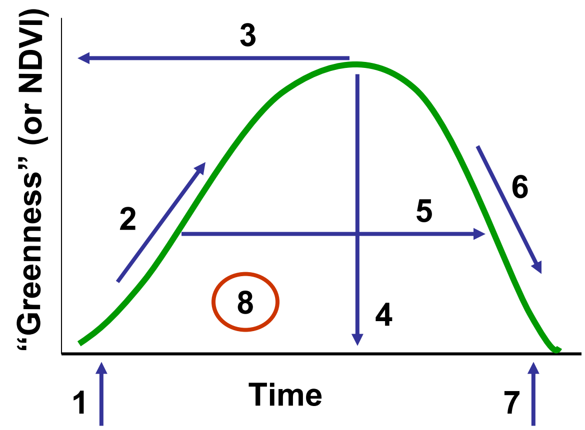
Temporal Series of MODIS NDVI Images



Fall

9 September ‘02

Temporal Profile Parameters



1 start of green-up

2 rate of growth

3 maximum "greenness"

4 date of maximum

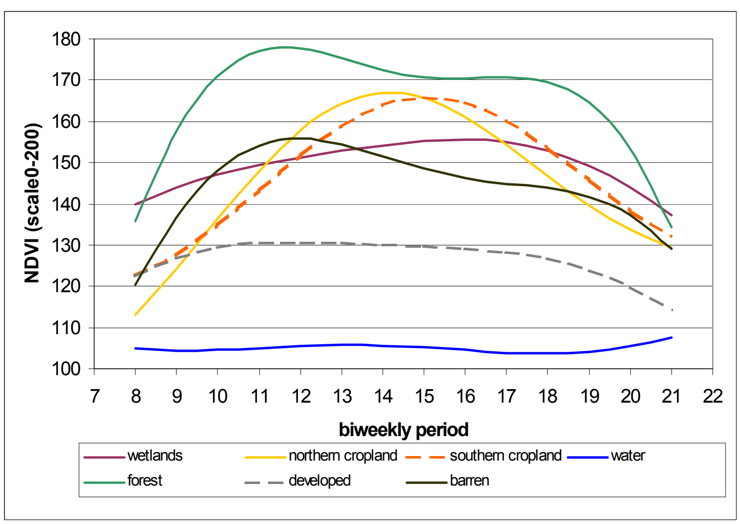
5 duration of greenness

6 rate of senescence

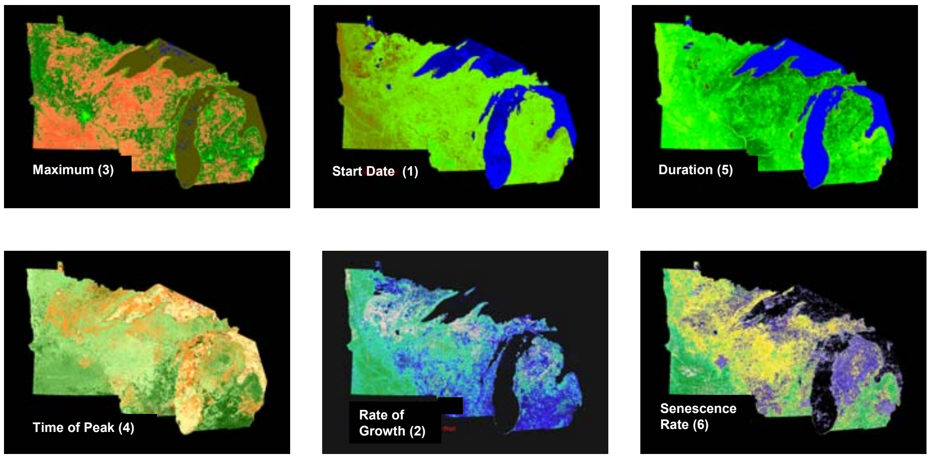
7 end of growing season

8 total seasonal accumulation (area under the curve)

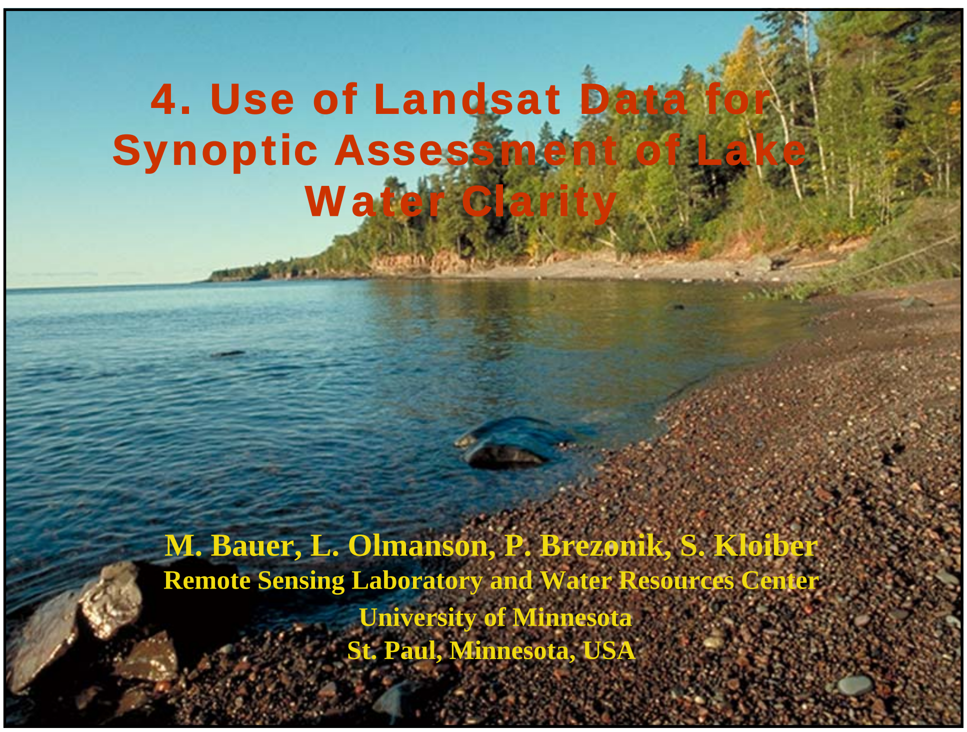
Examples of Temporal Profiles for several Minnesota cover types



Example Images of Temporal Profile Metrics

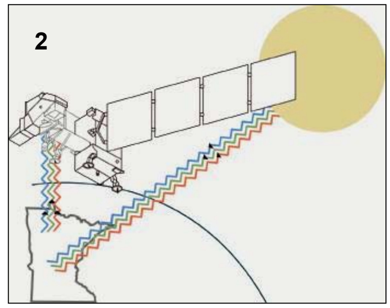


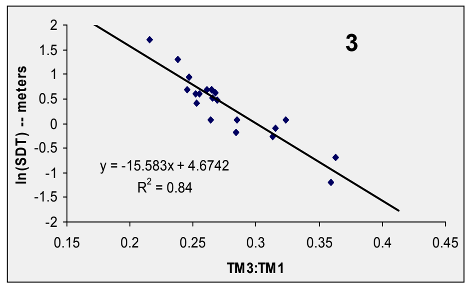
AVHRR NDVI, 1998



Basic Method

1

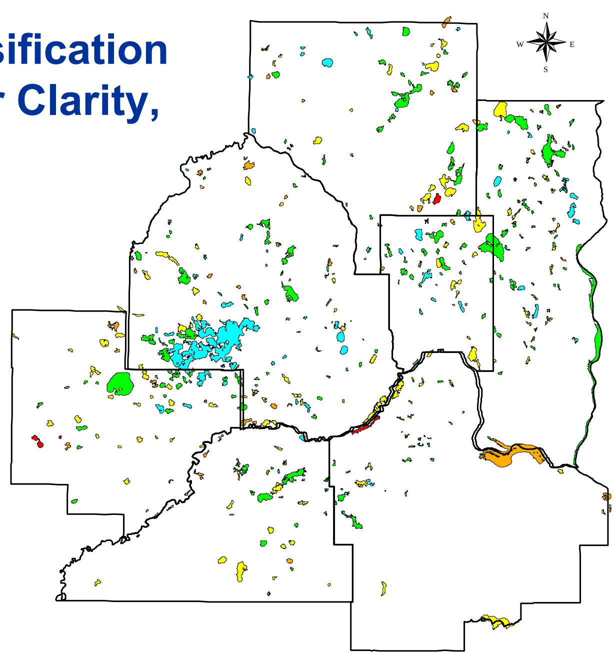




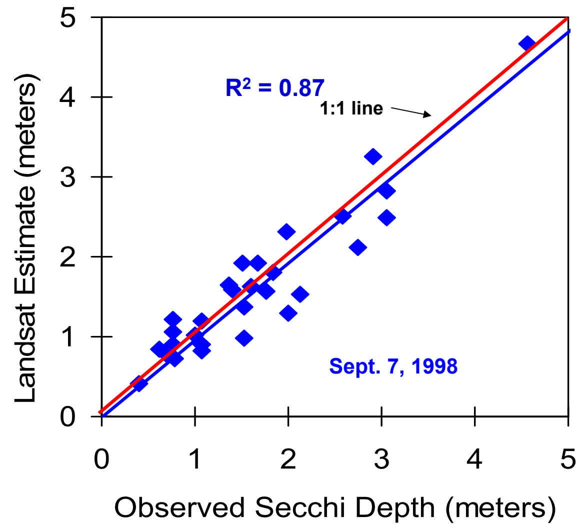
Landsat Classification of Lake Water Clarity, 1998

TSI(SDT)	SDT (m)
30	8
40	4
50	2
60	1
70	0.5
80	0.25
90	0.125

7-county Twin Cities Metropolitan Area



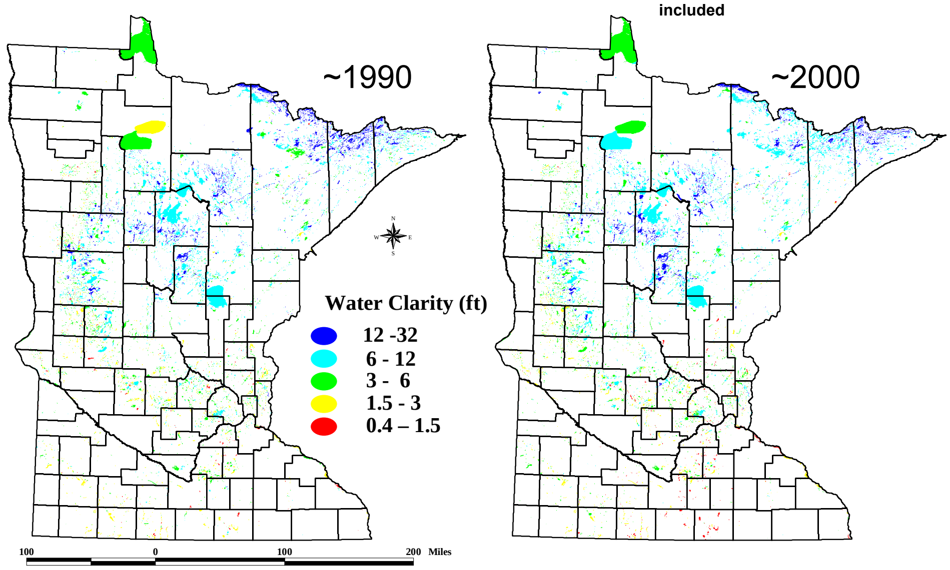
Agreement between Landsat Estimates and Lake Measurements



Landsat Estimation of Lake Water Clarity

~1990 and ~2000 Assessments are complete and
~1975, ~1985, ~1995 Landsat images have been acquired

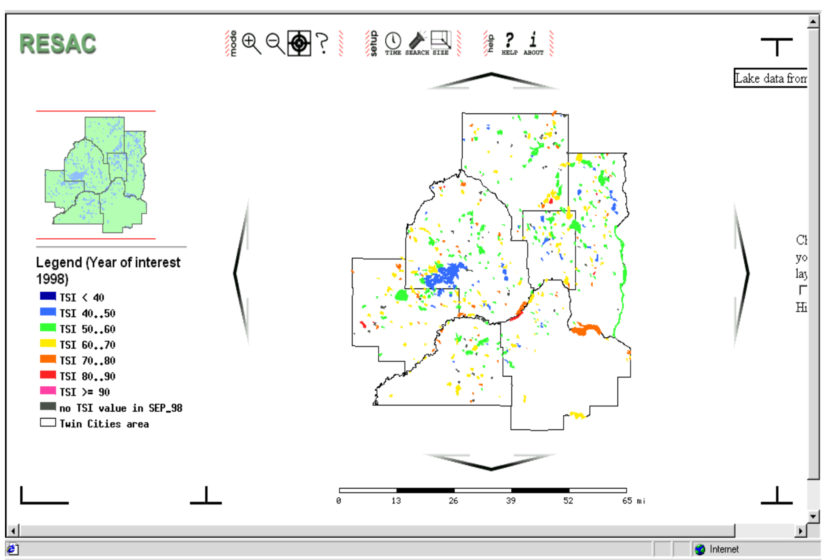
- Over 10,000 Lakes Classified
- All lakes 20 acres or larger are included



- Landsat data can be effectively used to monitor lake water clarity (quality) over time and large geographic areas

Results can be used to improve lake management and policy, and to develop a better understanding of lake systems on a regional scale

Internet Delivery of Information: Lake Browser http://water.umn.edu/

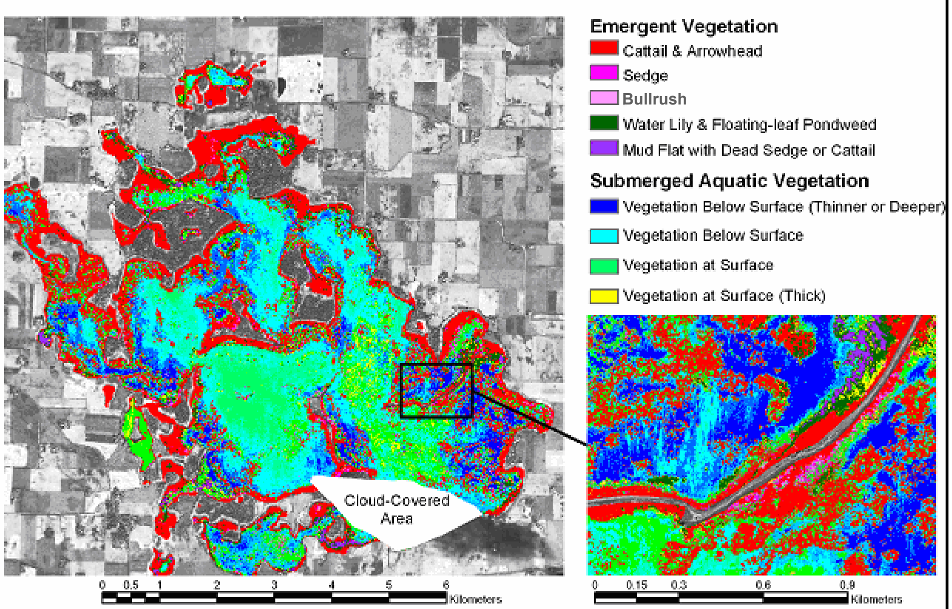


5. Aquatic Vegetation Mapping

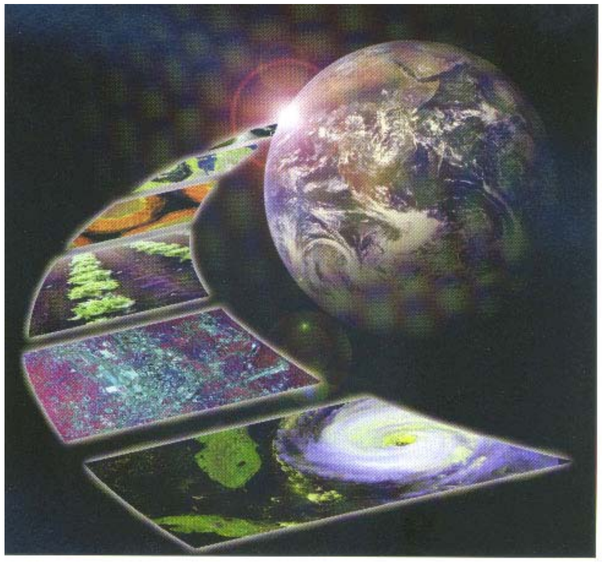
IKONOS
High
Resolution
(4-meter)
Satellite
Imagery

Swan Lake, MN

IKONOS Classification of Aquatic Vegetation



Future Perspectives

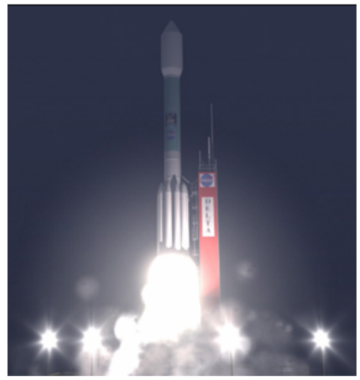


Numerous sources of digital imagery

- Landsat….will continue to be the 'workhorse' of satellite RS
- Earth Observing System = suite of sensors and long term observations on Terra and Aqua satellites
- Commercial satellites with high spatial resolution
  IKONOS, QuickBird, ORBIMAGE
- Satellites operated by other countries
  SPOT, EnviSat, RadarSat, ….
- Hyperspectral (50-300 spectral bands, spectroscopic analysis), lidar and radar
- Airborne systems -- yes, airplanes will continue to fly and collect data

Recent Satellite Launches

- Landsat-7, 1999
- IKONOS, 1999
- QuickBird, 2001
- ORBIMAGE-3, 2003
- EOS / Terra, 1999
- EOS / Aqua, 2002
- EnviSat, 2002
- SPOT-5, 2002
- NOAA-17, 2002



EOS Aqua launch

By the end of 2004 there will be over 25 Earth observation satellites in orbit

Improvements and Advancements in Technology and Capability

- Increasing use of digital imagery
- "Hypermedia" --- no single source
- Increasingly sophisticated software and hardware that anyone can use
- More "customizable" products
- Software adapted to standards

  e.g., open GIS
- Greater awareness of the public

  TerraServer, imagery on CNN, etc.

Benefits from Other Technologies

- GIS and image processing -- more sophisticated and well integrated
- Improved process models that use RS inputs
- Computers
  - more powerful, less expensive
- Telecommunications and the Internet
  - will simplify and speed data and information delivery
- Global Positioning System
  - improved navigation and location information will be commonplace

Some concluding thoughts

- Aerial photography has been in use for 75 years and will continue to play a key role in mapping and monitoring.
- Satellite remote sensing, a much younger technology, has blossomed in recent years and we are now realizing the long-expected benefits of routine Earth observations from space.
- In the next few years we will see even more multi-source, multi-scale remote sensing data
  - Hyperspectral, high-resolution, microwave, lidar,…
- Quantitative measurements of biophysical properties of land, vegetation, water, and atmosphere are rapidly developing.
- These new data and measurements are finding their way into spatial models of environment and natural resources.

New era: "The image information age"

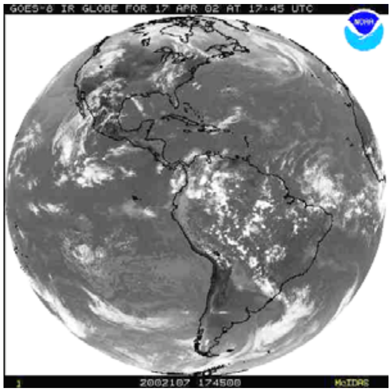
- "The map of the future will be an 'intelligent' image," Lawrie Jordan, President, ERDAS

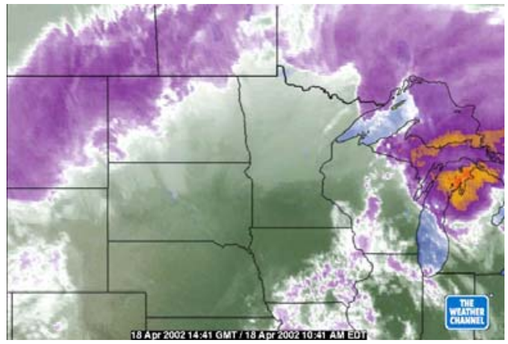
Some of the things that will enhance the acquisition, analysis and applications of remote sensing and spatial data

- Continued improvements in sensors.
- Improvements in computing capacity, Internet, and analysis and visualization tools.
- Use of spatial data will increase as access to data and tools for analysis improve (spatial literacy will increase).
- Data integration – spatial data will become increasingly common in the digital environment.
- Time lag between data acquisition and generation of information will decrease.

Adapted from The Future of Spatial Data and Society (Nat'l. Academy of Sciences, 1997)

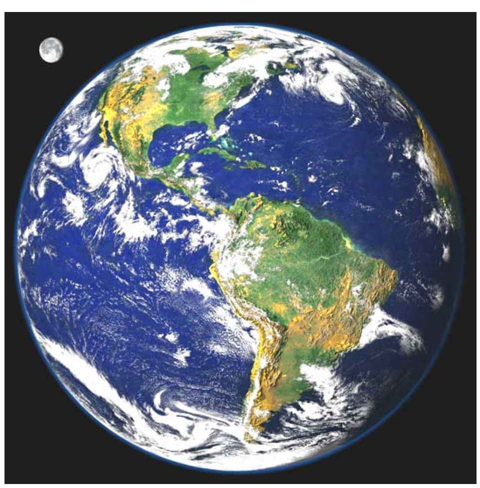
The most familiar remote sensing: Satellite image of today's weather systems





Perhaps in a few years remote sensing of natural resources and environment will be equally familiar.

"Once a photograph of the Earth is taken from outside is available, a new idea as powerful as any in history will be let loose."



"The Nature of the Universe," Sir Fred Hoyle, 1950.

Thank you

Questions….

Copies of presentation slides can be found at:

http://rsl.gis.umn.edu/rs101.html