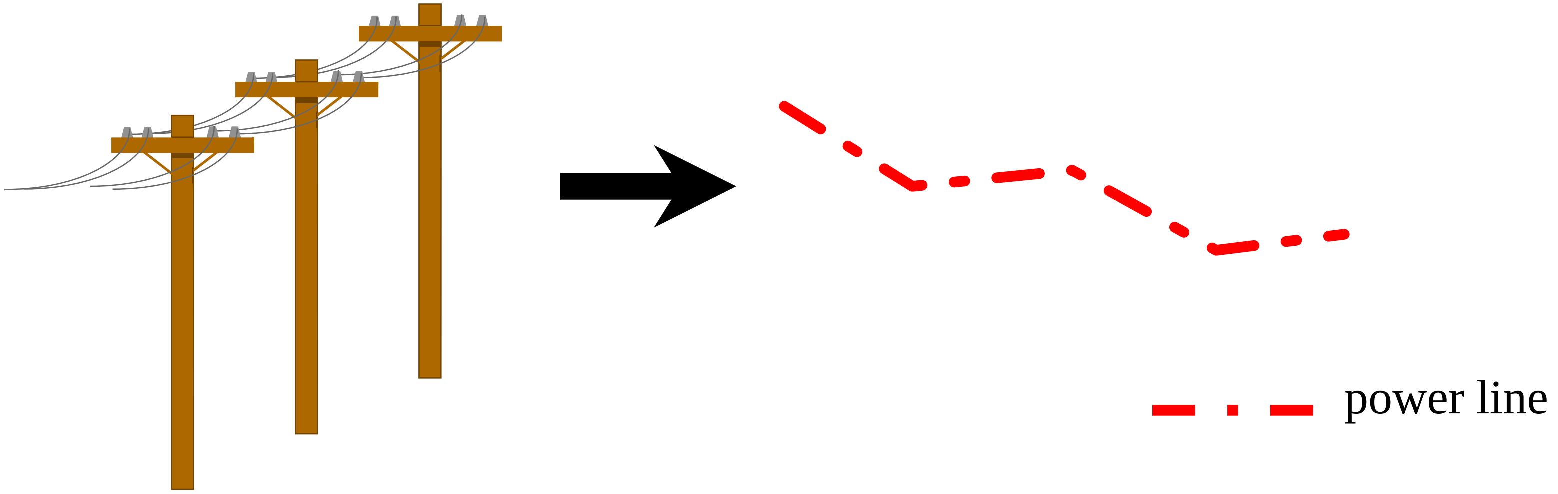
Chapter 7: Making Maps with GIS

- 7.1 The Parts of a Map
- 7.2 Choosing a Map Type
- 7.3 Designing the Map

What is a map?

- "A **graphic depiction** of all or part of a **geographic realm** in which the **real-world features** have been replaced by **symbols** in their **correct spatial location** at a **reduced scale**."



Map Function in GIS

- Storage - maps are a means of **data storage**
- Temporary communication – as an aid to an activity in progress e.g. **navigation**
- Intermediate check of data – **before** the task is done
- Final report - maps provide useful ways of **displaying data in a meaningful way** (→ information)

- To be effective, must be **correctly designed and constructed**.

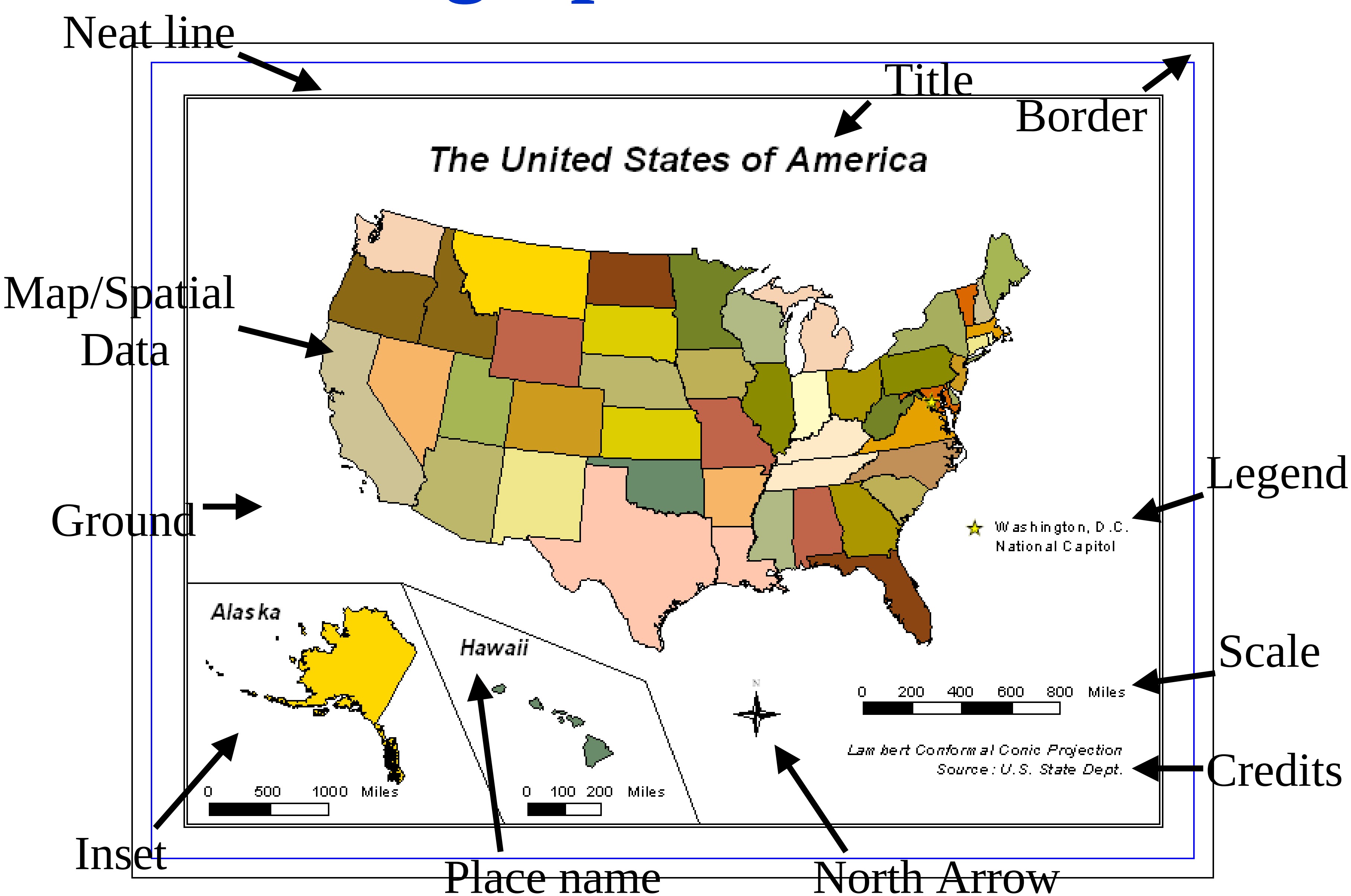
Map Design Considerations

- Maps are a **means of communication** and **organization of thoughts**, they **transmit some spatial information** to the map reader
- Success or failure depends on whether or not the map **communicates** the intended information
- Cartography as a **communication system**:

  "How do I say what to whom?"

  - **cartographer** = I
  - **map reader/audience** = whom
  - **map design & production methods** = how
  - **subject & goals of map** = what

Cartographic Elements



Choosing a Map Type

- Cartographers have designed **hundreds of map types**: methods of cartographic representation.
- Not all GISs **allow** all types.
- Most have a set of **basic** types
- Depends heavily on the **dimension of the data** to be shown in the map figure.

Scales of Measurement

- **Thematic data** can be divided into four types

1. The Nominal Scale
2. The Ordinal Scale
3. The Interval Scale
4. The Ratio Scale

As we progress through these scales, the types of data they describe have increasing information content

Data Symbolization

- There are a number of characteristics of symbols that we can use of to make **visual distinctions** in **thematic information** (Jacques Bertin's **Visual Variables**):
  - Size
  - Shape
  - Color Hue (color)
  - Color Value (intensity)
  - Texture
  - Orientation
  - Arrangement

Color and Map Design

- Color is a **complex visual variable** and in a GIS is specified by RGB or HSI values.
- Red, Green, Blue are **additive** primaries.
- Magenta, Cyan and Yellow are **subtractive** primaries.
- Intensity maps **better** onto values than hue.

Example: Choropleth Mapping

- Data should be **Areas** (e.g. States)
- Data should not suffer from **‘area effect’**.
  - Population?
  - Per capita Income?
  - Elevation?
  - Temperature?
- Boundaries **unambiguous**.
- Areas **non-overlapping**.

Choropleth Maps

- Greek: choros (place) + plethos (filled)
- These are used to map categorical and quantitative data over defined areas
  - **polygonal enumeration units**

    e.g. census tract, counties, watersheds, etc.
- Data values are generally **classified** into ranges
  - allow map reader to readily interpret the map
- Polygons can produce **misleading** impressions
  - area/size of polygon vs. quantity of thematic data value

Classifying Thematic Data

- Data values are **classified into ranges** for many thematic maps (especially choropleth)
  - This aids the reader's **interpretation** of map
- Trade-off:
  - presenting the underlying data **accurately**

    VS.

  - **generalizing** data using classes
- Goal is to **meaningfully classify** the data
  - **group features** with similar values
  - assign them the **same symbol**
- But how to **meaningfully** classify the data?

Creating Classes

- **How many** classes should we use?
  - too few - **obscures** patterns
  - too many - **confuses** map reader
    - difficult to recognize more than **seven** classes
- How do we **create** the classes?
  - assign classes **manually**: create meaningful classes, such as population above / below poverty level
  - **equal intervals**: This ignores the data distribution, which can be misleading too!

Creating Classes

- How do we create the classes (cont.)
  - **"natural" breaks** based on data distribution: minimize within-class variation and maximize between-class variation
  - **quartiles**: top 25%, 25% above middle, 25% below middle, bottom 25% (quintiles uses 20%)
  - **standard deviation**: mean+1s, mean-1s, mean+2s, mean-2s, …

The Effect of Classification

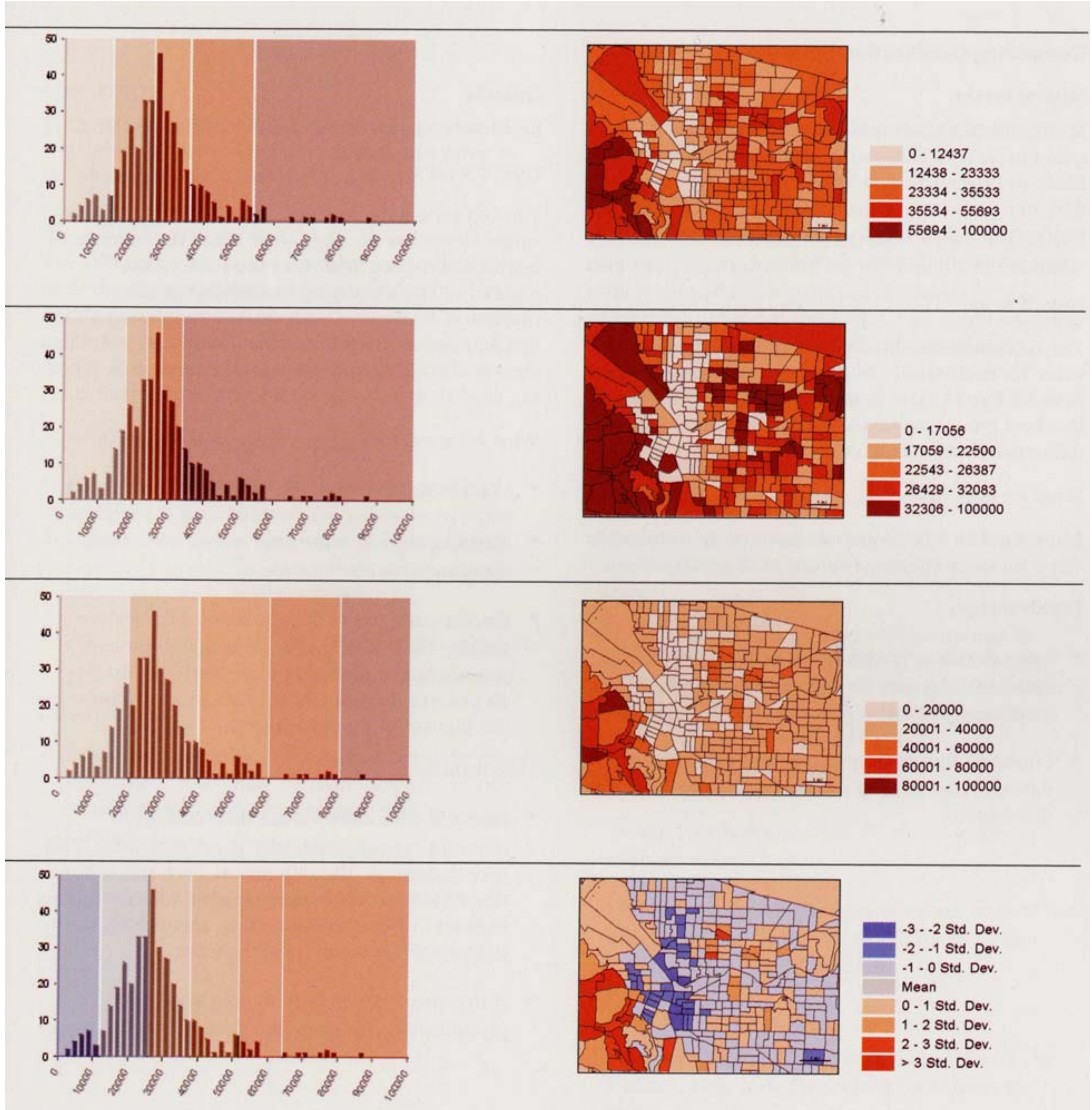
- **Four common ways** to display continuous data in ArcGIS (i.e. these are options in Symbolization):
  - Equal Interval
  - Quantiles
  - Natural Breaks
  - Standard Deviation

Natural Breaks

Quantiles

Equal Interval

Standard Deviation



The Design Loop

- **Create** map layout / **draw** on screen
- **Look**
- **Edit** map layout
- Look **again**
- **Repeat** until happy
- Make **final** plot

Map Design

- **Visual balance** is affected by:
  – the **"weight"** of the symbols
  – the **visual hierarchy** of the symbols and elements
  – the **location** of the elements with **respect to each other** and the **visual center** of the map.

Chapter 8: How to Pick a GIS

8.1 The Evolution of GIS Software

8.2 GIS and Operating Systems

8.3 GIS Software Capabilities

8.4 GIS Software and Data Structures

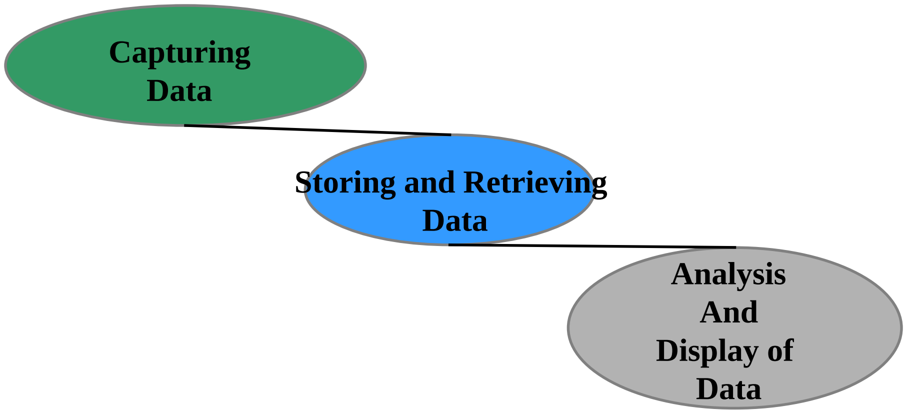
8.5 Choosing the Best GIS

A Functional Definition of GIS

- A GIS is often defined **not for what it is** but for **what it can do**.
- If a GIS does not **match the requirements for a problem**, no GIS solution will be forthcoming.
- A GIS may have **overcapacity**: It may be **too sophisticated**, or bring too many capabilities to bear (swatting a fly with a Howitzer)

The "Critical Six" Functional Capabilities

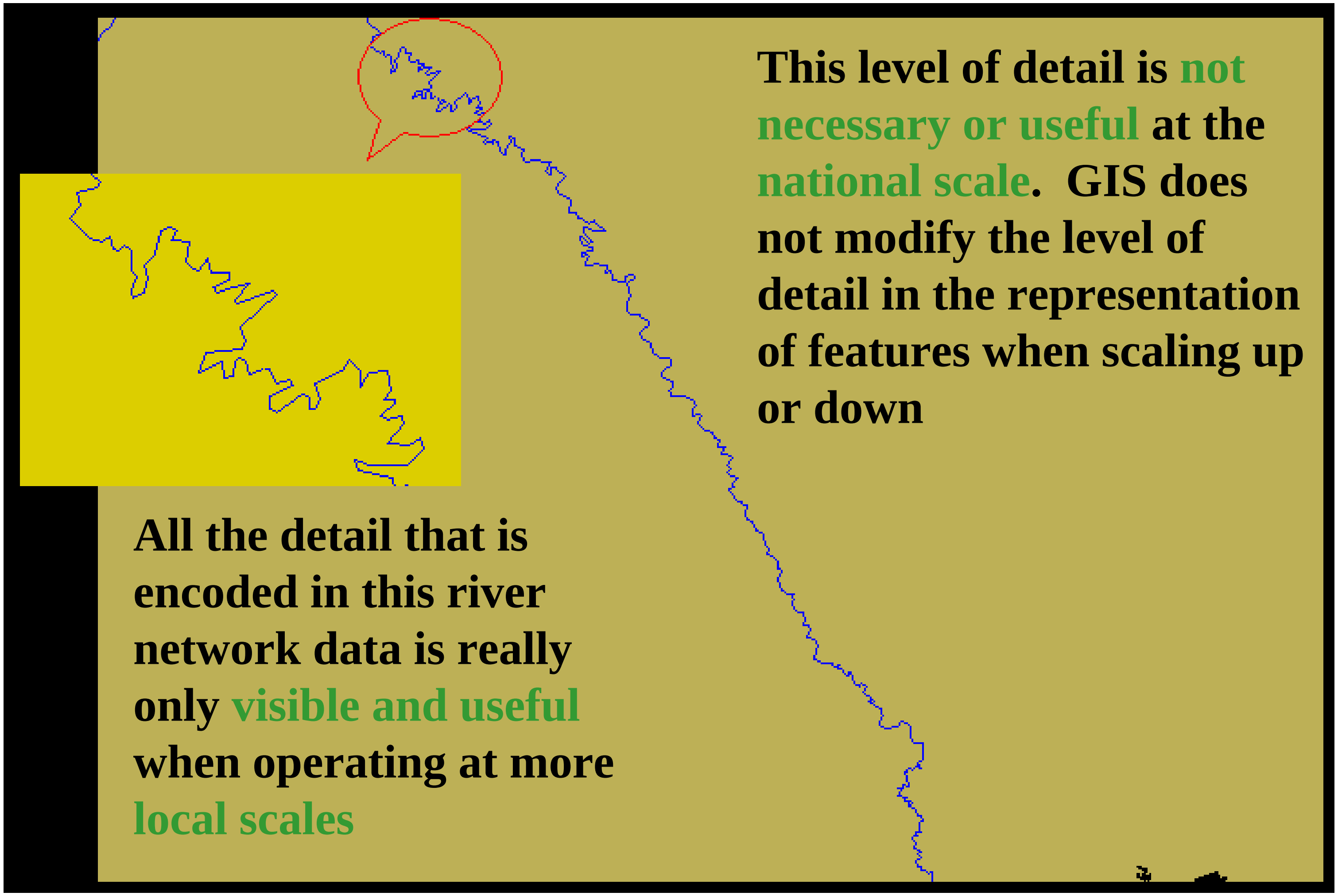
A. Data capture
B. Storage
C. Management
D. Retrieval
E. Analysis
F. Display



A. Data Capture Functions

- Digitizing
- Scanning
- Mosaicing
- Editing
- Generalization
- Topological cleaning
- Geometric correction

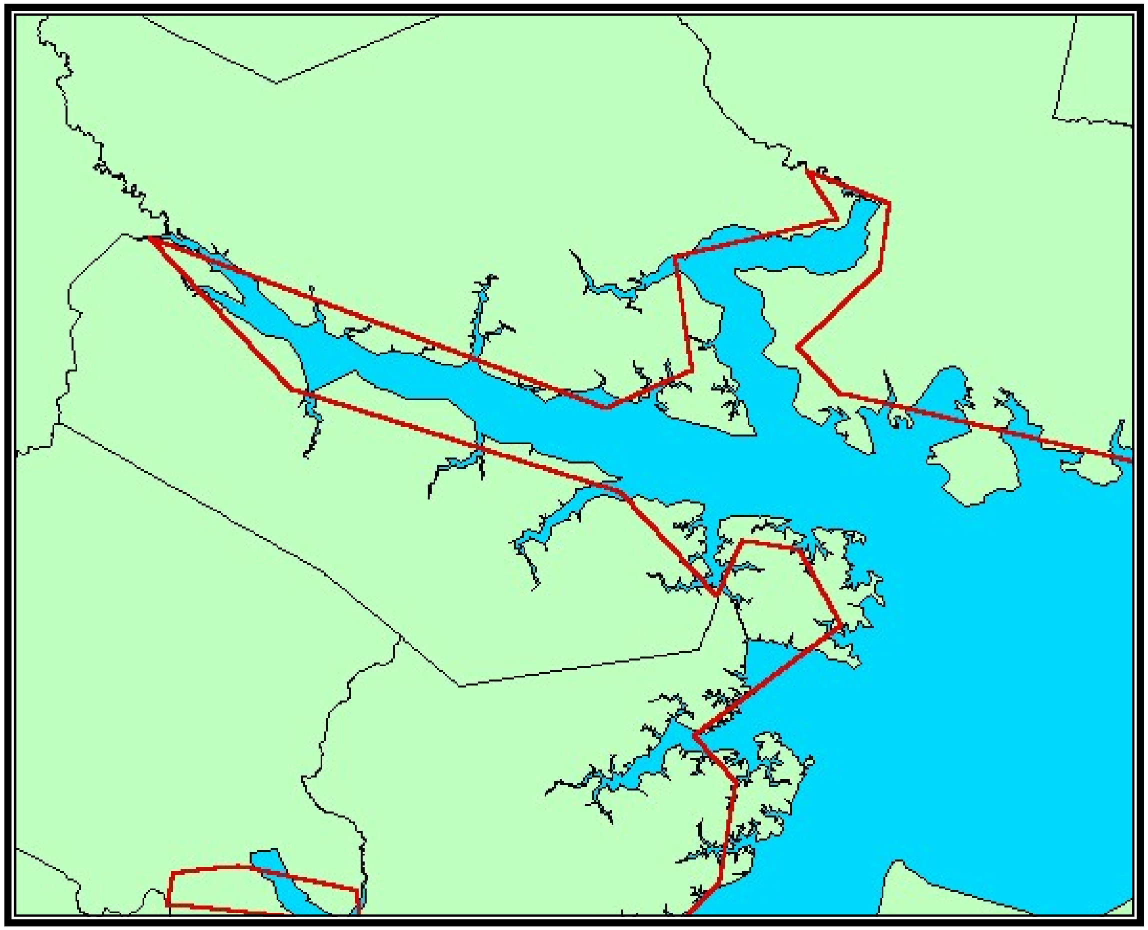
Maps and GIS - Scaling Up



This level of detail is not necessary or useful at the national scale. GIS does not modify the level of detail in the representation of features when scaling up or down

All the detail that is encoded in this river network data is really only visible and useful when operating at more local scales

Maps and GIS - Scaling Down



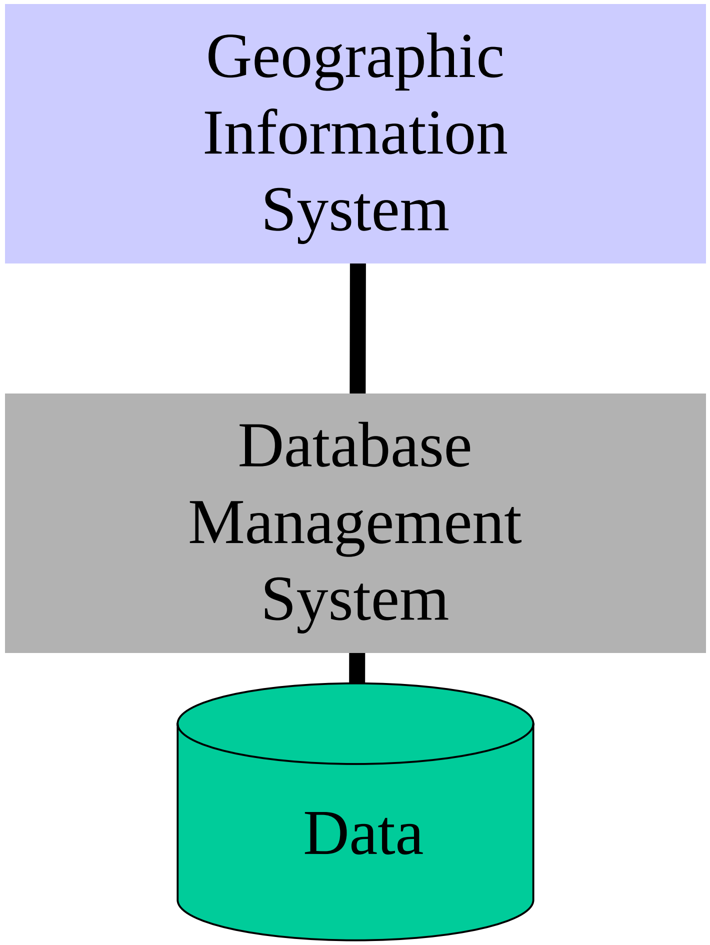
•Here we can see a national scale coastline (shown in red) superimposed over local scale data, we can clearly see the **generalization** and **lack of detail**

B. Storage functions

- Compression (of **data**)
- Metadata handling (to give data **context**)
- Control via macros or languages (to allow the system to be used in **creative ways**)
- Format support (to allow the system to be used with **diverse datasets**)

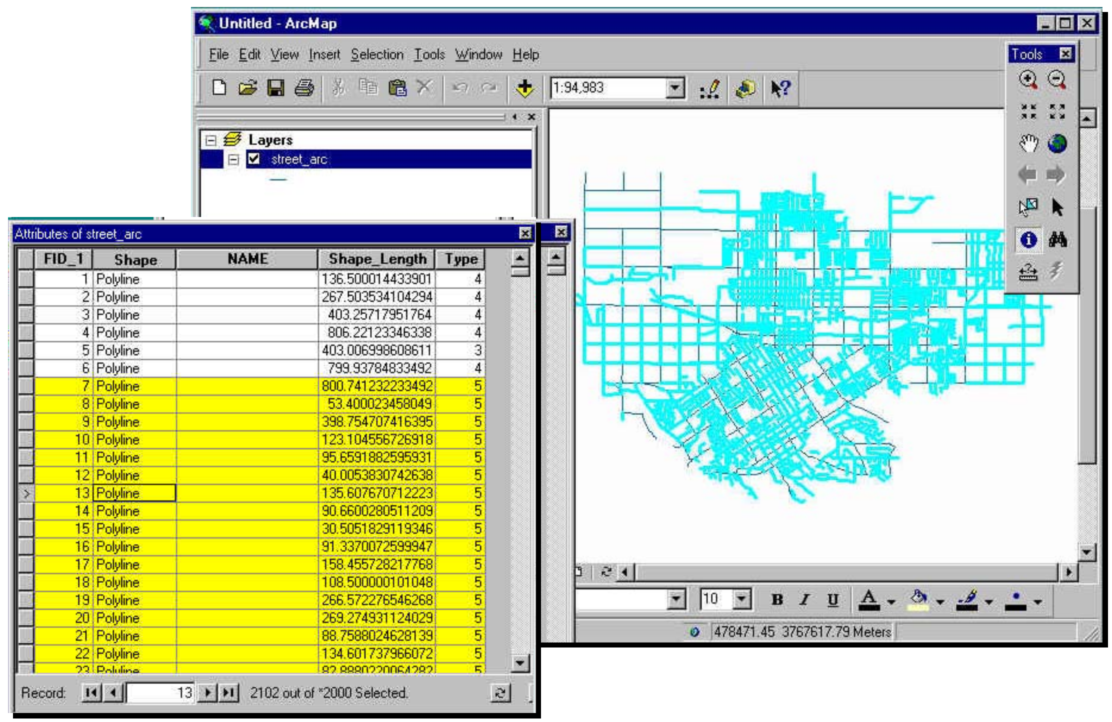
C. Data Management Functions

- Physical model support
- DBMS
- Address matching
- Masking
- Cookie cutting



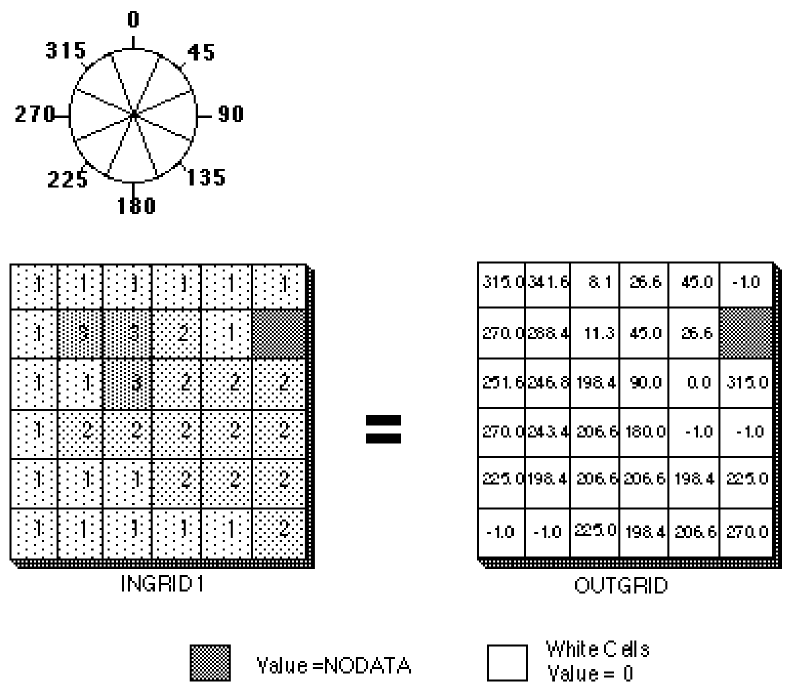
D. Data Retrieval Functions

- Locating
- Selecting by attributes
- Buffering
- Map overlay
- Map algebra

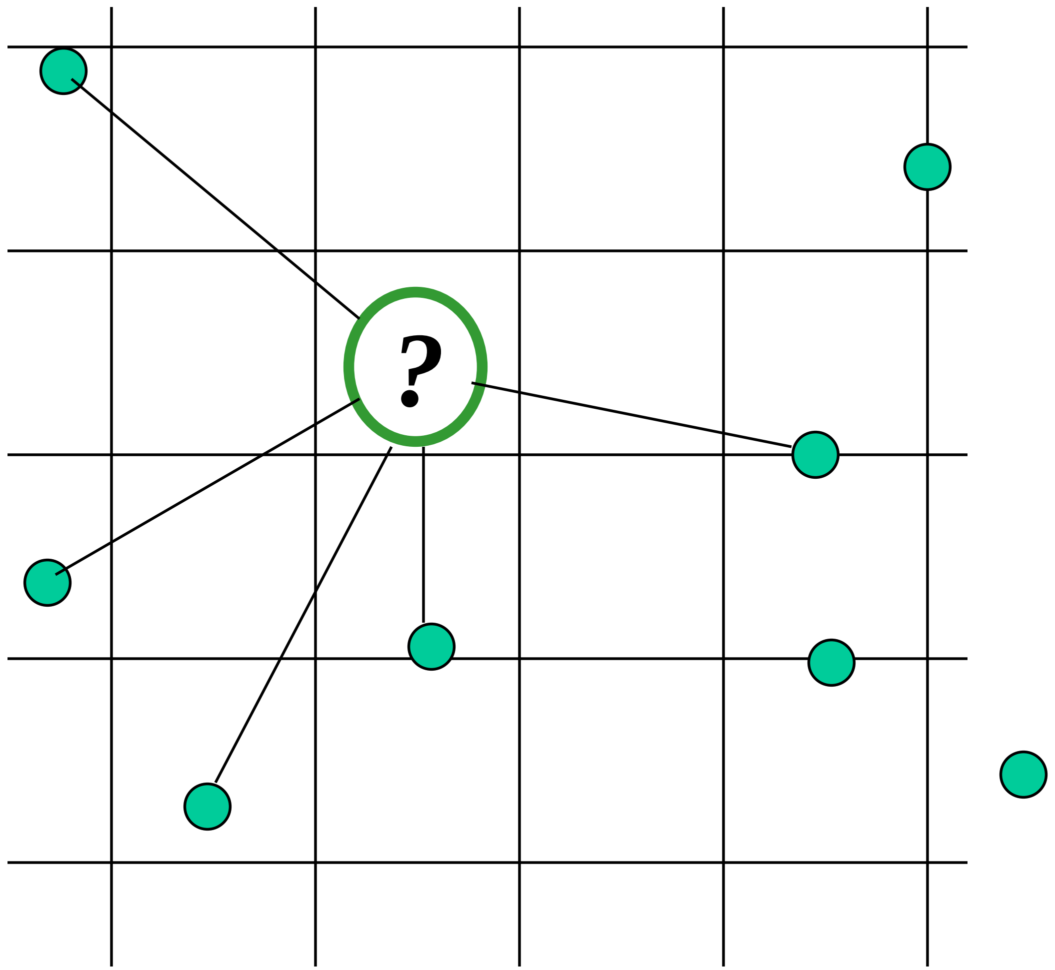


E. Data Analysis Functions

- Interpolation
- Optimal path selection
- Geometric tests
- Slope and aspect calculation



Interpolation

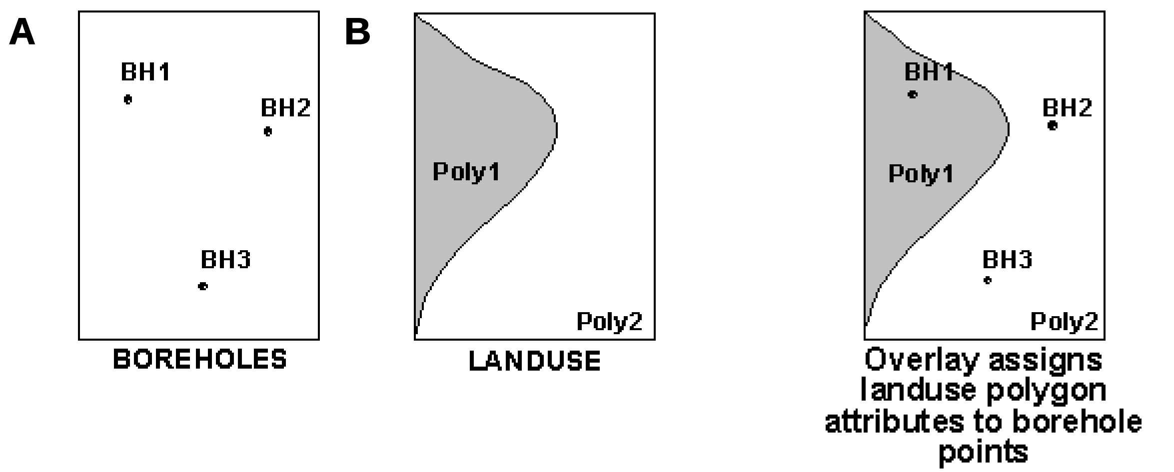


Geometric Tests

Point in Polygon Analysis

- Overlay point layer (A) with polygon layer (B)
  - **In which** B polygon are A points located?
    - » **Assign polygon attributes** from B to points in A

Example: Comparing soil mineral content at sample borehole locations (points) with land use (polygons)...



Point	Zn	Pb
BH1	140	65
BH2	178	54
BH3	101	87

Poly	Landuse
1	Agriculture
2	Urban

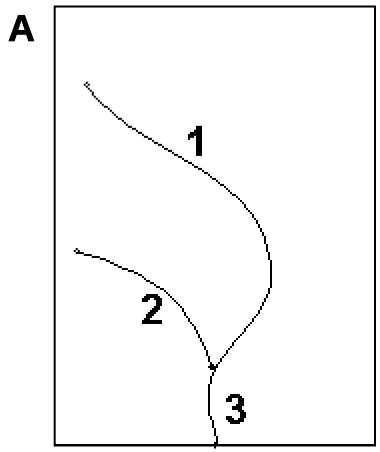
Point	Zn	Pb	Landuse
BH1	140	65	Agriculture
BH2	178	54	Urban
BH3	101	87	Urban

Geometric Tests

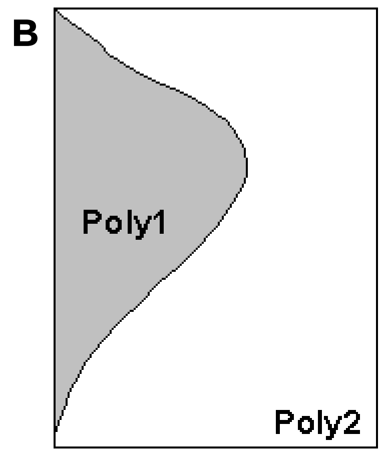
Line in Polygon Analysis

- Overlay line layer (A) with polygon layer (B)
  - – **In which** B polygons are A lines located?
    - » **Assign polygon attributes** from B to lines in A

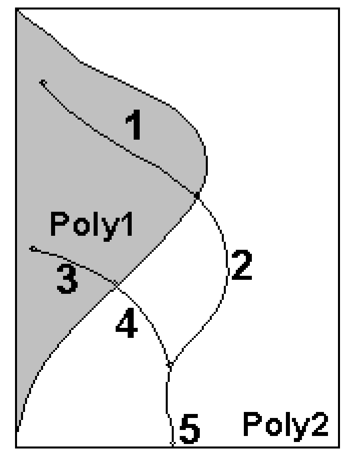
Example: Assign land use attributes (polygons) to streams (lines):



STREAMS



LANDUSE



Overlay splits stream line entities and assigns landuse poly attributes to streams

Line	Length
1	780
2	520
3	225

Poly	Landuse
1	Agriculture
2	Urban

Line	Length	Landuse
1	440	Agriculture
2	340	Urban
3	220	Agriculture
4	300	Urban
5	225	Urban

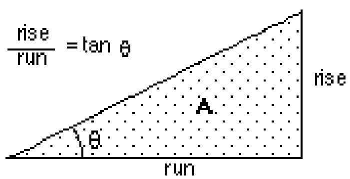
Slope and Aspect

- These are **measurements of terrain attributes**, usually calculated from a digital elevation model
- **Slope and aspect** are calculated for each cell in the grid, by comparing a cell's elevation to that of its neighbors
  - Usually **eight neighbors** are used and the result is expressed as an angle, but the exact method varies
  - It is important to know exactly what method is used when calculating slope, and exactly how slope is defined, because **different methods** can give **different results**

Slope and Aspect

- We can **calculate** these topographic attributes directly from the grid-elevation values using a second-order finite difference scheme applied over a 3x3 neighborhood

Degree of slope = θ



Degree of slope = 30
Percent of slope = 58

Slope

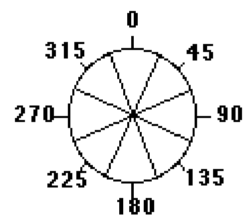
The actual algorithm that is used to calculate slope is:

```
rise_run = SQRT(SQR(dz/dx)+SQR(dz/dy))
degree_slope = ATAN(rise_run) * 57.29578
```

where the deltas are calculated using a 3x3 roving window,

```
a b c
d e f
g h I
```

```
(dz/dx) = ((a + 2d + g) - (c + 2f + i)) / (8 * x_mesh_spacing)
(dz/dy) = ((a + 2b + c) - (g + 2h + i)) / (8 * y_mesh_spacing)
```



Aspect

1	1	1	1	1	1
1	3	3	2	1	
1	1	3	2	2	2
1	2	2	2	2	2
1	1	1	2	2	2
1	1	1	1	1	2

INGRID1

=

315.0	341.6	8.1	26.6	45.0	-1.0
270.0	288.4	11.3	45.0	26.6	
251.6	246.8	198.4	90.0	0.0	315.0
270.0	243.4	206.6	180.0	-1.0	-1.0
225.0	198.4	206.6	206.6	198.4	225.0
-1.0	-1.0	225.0	198.4	206.6	270.0

OUTGRID

Value = NODATA

White Cells Value = 0

F. Data Display Functions

- Desktop mapping
- Interactive modification of cartographic elements
- Graphic file export

Functional Capabilities are By-products of Data Structure

- **Raster systems** work best in forestry, photogrammetry, remote sensing, terrain analysis, and hydrology.
  - Datasets come from **remote sensing** / are **continuous** in nature
- **Vector systems** work best for land parcels, census data, precise positional data, and networks.
  - Datasets come from **surveying/gps** / are **discrete** in nature

Vector

- **Precision** intact
- Used when **individual coordinates** are important
- **More concise** spatial description
- Assumes **feature model** of landscape
- Easy to transform data e.g. **map projections**

Raster

- Better for **field (continuous) data**
- Used by most **imaging** systems
- Can be **compressed**
- Easy to **display and analyze**
- Many **common** formats
- However, most systems now **use both**
- Raster layer often **backdrop-onscreen editing**

The Big Eight

- Form the **bulk of operational GIS** in professional and educational environments
- There are some **significant differences** between these “big eight” systems.

Chapter 9: GIS in Action

9.1 Introduction

9.2 Case Study 1: GIS Fights the Gypsy Moth

9.3 Case Study 2: GIS and Road Accidents in CT

9.4 Case Study 3: GIS and the Events of 9/11/01

9.5 Case Study 4: Channel Island GIS

9.5 Case Study 5: GIS and GPS to Map Sliding Rocks

Understanding GIS by Case Study

- Use of GIS is **best understood** by examining case studies.
- Case studies in this chapter cover **rural, suburban, urban, and coastal** GIS applications.
- **Rural**: Gyspy Moth in Michigan
- **Suburban**: Road Accidents in Connecticut
- **Urban**: Aftermath of the World Trade Center attacks
- **Coastal**: Channel Islands of California
- **Wildlands**: Sliding Rocks in Death Valley

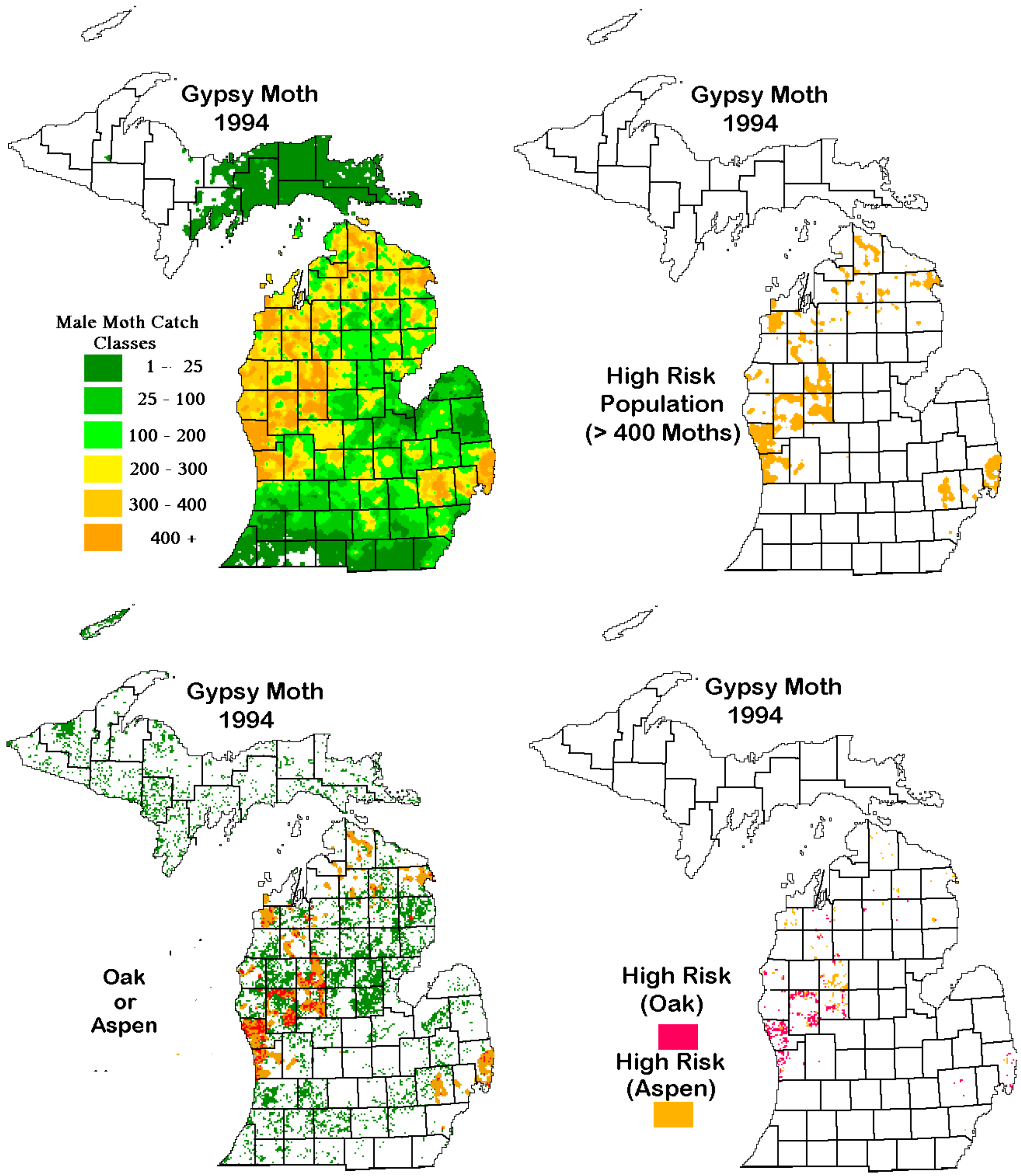
The Gypsy Moth

Locations of Traps for Gypsy Moths in Michigan

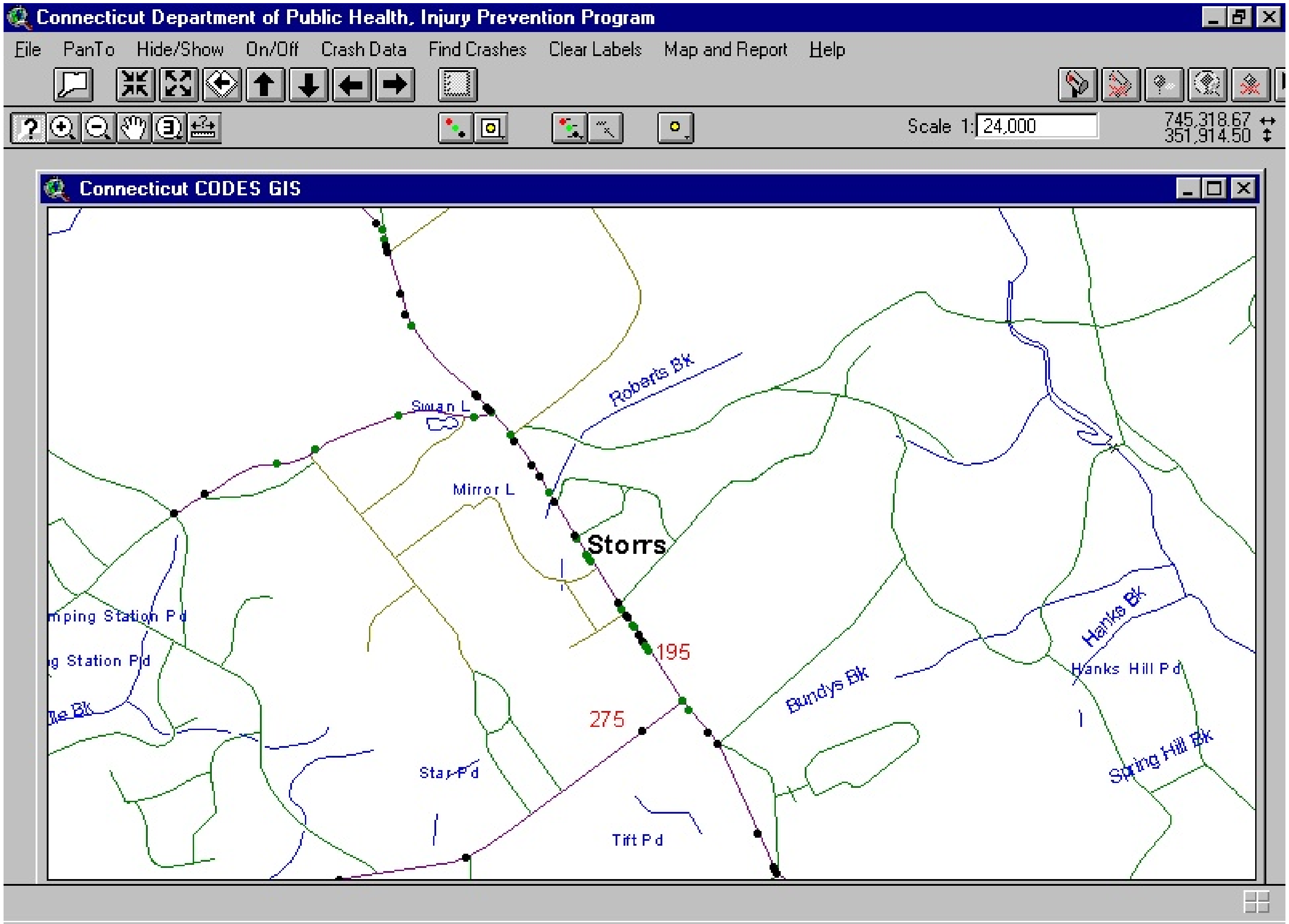
Data Processing

- Data are **aggregated annually** in a central GIS, forms are entered and **locations geocoded**.
- Statewide gypsy moth infestation are **interpolated** using **inverse distance squared weighting** and mapped.
- An **overlay of tree species** data is then used to **map the trees at risk of defoliation** and therefore to be sprayed.

Risk to Trees in Michigan from Gypsy Moth

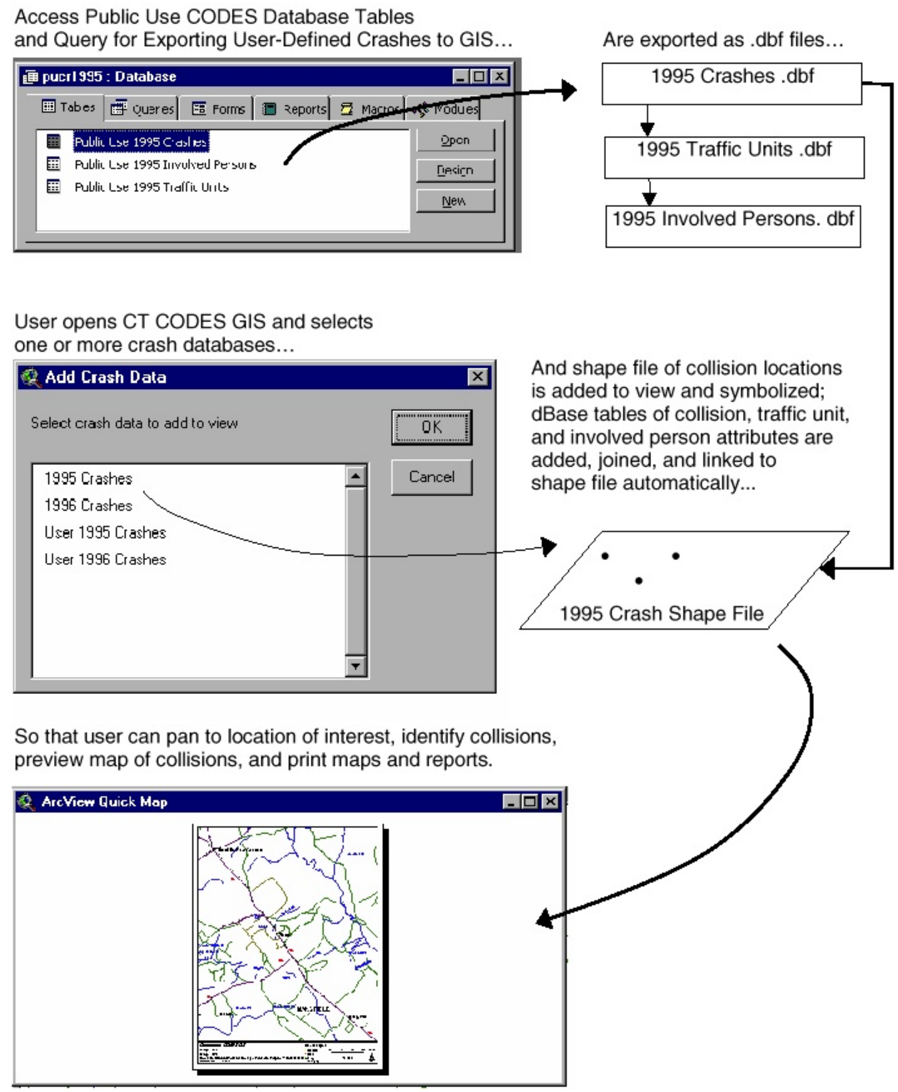


Connecticut CODES GIS



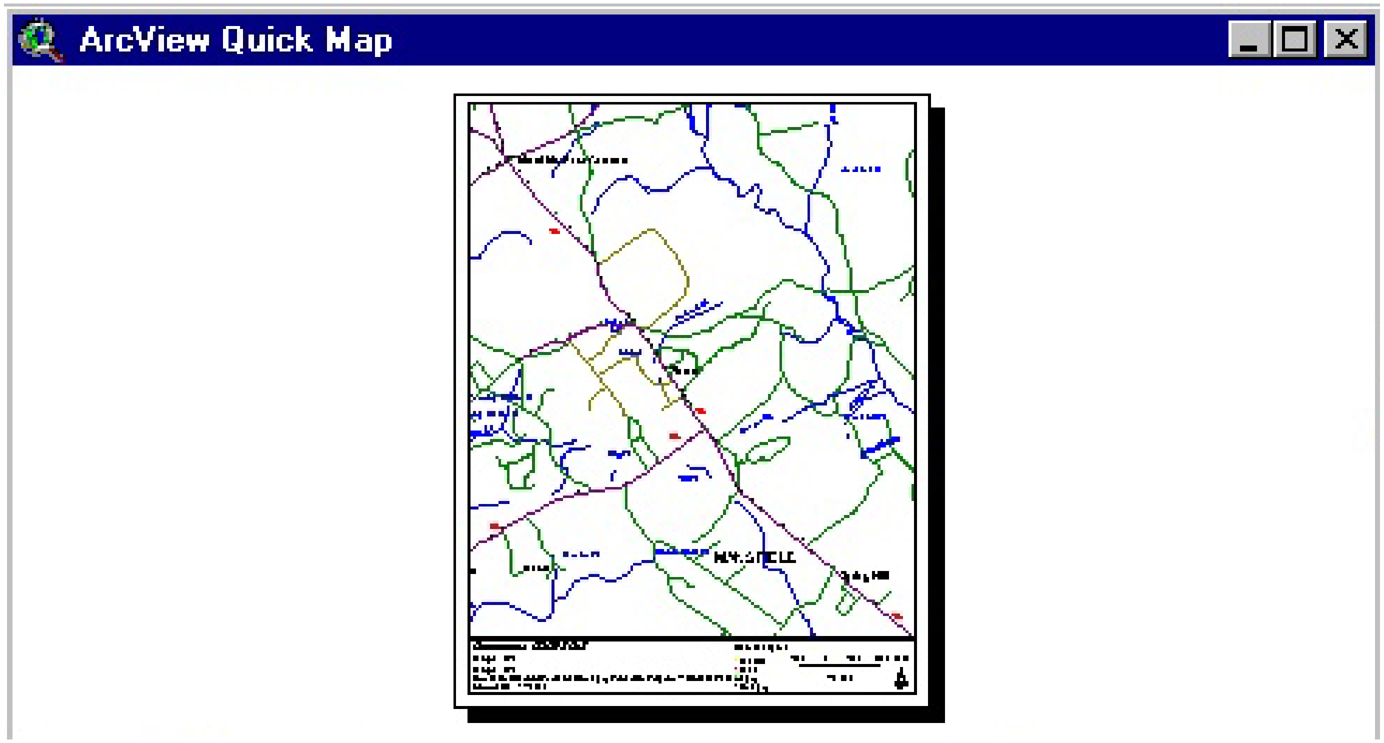
Search and Query

- Users can perform **detailed queries** to select a set of collisions, and **add them as a layer** in the GIS.
- In the GIS, users can find **where a collision occurred**, or find out **what kinds of collisions occurred** in a place.



ArcView Quick Map

•The user can pan to location of interest, identify collisions, preview map of collisions, and print maps and reports.

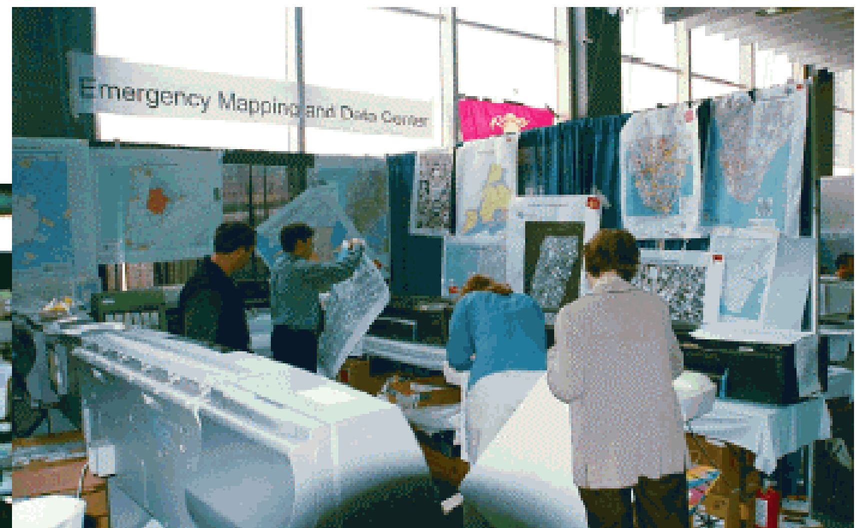


Data Used in the Study

- **Motor vehicle crash data** from Police Accident reports for 1995 and 1996, coded by the Accident Records Section of ConnDOT.
- **Trauma registry, emergency department, and inpatient records** maintained by CHREF, an arm of the CT Hospital Association.
- **Mortality records** maintained by the Vital Records Section of the Health Dept.

GIS World Trade Center Operations at Pier 92

- **GIS support** for firefighters, rescue workers, utility crews
- 24 hours a day / 7 days a week **support** for 2+ months
- 50+ **GIS professionals**



Data

- NYCMap
  - Orthophotography
  - Planimetric maps
- Thermal imagery
- LIDAR imagery
- GPS data

Problems

- Maintaining **building status** database
- **Unique identifiers** for the buildings?
- Data **consistency**
- Data **integrity**
- **TIME!**

Lessons Learned

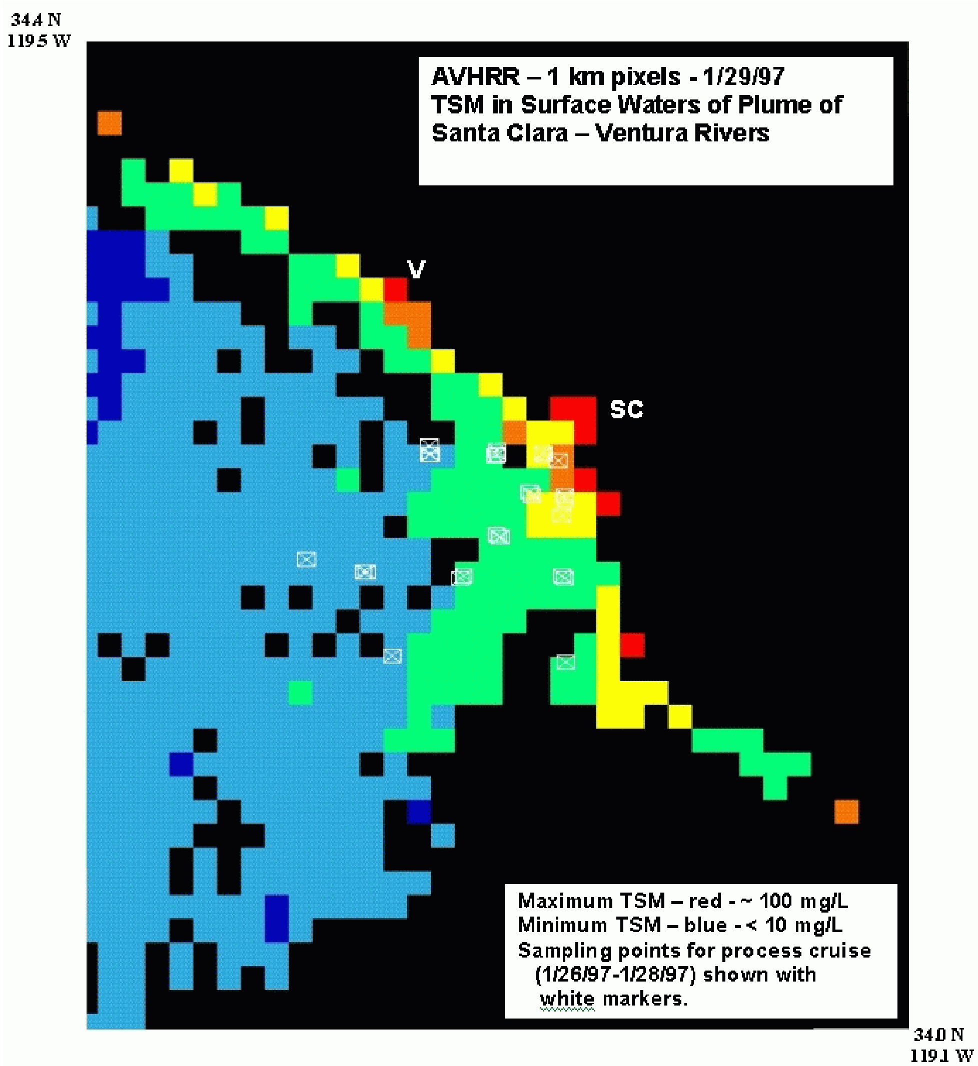
- NYC GIS infrastructure was **critical**
- Cities should **connect** their spatial data to its attributes!
- Need for **cartographic standards**
- Need **mobile access** to GIS
- **Version management** for multi-user environment

Channel Islands GIS

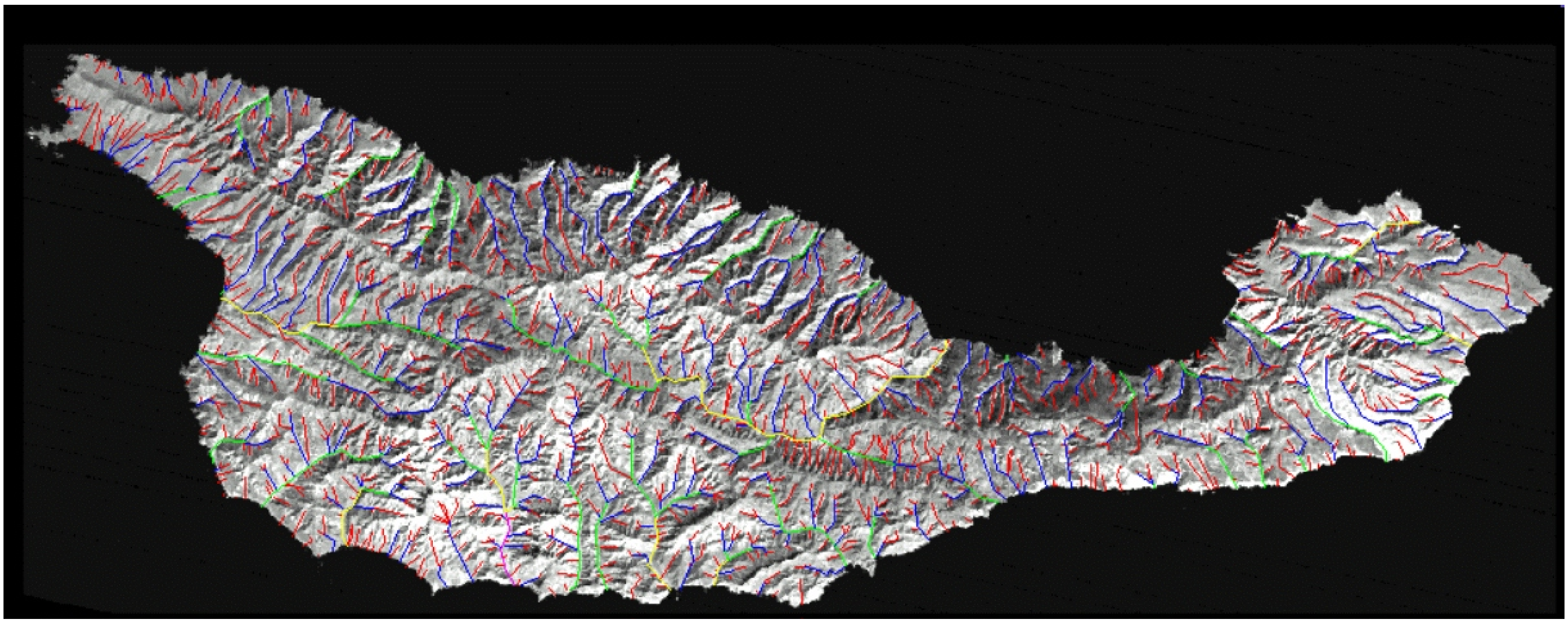
- **Collaborative** GIS
- **Many** contributors and developers
- **Public domain** and **mission-specific** data
  - UCSB
  - NOAA Channel Islands National Marine Sanctuary
  - Channel Islands National Park
  - Santa Cruz Island Reserve
  - UC Natural Reserve System
  - State of California Fish and Game (Oil Spill Prevention & Response)

Plumes and Blooms Project

AVHRR Sediment Plume
Santa Clara/Ventura Rivers

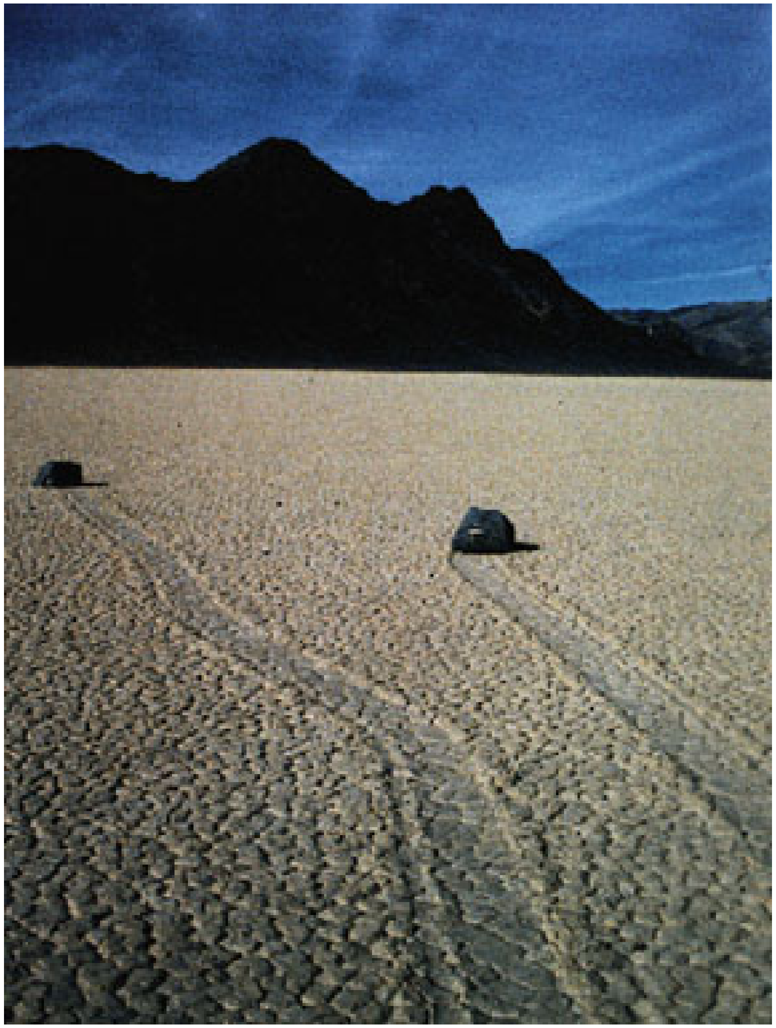


Santa Cruz Island: Watersheds

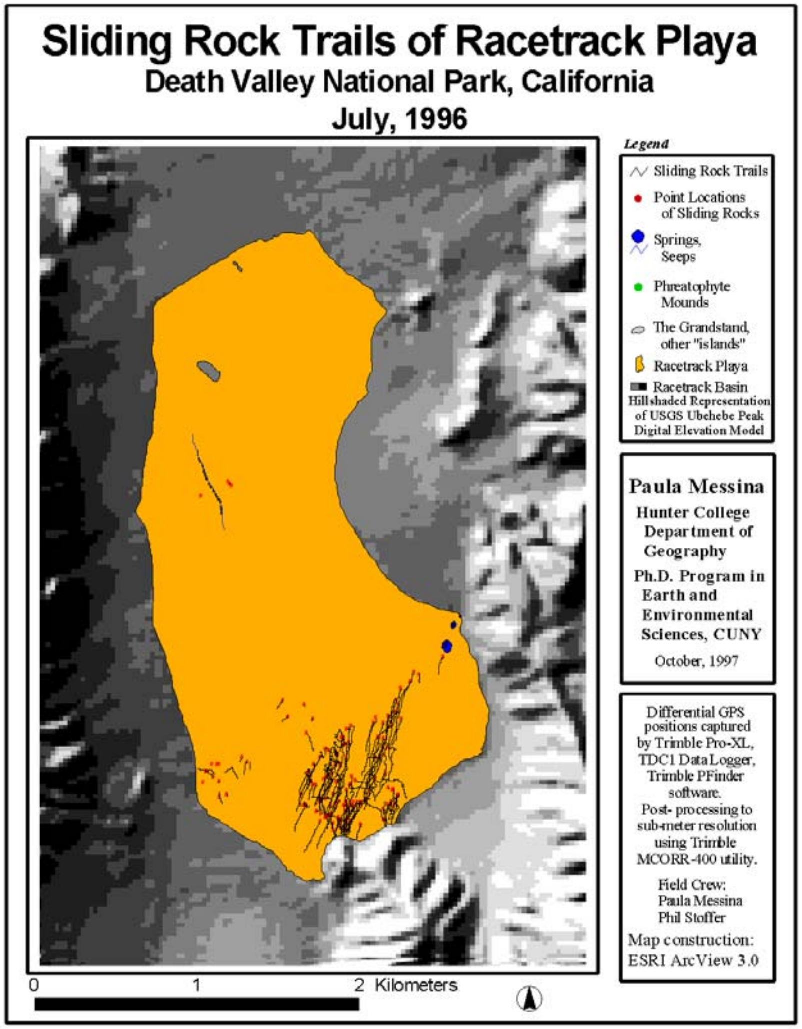


“Ellen” and “Bessie”

Two rocks, “Ellen” and “Bessie”, apparently **slid** to the northwest, imprinting trails as evidence of their unusual activity.



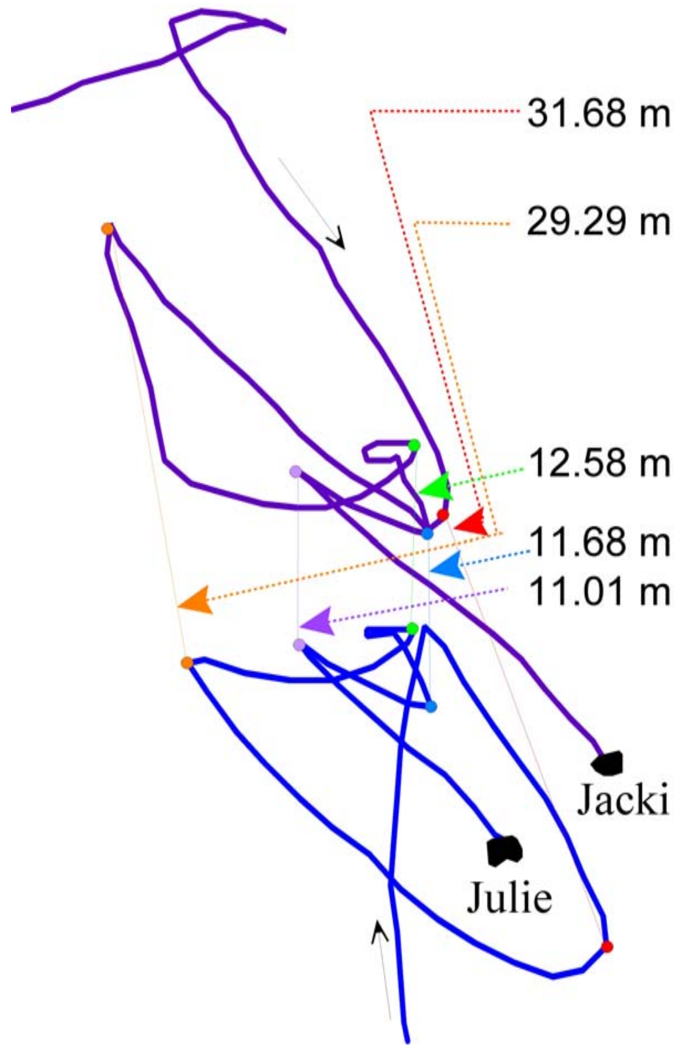
GPS and GIS to the Rescue



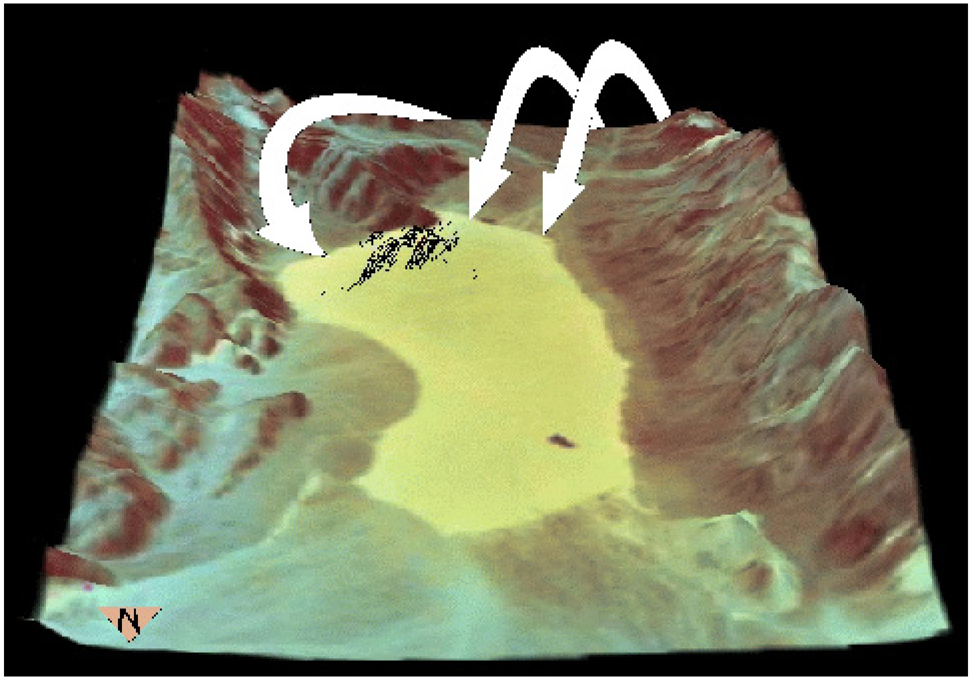
- The **exact locations** of all rocks and precise plans of all trails on the 667 hectare playa were captured by **Global Positioning System** (GPS), exported to ArcView GIS, and **analyzed** using a variety of spatial and statistical methods.

Spatial Patterns

- The trails of "Jacki" and "Julie" suggest a **high degree of similar motion**. However, although somewhat congruent, the rocks apparently converged during their journeys. There appeared to be **no correlation** between the size, shape, or lithology of a rock, and the length or straightness of its trail.



Terrain Analysis



Analysis of the surrounding terrain, using the USGS Digital Elevation Model (DEM), provided the clue that had remained hitherto elusive. The **slope and aspect** of the basin **directs airflow** along very specific vectors. Direct measurements of the wind revealed that wind speeds up to six times faster, and up to 50 degrees deviant occurred at locations only 400 meters apart.

Chapter 10: The Future of GIS

10.1 Why Speculate?

10.2 Future Data

10.3 Future Hardware

10.4 Future Software

10.5 Some Future Issues and Problems

Theme of the Course

- GIS's place in **understanding geographic distributions** and their mapping and prediction **in the real world**.
- So what does the **future** hold for GIS?
  - How might we see the **capabilities** you have already learned about **continuing to expand** in the future?

Compared to 10 Years Ago:

- **Acquiring data** for a new GIS is **no longer a major problem**.
- **GPS** has become a **major source** of new GIS data, and comes increasingly from **integrated GPS/GIS systems**.
- **Digital map images** such as scanned maps and air photos are often used as a background image for cross-layer registration and update.

Trends in GIS Data

- **Remote sensing** will become an (even more) important source of GIS data as **the cost of data falls** and new sorts of data arrive.
- **Data exchange** will become more common and has been **facilitated by exchange standards**.

Major Influences on GIS

- Advanced GIS work has been influenced significantly by the **workstation / powerful PC**.
- GIS has quickly incorporated **distributed systems and databases**.
- The **microcomputer** has allowed GIS to be **applied to new fields** and has **improved GIS education**.
- The **mobility** of portable GIS and GPS systems has revolutionized GIS use.

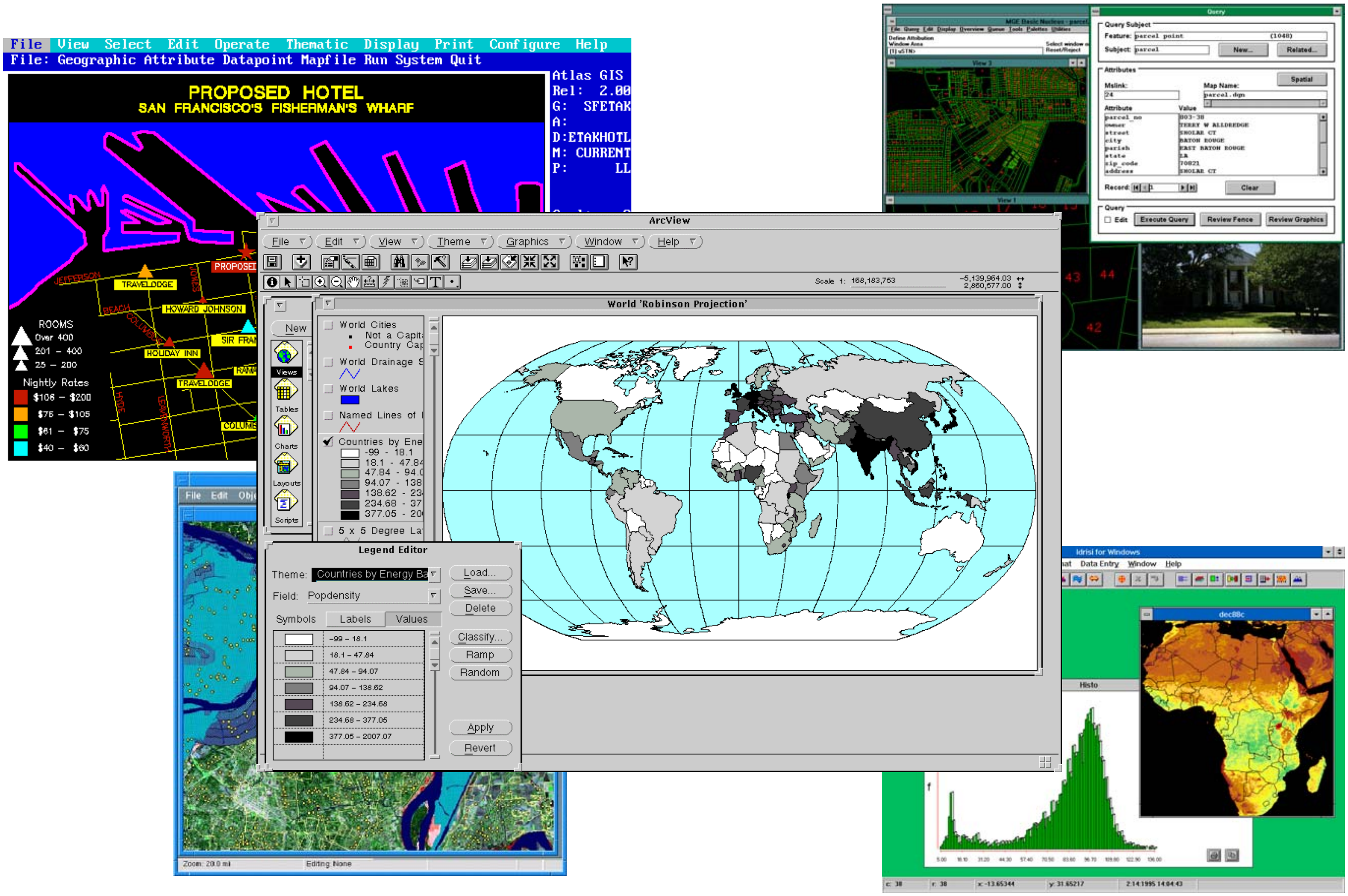
GIS Improvements

- Improvements in the **user interface** have substantially altered GIS "look and feel."
- Basic data differences such as raster vs. vector have **disappeared** as GISs have become **more flexible**.
- **Object-oriented programming** and databases are likely to improve GIS.
- GIS software is now **easier to install and maintain**.

Some of the Future is NOW!

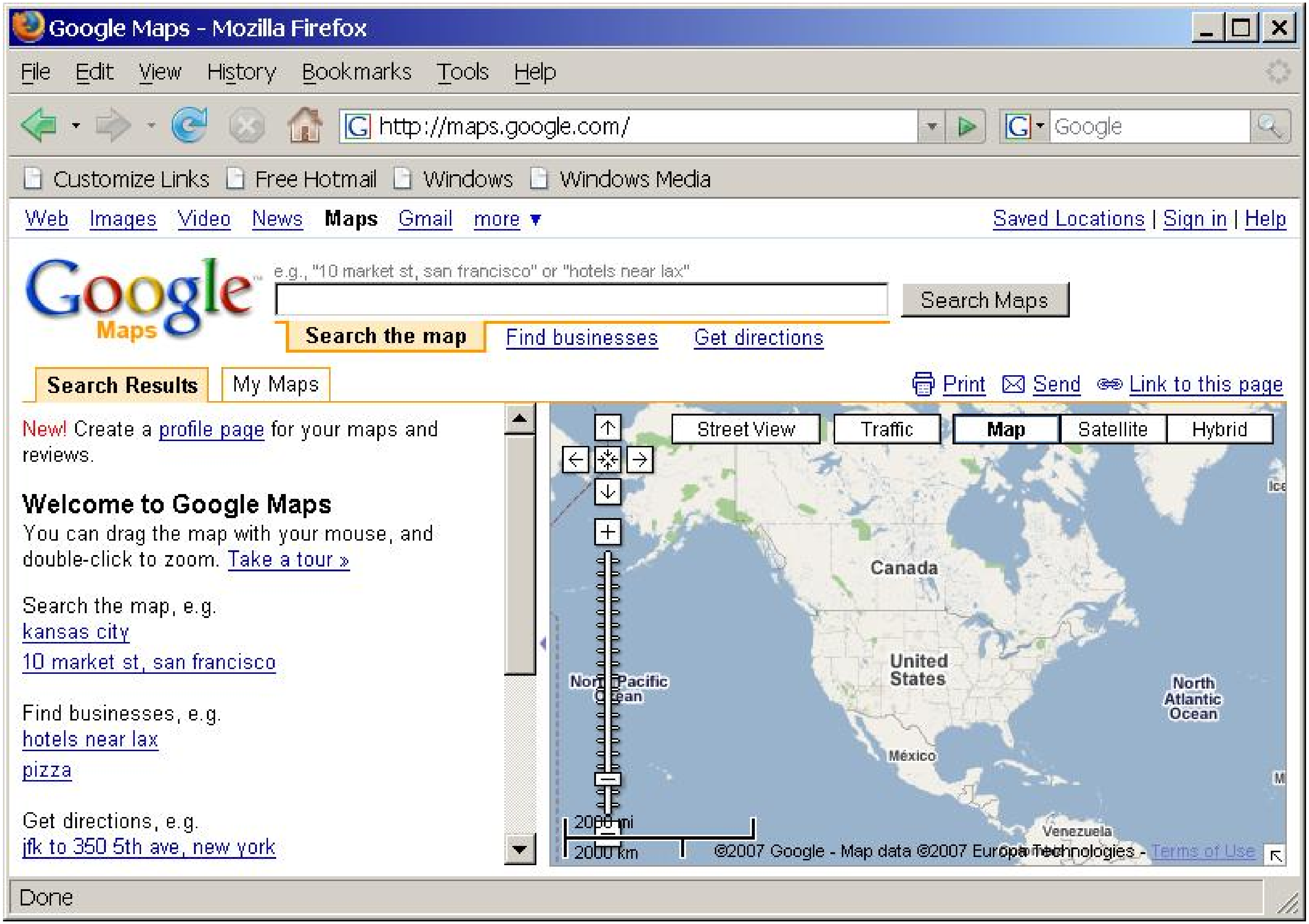
- Desktop mapping. "**Business Geographics**."
- Real **high end power**.
- GIS/GPS **integration**.
- **Rapidly maturing market** with broad public acceptance and knowledge
- **The Web**. More than data delivery.

Desktop Mapping



In-Vehicle Navigation Systems

GIS/GPS Integration


Google Maps - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://maps.google.com/
Google
Customize Links
Free Hotmail
Windows
Windows Media
Web Images Video News Maps Gmail more
Saved Locations | Sign in | Help
Google Maps
e.g., "10 market st, san francisco" or "hotels near lax"
Search Maps
Search the map
Find businesses
Get directions
Search Results
My Maps
Print
Send
Link to this page
New! Create a profile page for your maps and reviews.
Welcome to Google Maps
You can drag the map with your mouse, and double-click to zoom. Take a tour »
Search the map, e.g.
kansas city
10 market st, san francisco
Find businesses, e.g.
hotels near lax
pizza
Get directions, e.g.
jfk to 350 5th ave, new york
Street View
Traffic
Map
Satellite
Hybrid
Canada
United States
North Pacific Ocean
North Atlantic Ocean
México
Venezuela
2000 mi
2000 km
©2007 Google - Map data ©2007 Europa Technologies - Terms of Use
Done

The Four Revolutions

- Workstation
- Microcomputer
- Network
- Mobility

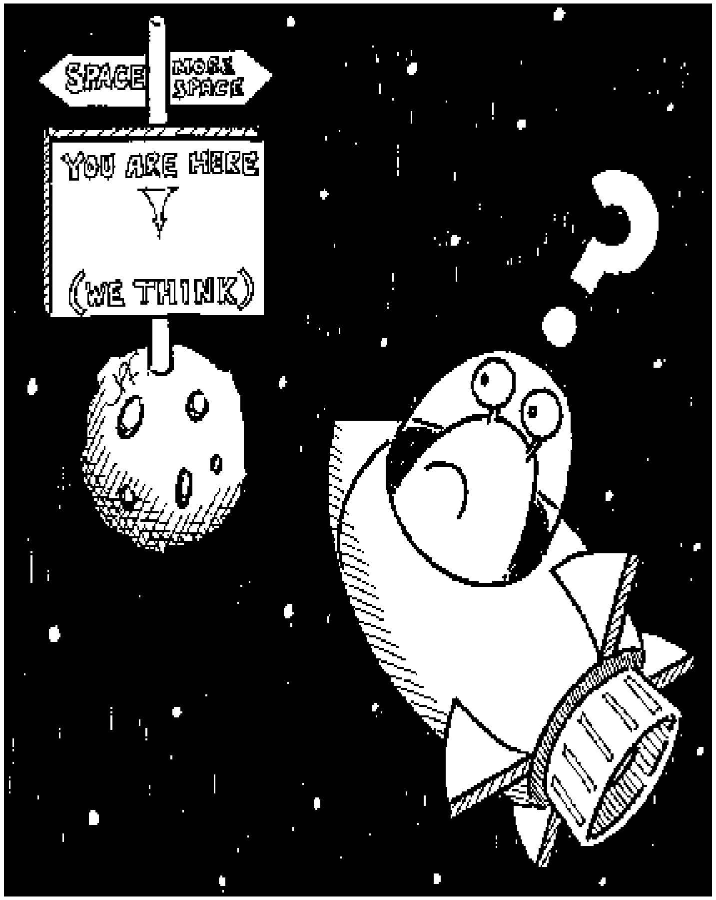
Wearable Computers Come of Age

Future GISs

- Scientific visualization and computer graphics will be **increasingly integrated** with GIS capabilities
- **Animated** maps
- **Interactive** maps
- **Augmented** reality

Future Issues

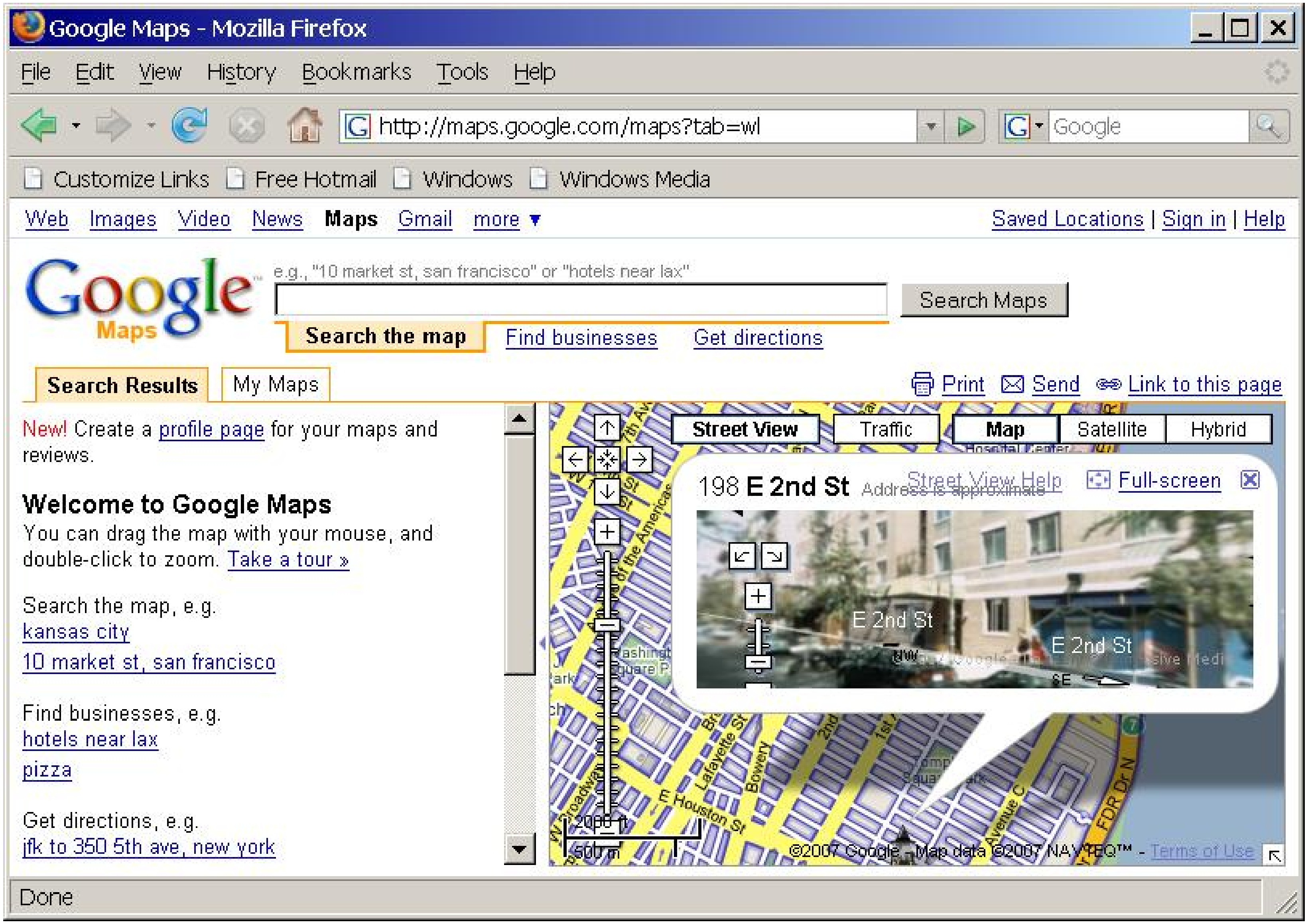
- New users
- Privacy
- Data ownership
- GI Science & Technology



New User Communities

- Archeology
- Epidemiology
- Law
- K-12 Education
- etc.
  - **Simpler** systems?
  - **Specialty** systems?

Privacy? Google Maps StreetView …



Future Issues

- **Privacy** will become a **critical issue** for GIS as use expands to **legal applications**.
- **Data ownership** will remain **critical** to GIS, with a **delicate balance** between public and private GIS data.
- GIS research is threatened by a **lack of funding** and should be protected by the GIS community.

The Role of Computing

"Computing is not about computers any more. It is about **living**."

Nicholas Negroponte, Founding Director of MIT's Media Lab. *Being Digital* (1995), p. 6.

The Apple iPhone 3G with GPS

GIS is an Approach to the World

GIS is not about systems any more.
It is about **geography**.

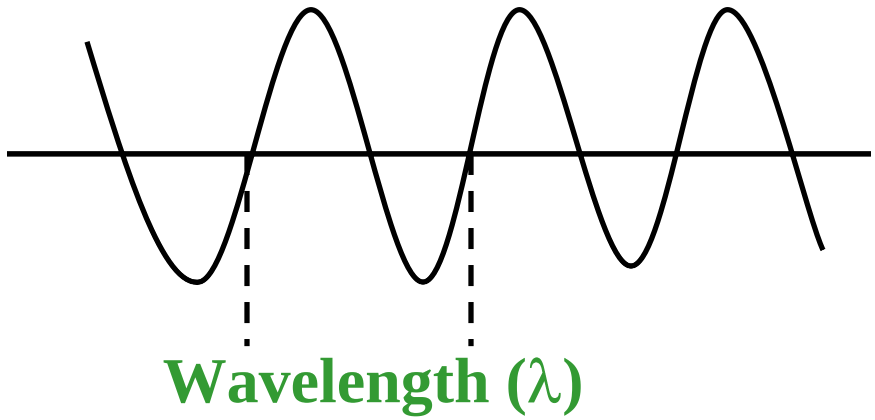
Greater potential than most other sciences for the tools and the science to go **above and beyond technology**.

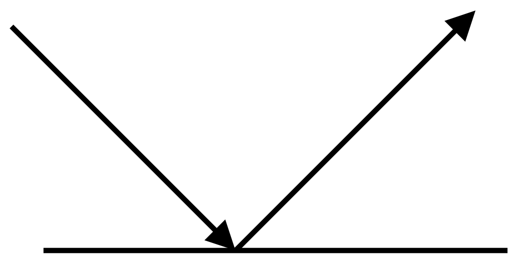
Introduction to Remote Sensing – Part 1

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

Solar Radiation

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

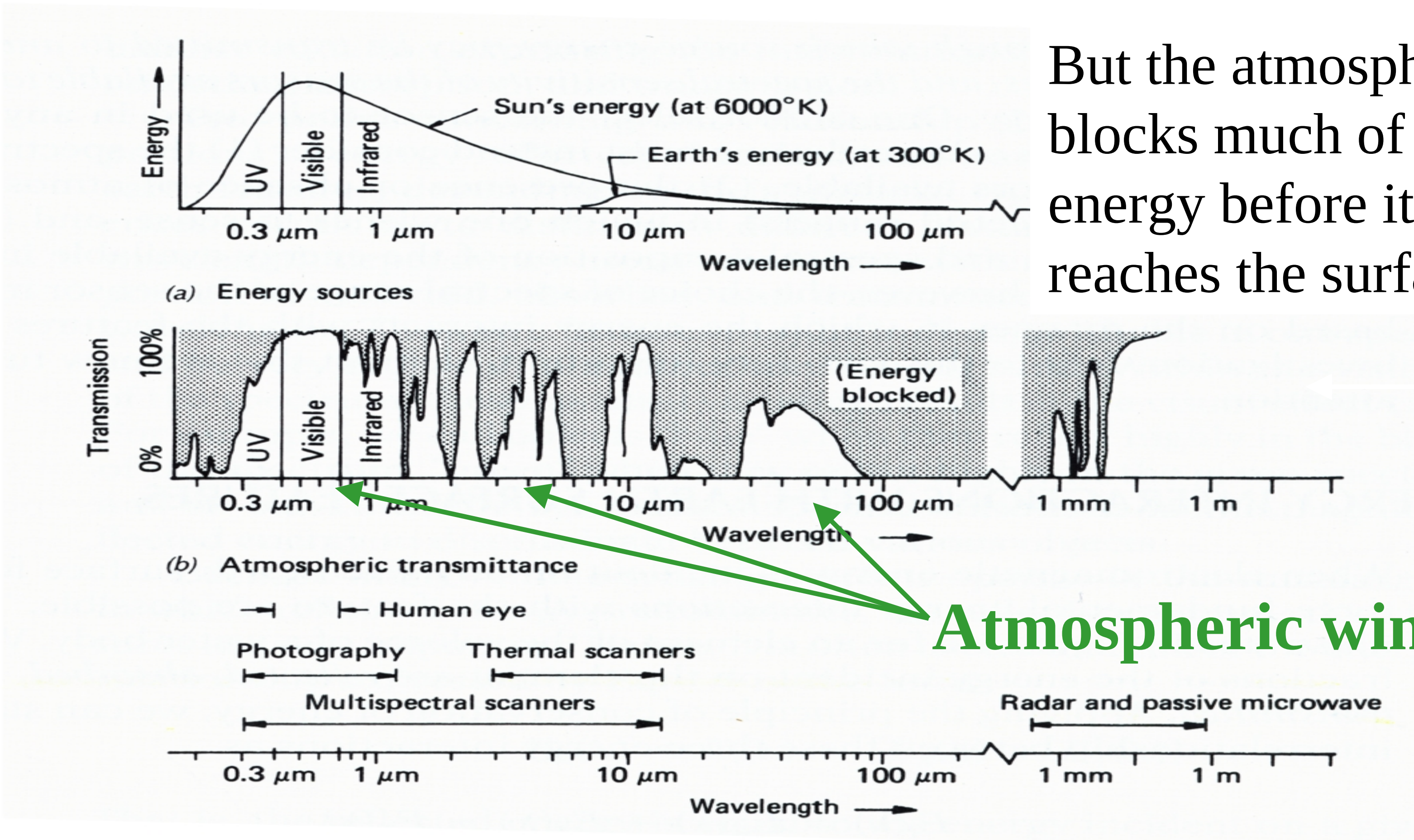




- EMR energy moves at the **speed of light (c)**: $c = f\lambda$
- ***f* = frequency**: The number of waves passing through a point within a unit time (usually expressed per second)
- **Energy** carried by a photon: $\varepsilon = hf$ [h=Planck constant (6.626×10^{-34} Js)]
- The shorter the wavelength,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

Solar Electromagnetic Radiation

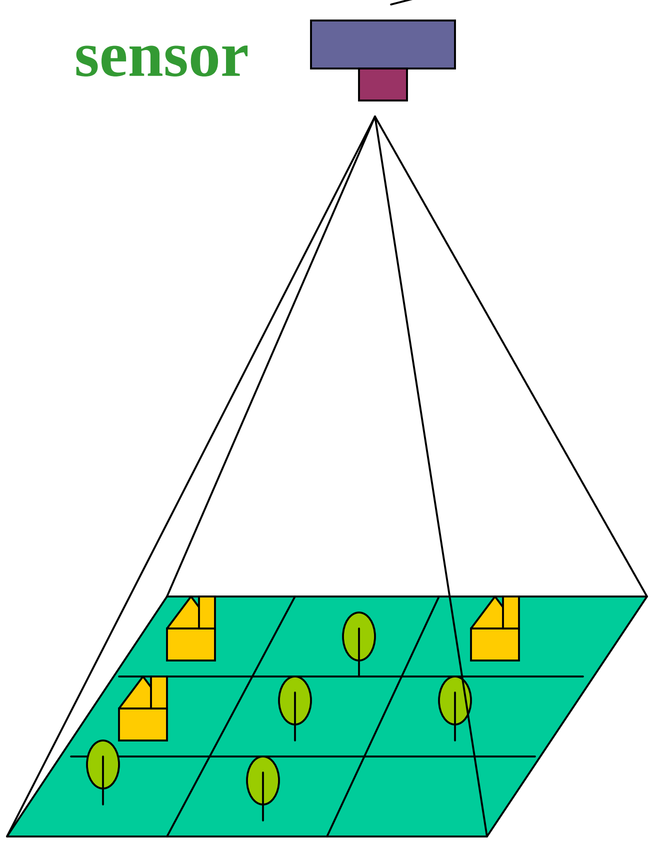
- The sun emits EMR across a **broad spectrum** of wavelengths:

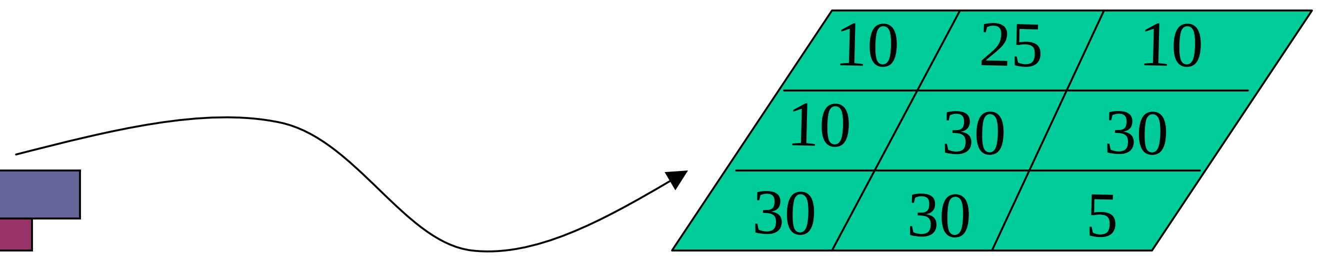


But the atmosphere blocks much of the energy before it reaches the surface

Atmospheric windows

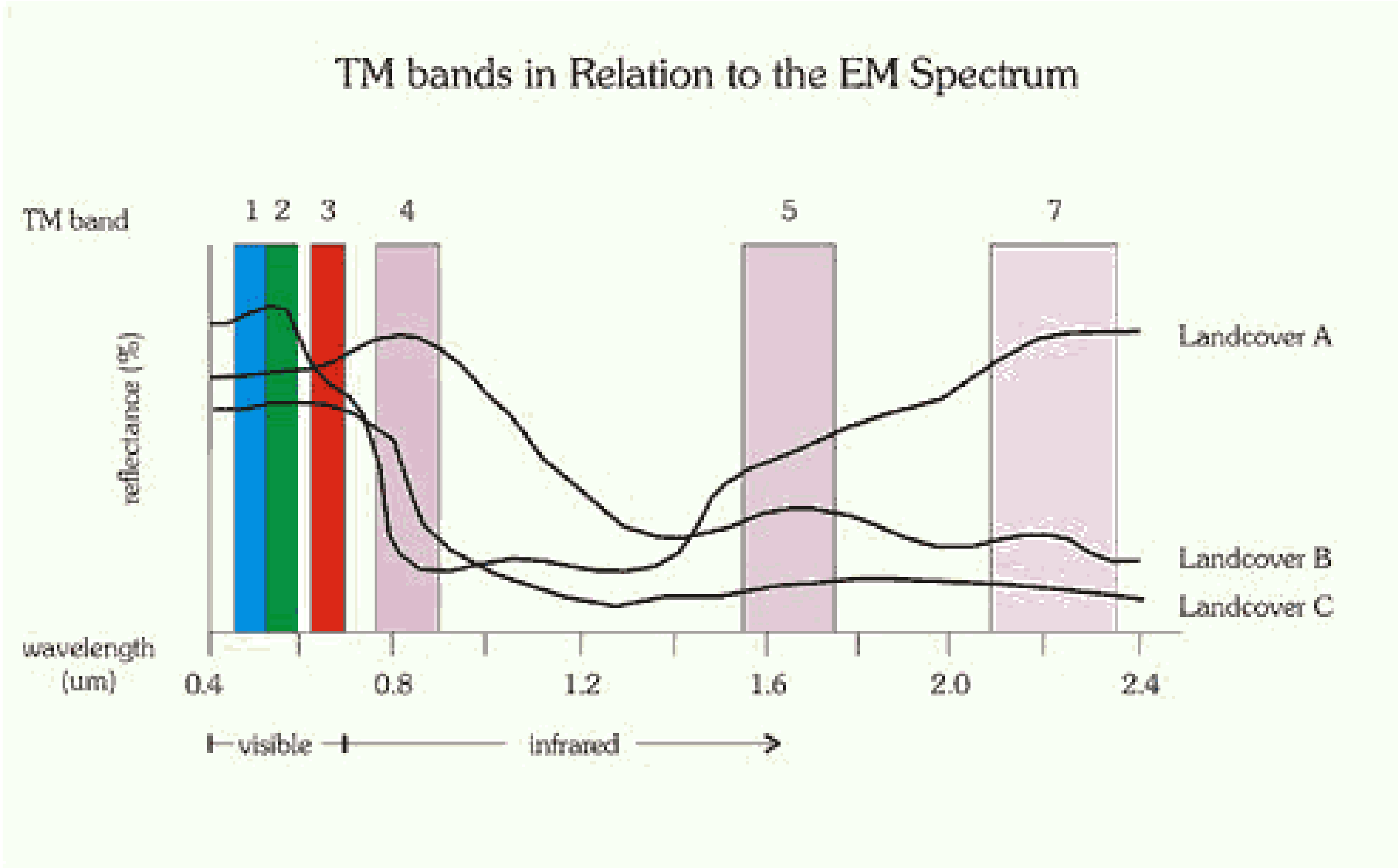
Digital Images





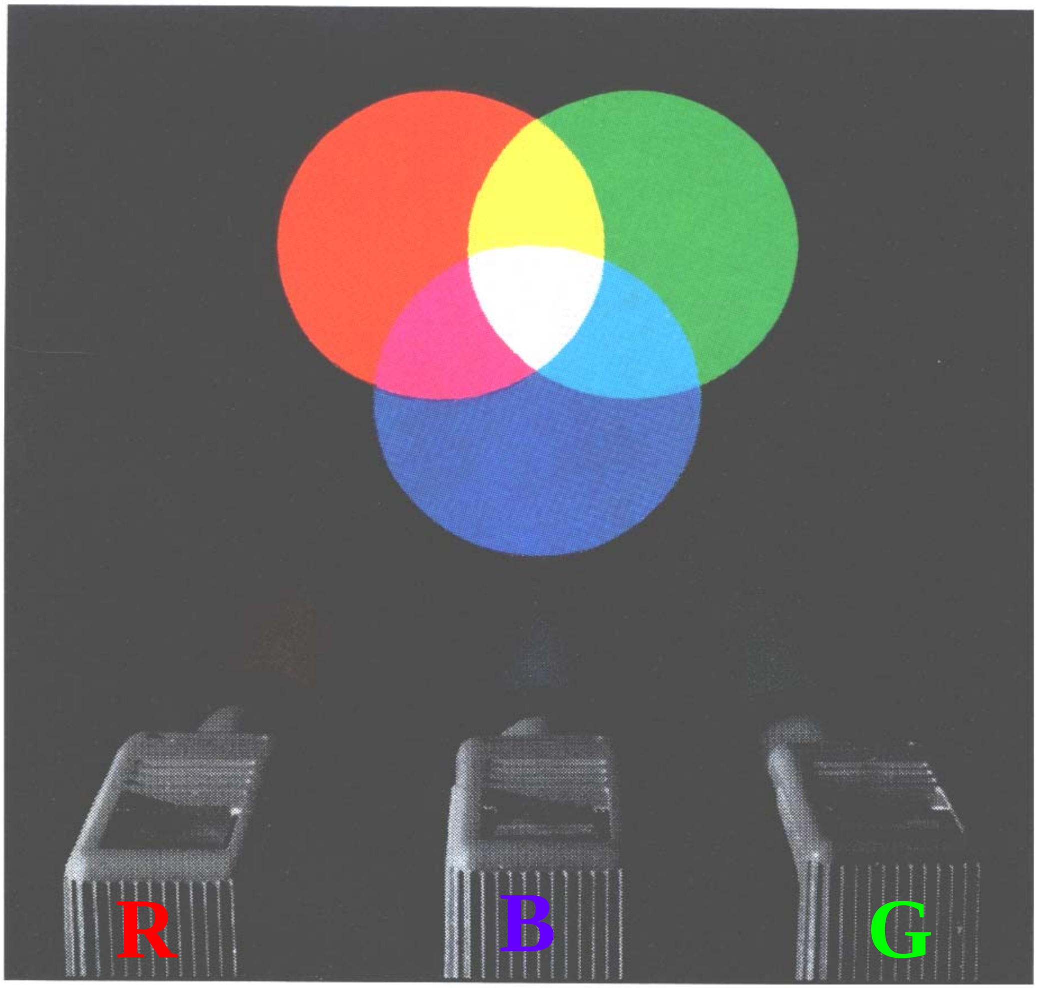
1. The area is covered with a **grid** of cells
2. Each cell has a **digital number** indicating the amount of energy received from the cell (in a certain wavelength range)
3. The cell is called a **pixel** (a picture element)
4. The size of the pixel is the **spatial resolution**

Multispectral Remote Sensing



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

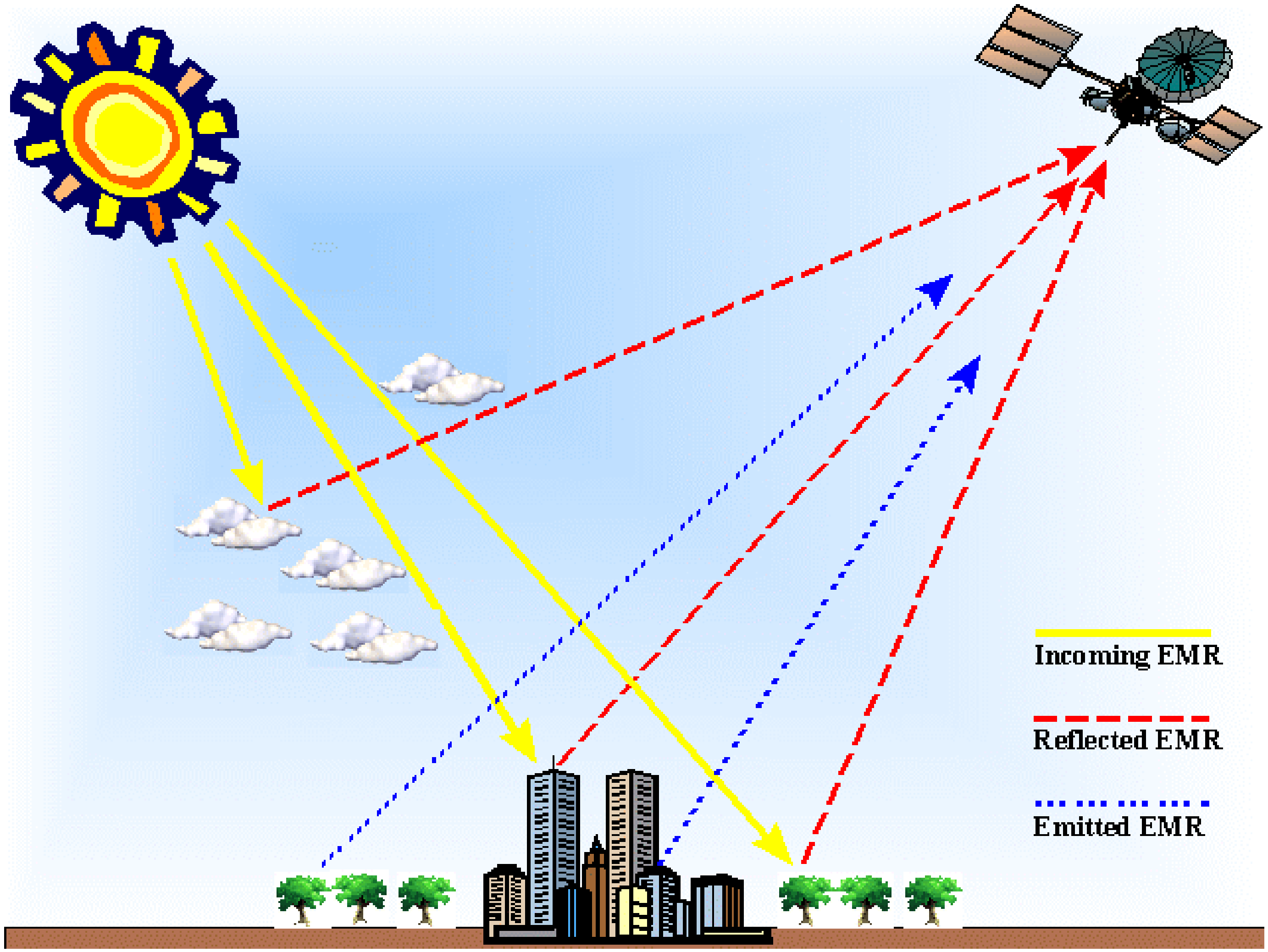
Color Arithmetic



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

Satellite Imagery - Sensing EMR

- Digital data obtained by sensors on satellite platforms

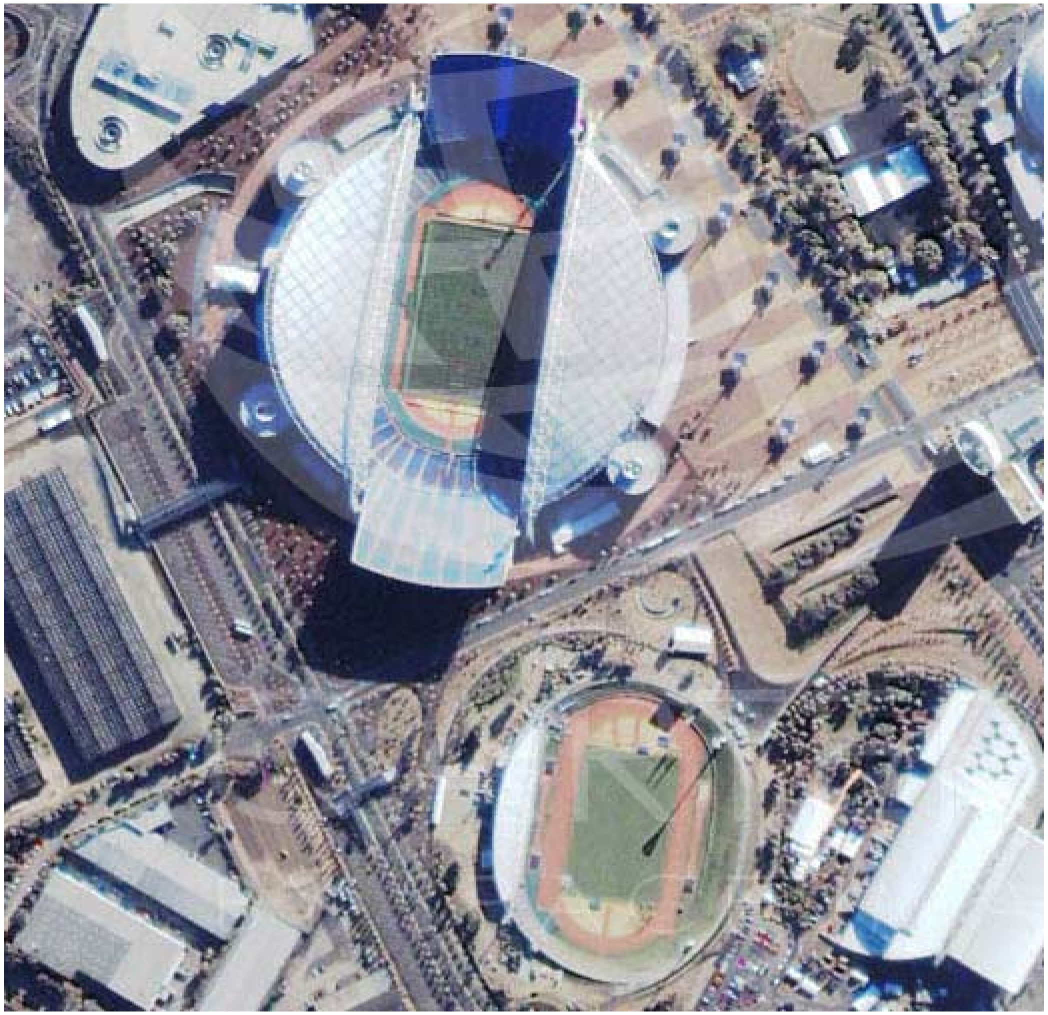


Satellite Imagery - 4 Resolutions

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

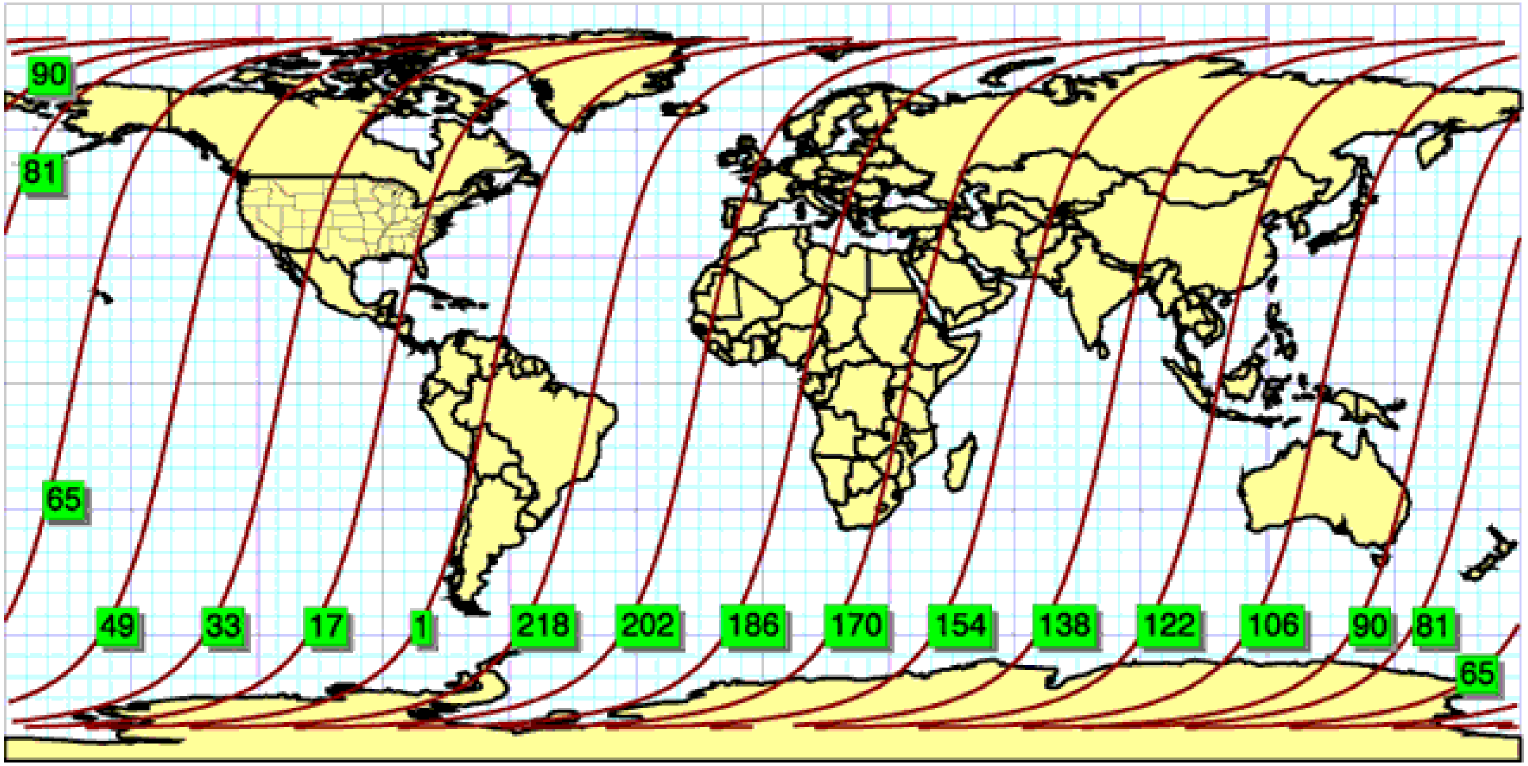
Spatial Resolution

IKONOS panchromatic image of Sydney Olympic Park - 1m



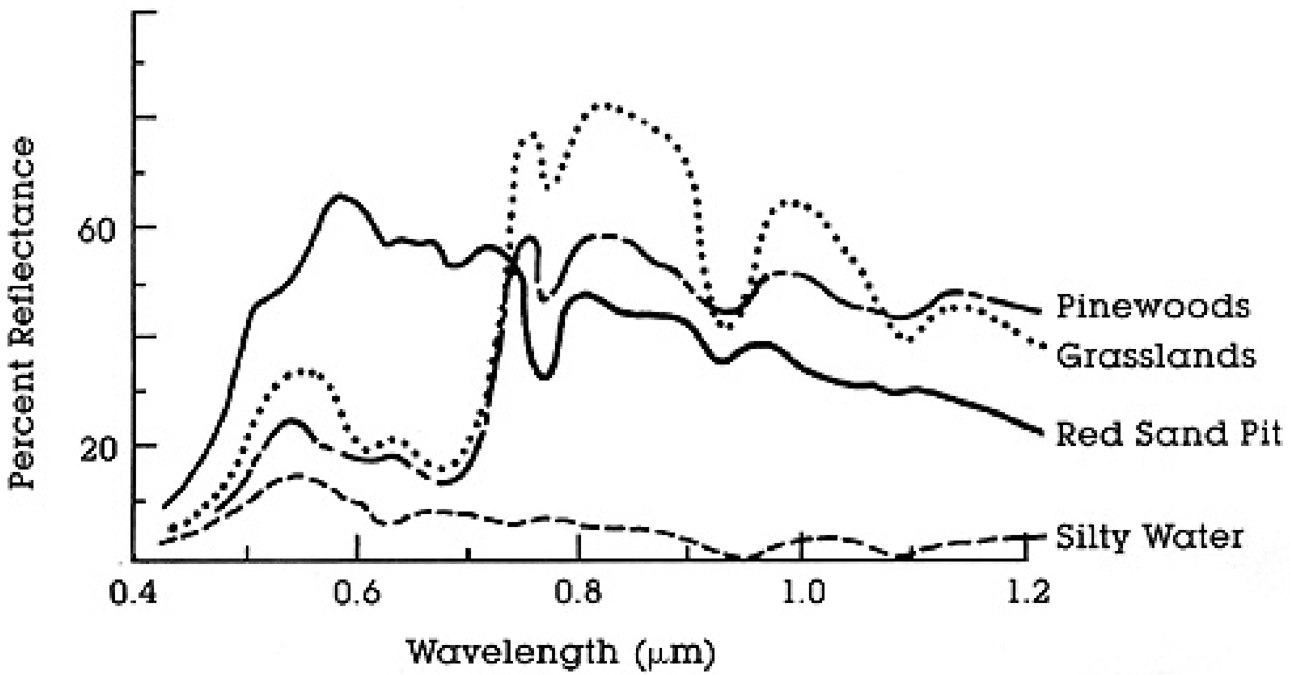
Temporal Resolution

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



Spectral Resolution

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



Radiometric Resolution

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

Image Pre-Processing

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

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

Image Enhancements

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

Spatial Enhancements

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

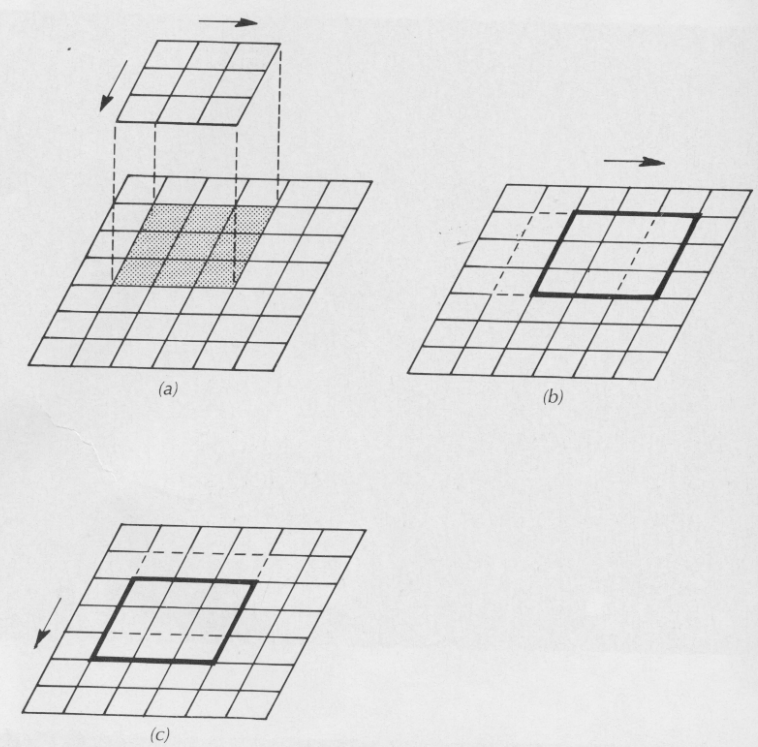


Figure 7.8 The moving window concept: (*a*) projection of 3 × 3 pixel window in image being processed; (*b*) movement of window along a line from pixel to pixel; (*c*) movement of window from line to line. (Adapted from [168].)

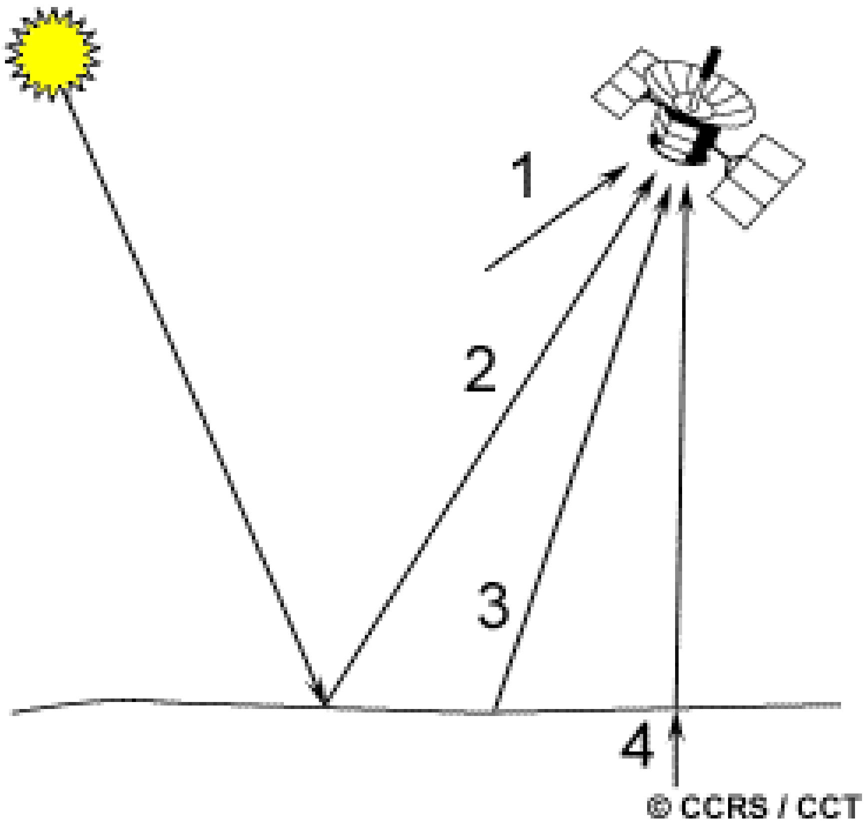
Spectral Enhancements

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

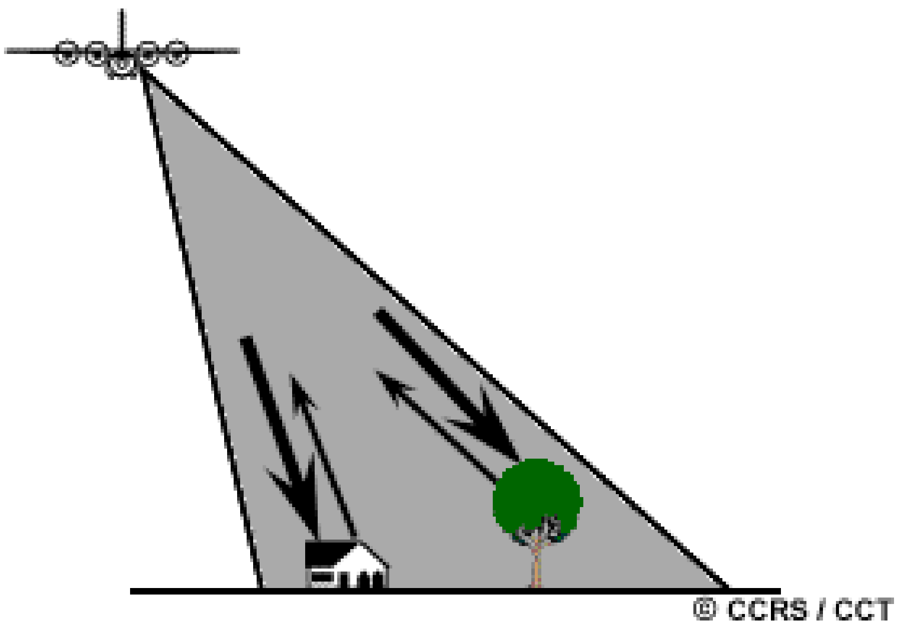
Classification

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

Passive vs. Active Remote Sensing



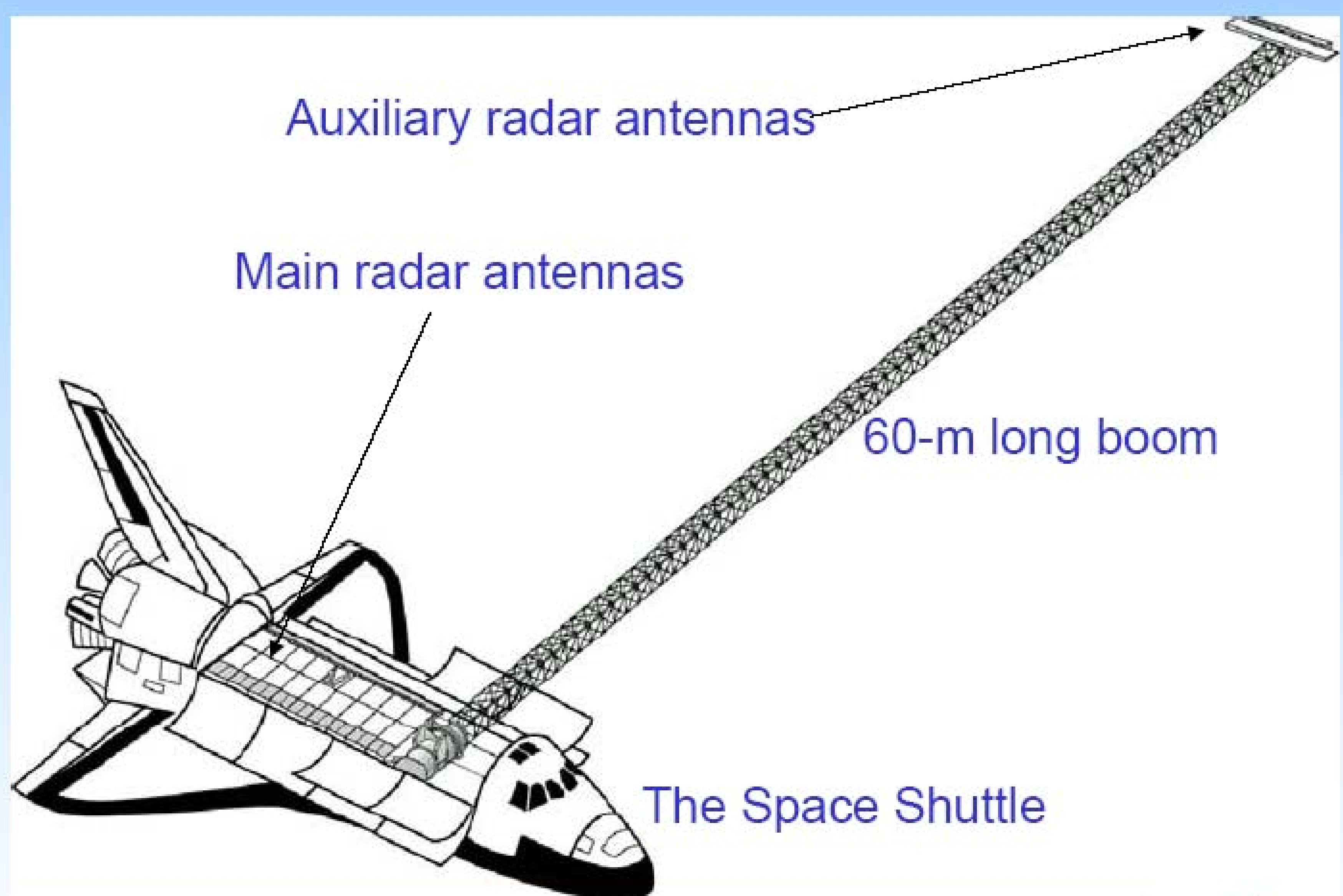
http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter3/chapter3_1_e.html



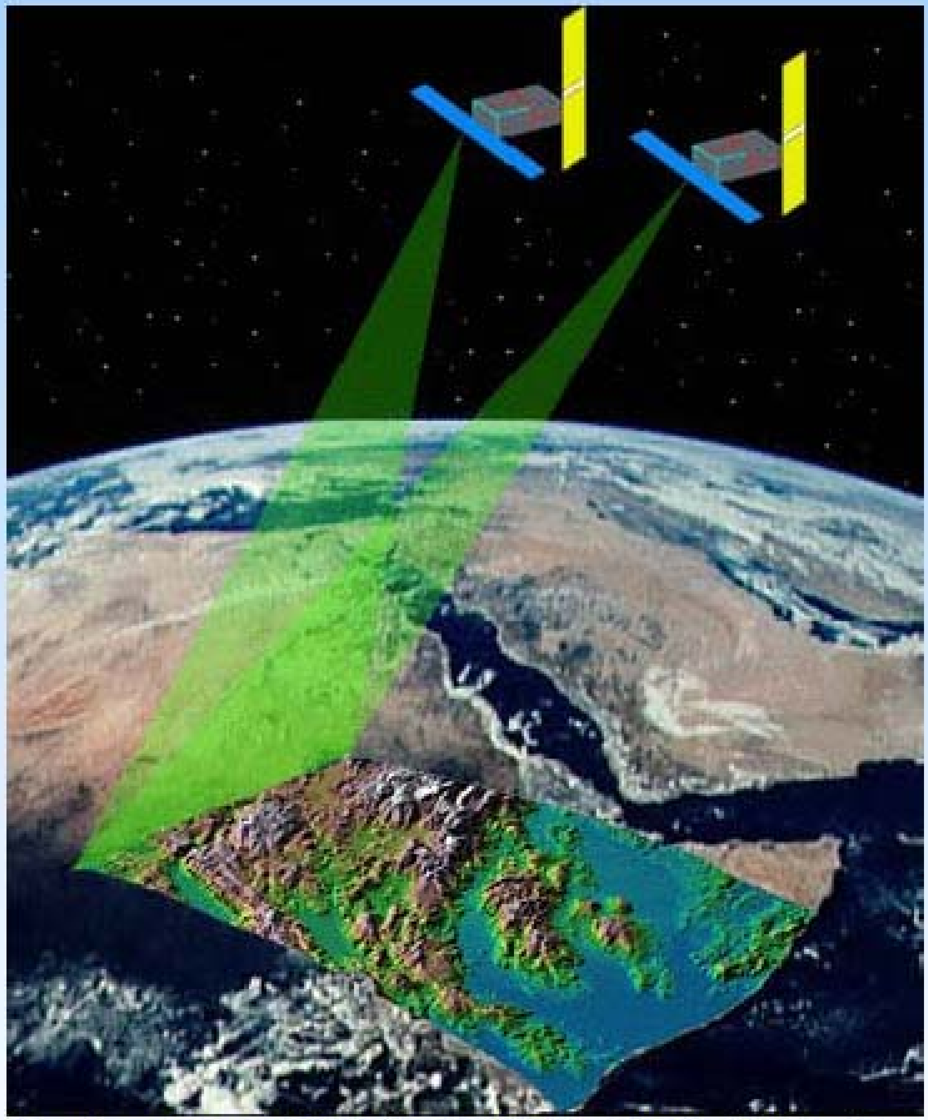
Passive sensors receive **solar energy reflected** by the Earth's surface (2), along with energy emitted by the atmosphere (1), surface (3) and sub-surface (4)

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

The NASA/DLR SRTM Mission



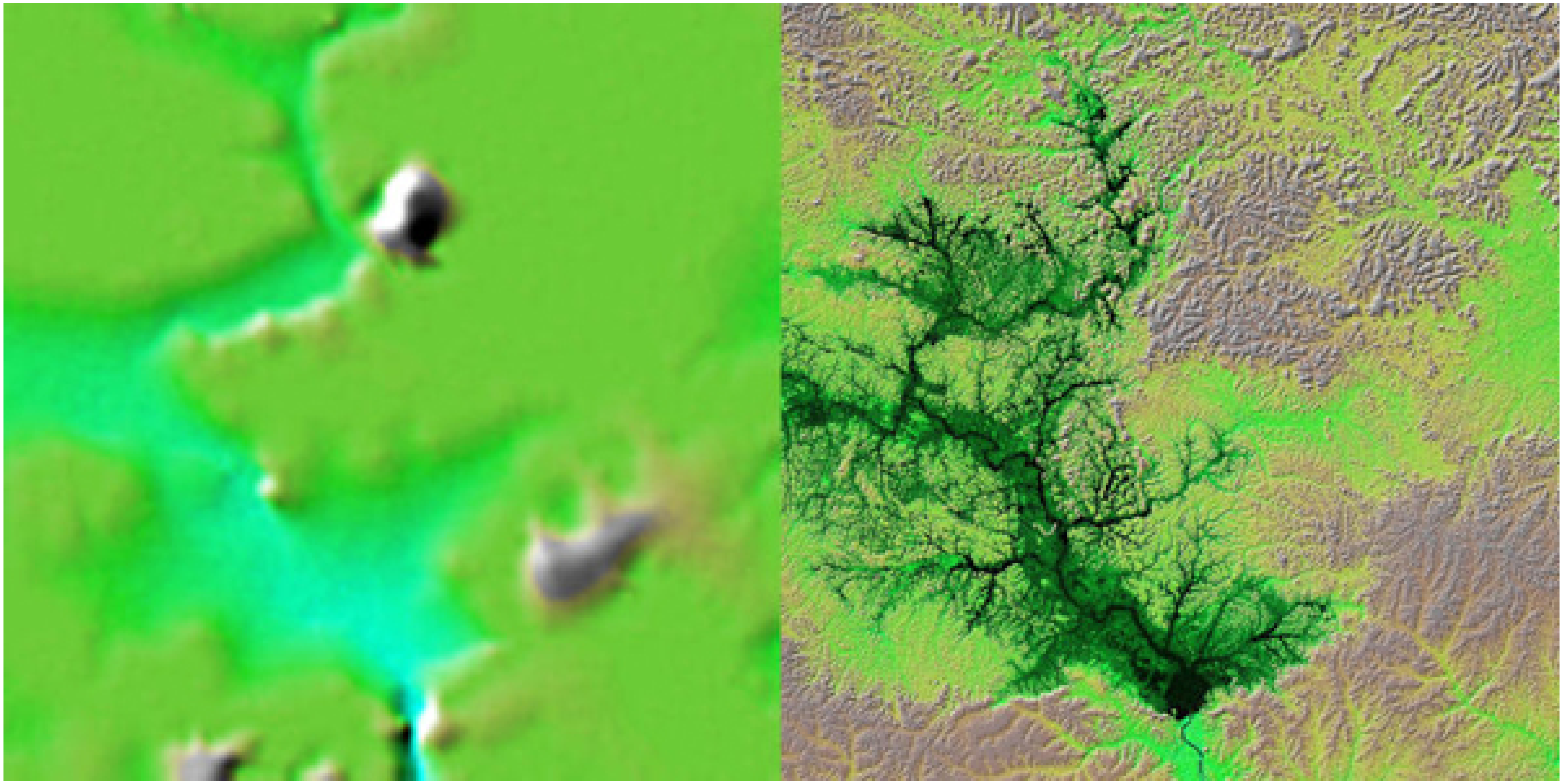
Radar Interferometry from Space



Drawing courtesy of Prof. Howard Zebker, Stanford University

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

Improvement Over Old Global DEMs



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

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

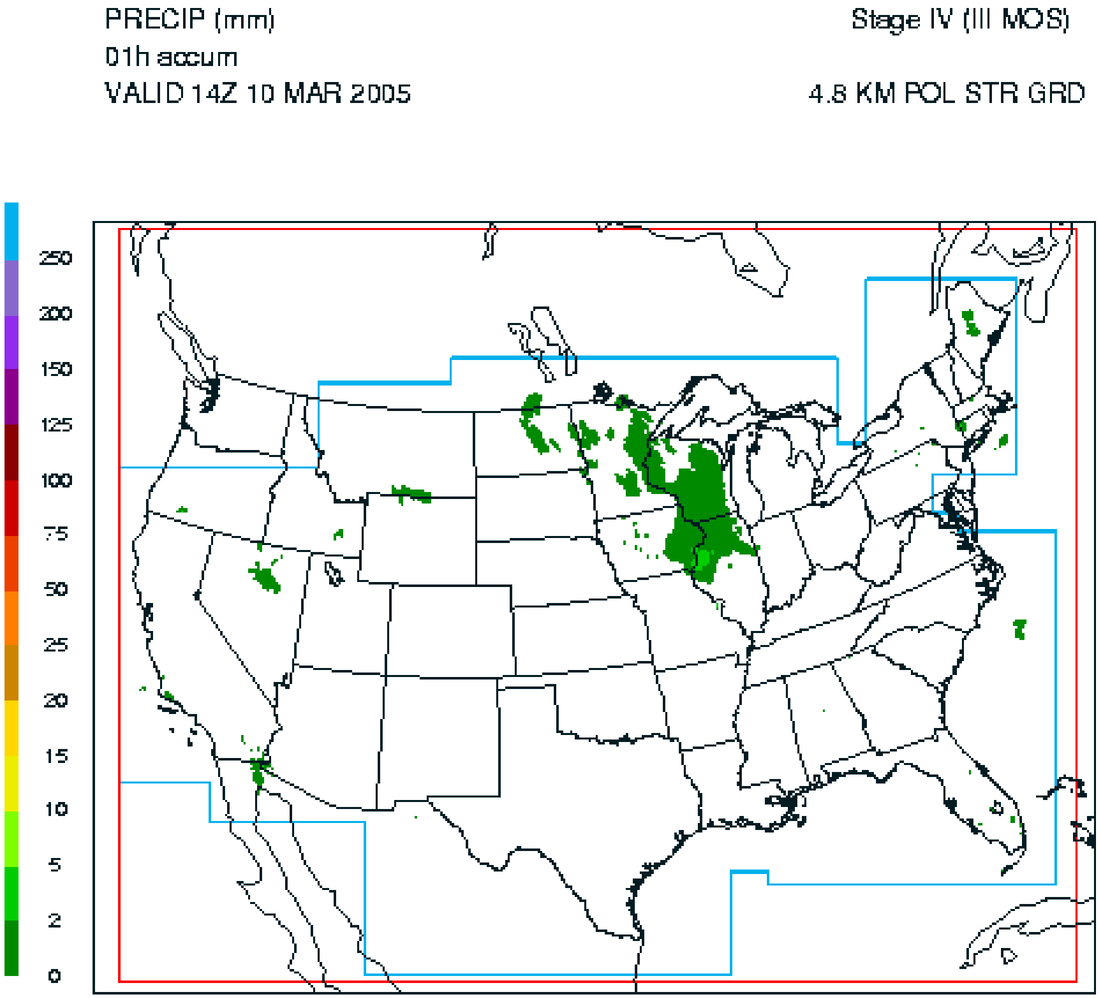
Nexrad Doppler Weather RADAR

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

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

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

CONUS Hourly Nexrad Rainfall



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

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

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

Introduction to Remote Sensing – Part 2

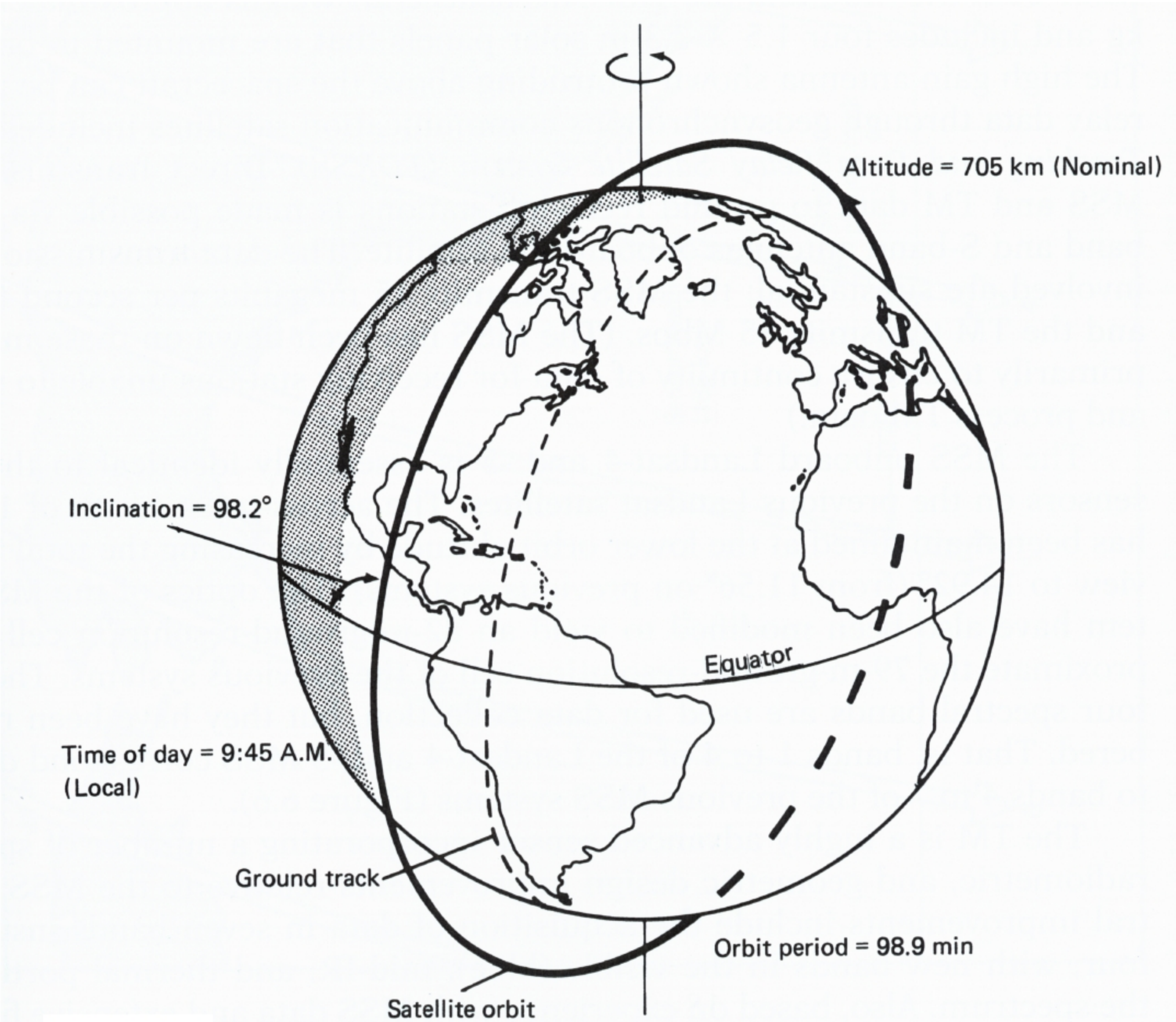
- Medium-resolution Sensors
  - Landsat Series
  - SPOT Series
- High-resolution Sensors
  - Ikonos
  - Quickbird
- Low(er)-resolution Sensors
  - GOES
  - AVHRR
  - MODIS

Landsat Platforms and their Sensors

Satellite	Launched	Decom.	RBV	MSS	TM	Orbit Info.
Landsat-1	23 Jul 1972	6 Jan 1978	1-3	4-7	none	18d/900km
Landsat-2	22 Jan 1975	25 Feb 1982	1-3	4-7	none	18d/900km
Landsat-3	5 Mar 1978	31 Mar 1983	A-D	4-8	none	18d/900km
Landsat-4	16 Jul 1982	--	none	1-4	1-7	16d/705km
Landsat-5	2 Mar 1984	--	none	1-4	1-7	16d/705km
Landsat-6	5 Oct 1993	Launch Failure	none	none	ETM	16d/705km
Landsat-7	15 Apr 1999	--	none	none	ETM+	16d/705km

RBV: Return Beam Vidicon {Blue, Green, Red}@~40m
MSS: Multi-spectral Scanner {Green, Red, NIR1, NIR2)@~80m
TM: Thematic Mapper {Blue, Green, Red, NIR, IR1, IR2}@~30m, TIR@120m
ETM: Thematic Mapper {Blue, Green, Red, NIR, IR1, IR2}@~30m, TIR@60m

Landsat Orbits



Sun-synchronous orbit of Landsat-4 and -5. (Adapted from NASA diagram.)

- Landsat satellites' orbits are designed to be **sun-synchronous orbits**, meaning that the satellites always cross the Equator at precisely the same local time (~10:00 am)
- In this way, images collected of different parts of the globe are collected under as **similar illumination conditions** as possible

‘Wiskbroom’ Sensors

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 72.

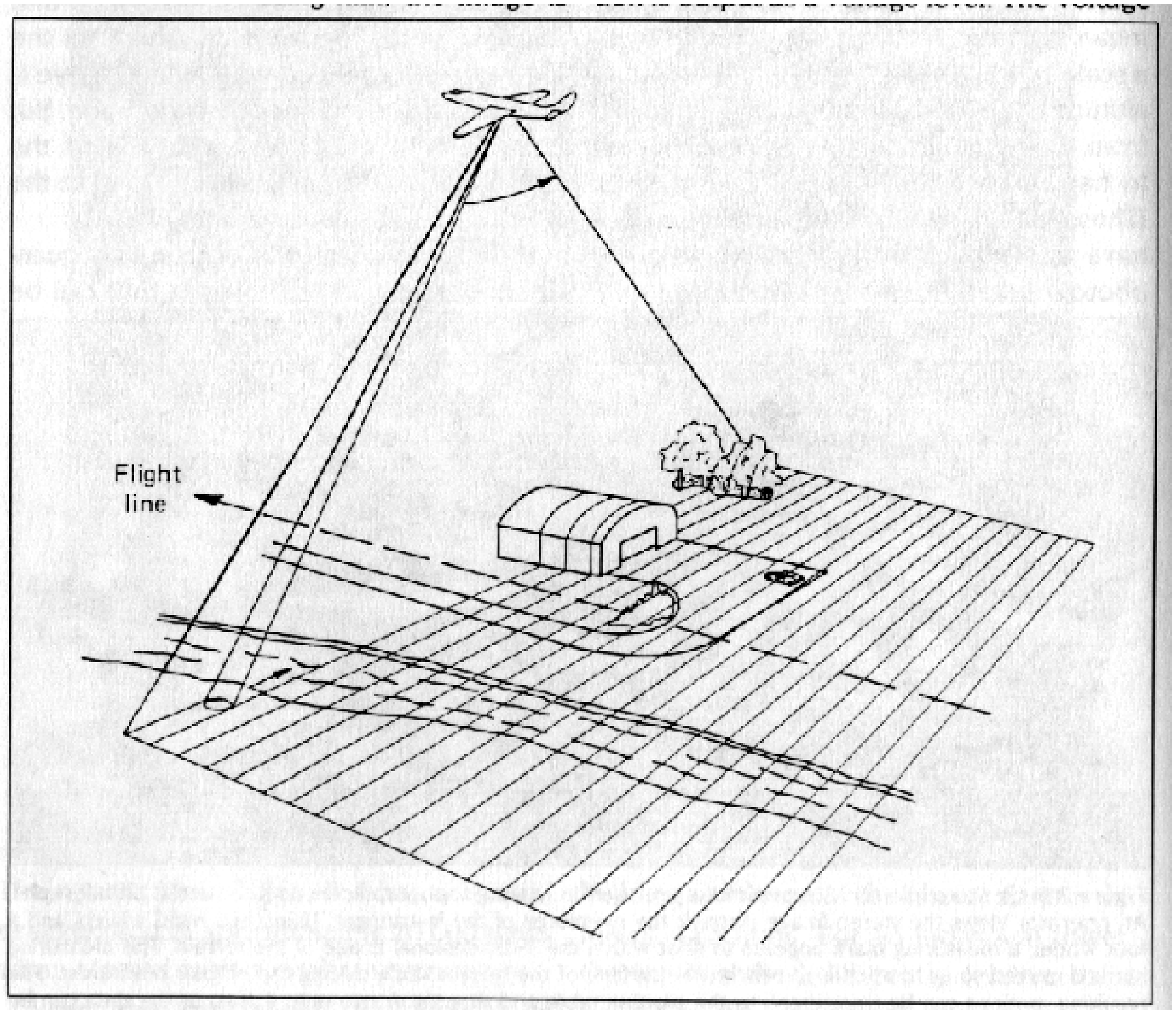


Figure 3.10 An Electro-Optical Scanner in Operation. (From *Remote Sensing and Image Interpretation* by Lillesand and Kiefer 1987, published by John Wiley and Sons.)

SPOT Characteristics

Launch Dates

SPOT 1: February 22, 1986
SPOT 2: January 22, 1990
SPOT 3: September 26, 1993
SPOT 4: March 24, 1998
SPOT 5: May 3, 2002

Temporal resolution = 26 days
Radiometric resolution = 8-bit

HRV imaging instruments: SPOT 1, 2 and 3

Spectral bands:	Spatial resolution	swath width
0.5-0.59 (green)	20x20 m	60km
0.61-0.68 (red)	20x20 m	60km
0.79-0.89 (NIR)	20x20 m	60km
0.51-0.73 (panchromatic)	10x10 m	60km

HRVIR imaging instruments: SPOT 4

Spectral bands:	Spatial resolution	swath width
1.58-1.75 (SWIR)	20x20 m	60km

HRG imaging instruments: SPOT 5

Higher spatial resolution: 5m panchromatic, 10m visible/NIR bands, 20m SWIR

These are the primary sensors, each platform carries other …

‘Pushbroom’ Sensors

Aronoff, S. 1989. Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa, Ontario, Canada, p. 74.

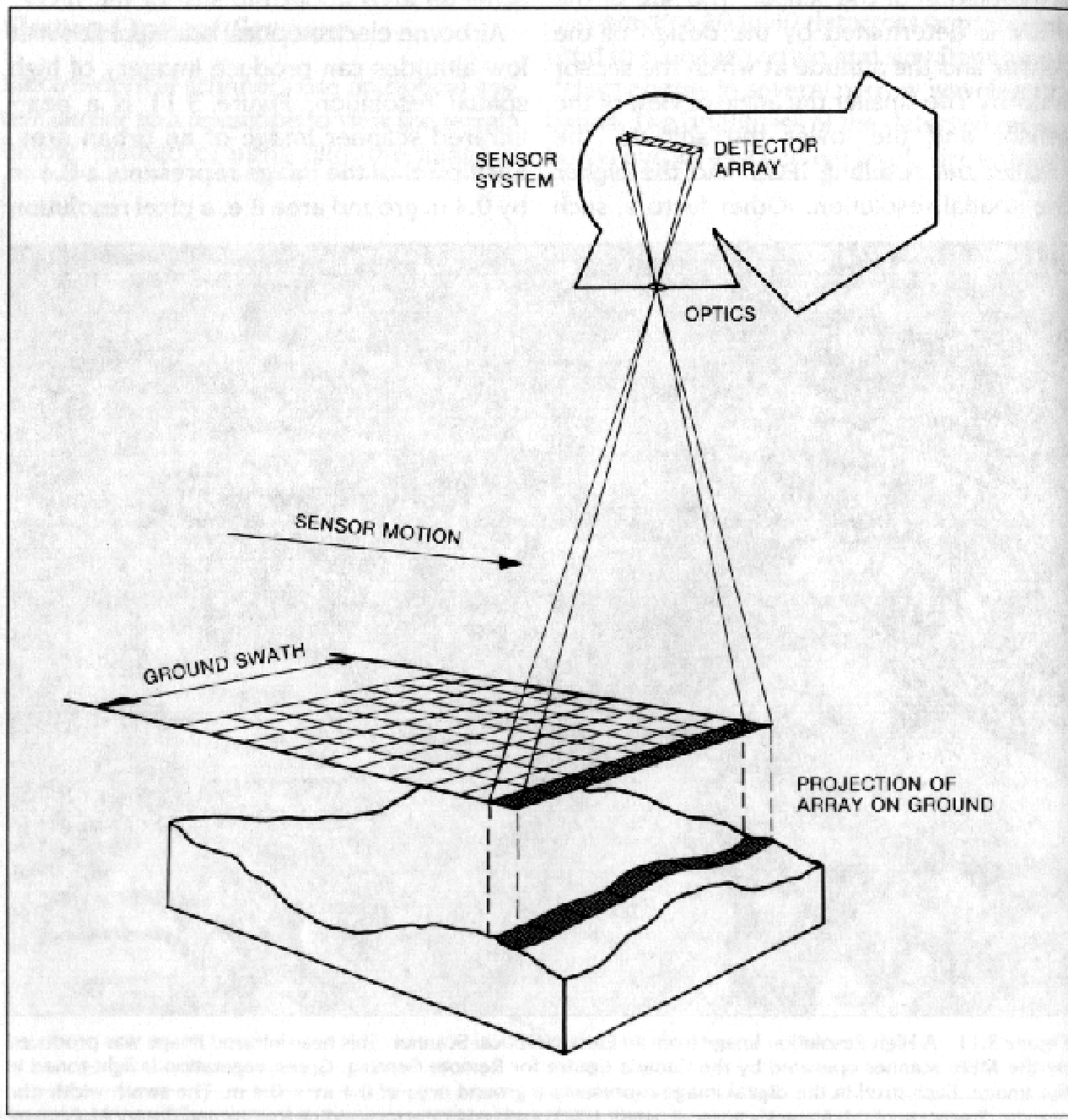


Figure 3.12 The Principle of Pushbroom Scanning.

Ikonos

Owner: Space Imaging (a **commercial** concern)

Launched: September 1999

Temporal resolution: 11 days (1-3 days considering oblique views)

Radiometric resolution: 11-bit (**8x better** than TM or SPOT)

Spectral bands	spatial resolution
0.45-0.52 (blue)	4m
0.51-0.60 (green)	4m
0.63-0.70 (red)	4m
0.76-0.85 (NIR)	4m
0.45-0.90 (Panchromatic)	1m

Swath width: 11km

Sensor systems: pushbroom system, **pointable** both along track and across track.

Orbit: 682km sun-synchronous having an equatorial crossing time of 10:30am

Quickbird

Owner: Digital Globe (another **commercial** concern, the competition!)

Launched: October 18, 2001

Temporal resolution: 1-5 days (considering oblique views)

Radiometric resolution: 11-bit (**8x better** than TM or SPOT)

Spectral bands	spatial resolution
0.45-0.52 (blue)	2.5m
0.52-0.60 (green)	2.5m
0.63-0.69 (red)	2.5m
0.76-0.90 (NIR)	2.5m
0.45-0.90 (Panchromatic)	60cm

Swath width: 16.5km

Sensor systems: pushbroom system, **pointable** both along track and across track.

Orbit: 450km sun-synchronous having an equatorial crossing time of 10:30am

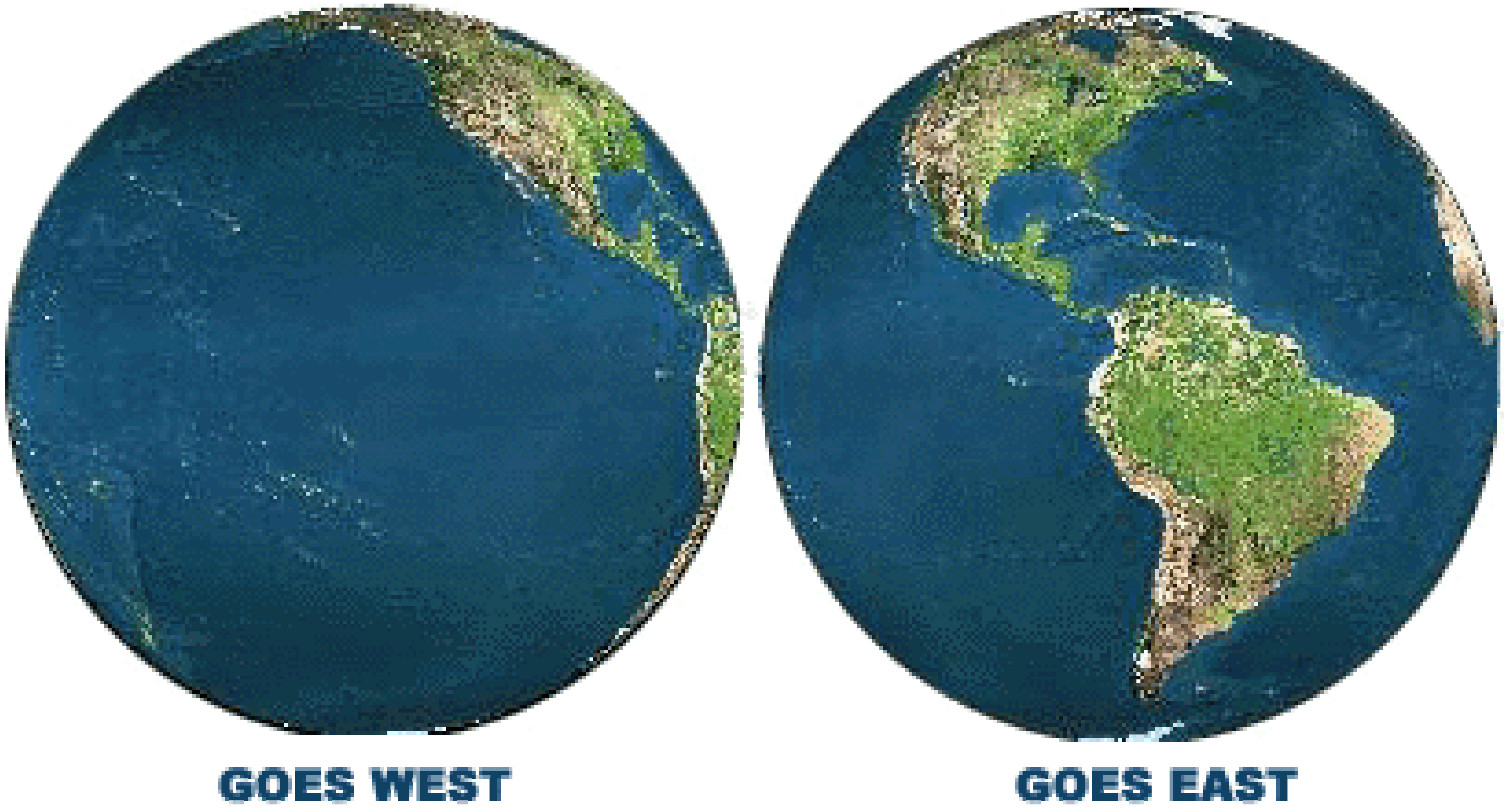
Geostationary Orbit

•Instead of revolving around the Earth every 90-100 minutes in a sun-synchronous orbit like the other satellites we have discussed, these satellites were placed into an orbit that **maintains a fixed relationship** with the Earth

•These orbits are **very high** (~35,800 km above the surface of the Earth), and the combination of this high orbit with a **broad field of view** means that sensors on these platforms can image a **'full-disk'** or half the planet at one time

•Because this orbit is geostationary, these satellites can image that half of the planet within their view **continuously** such that information can be gathered over the full diurnal night-day cycle, although spatial resolution is sacrificed in this approach (much bigger pixels!)

GOES-East and GOES-West



http://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html

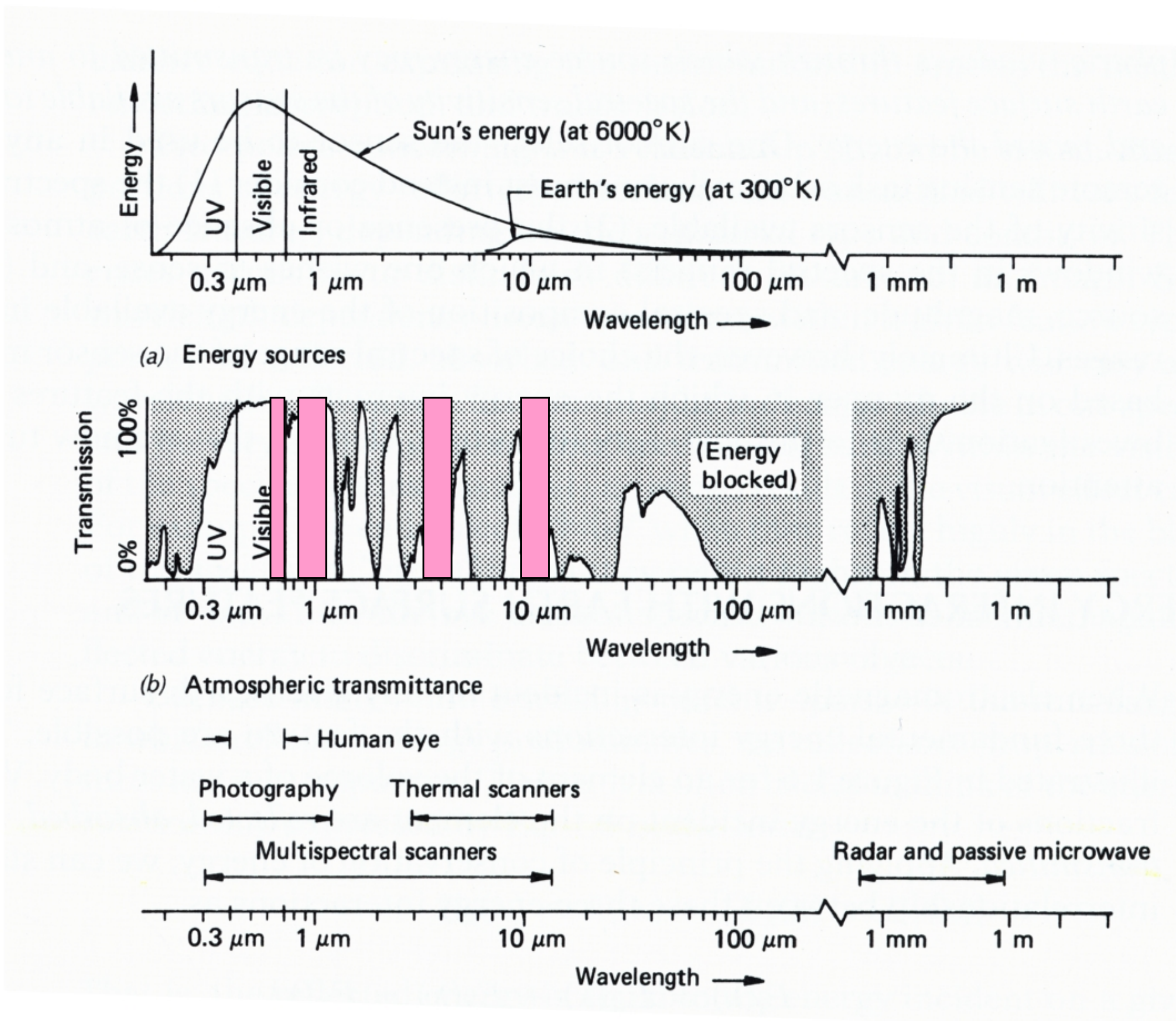
AVHRR Characteristics

TABLE 6.9 Characteristics of NOAA-6 to -15 Missions

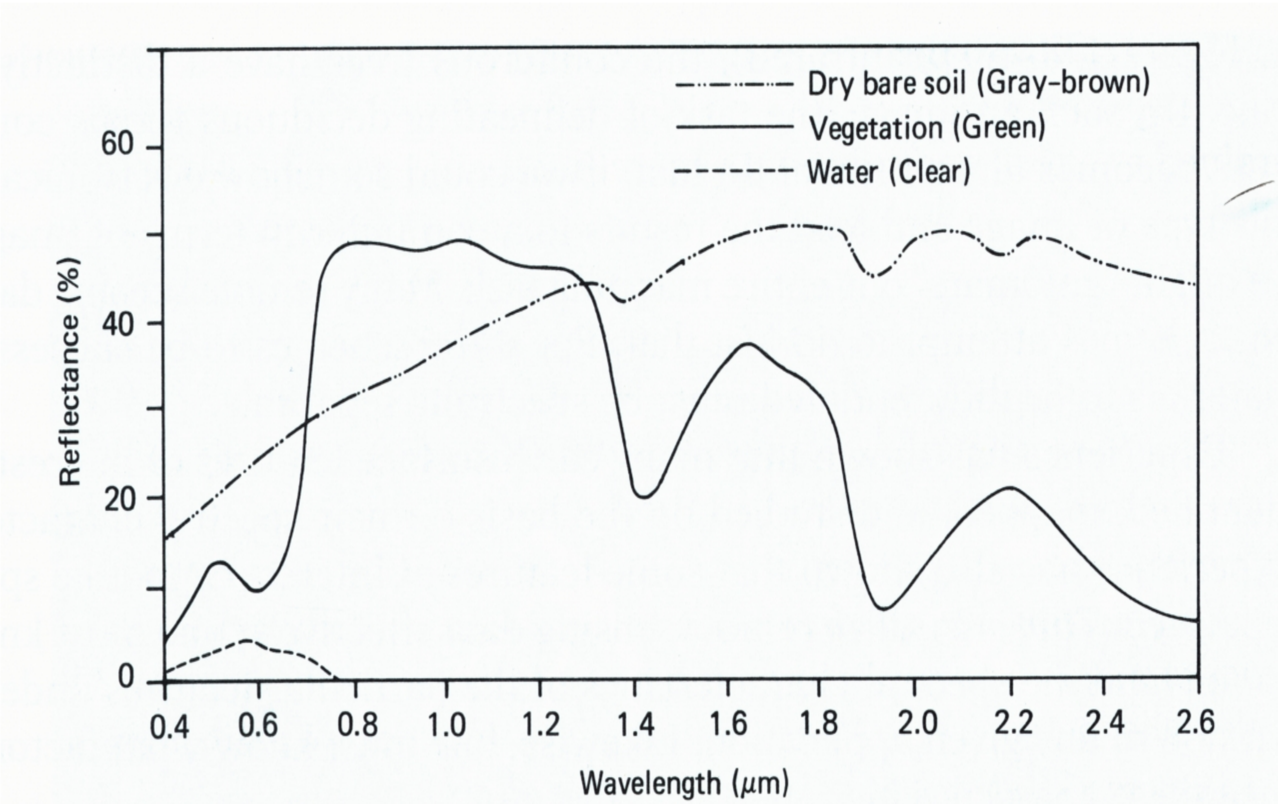
Parameter	NOAA-6, -8, -10, -12, and 15	NOAA-7, -9, -11, and -14[a]
Launch	6/27/79, 3/28/83, 9/17/86, 5/14/91, 5/13/98	6/23/81, 12/12/84, 9/24/88, 12/30/94
Altitude, km	833	870
Period of orbit, min	101	102
Orbit inclination	98.7°	98.9°
Orbits per day	14.2	14.1
Distance between orbits	25.6°	25.6°
Day-to-day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

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

AVHRR Bands


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

Normalized Difference Vegetation Index

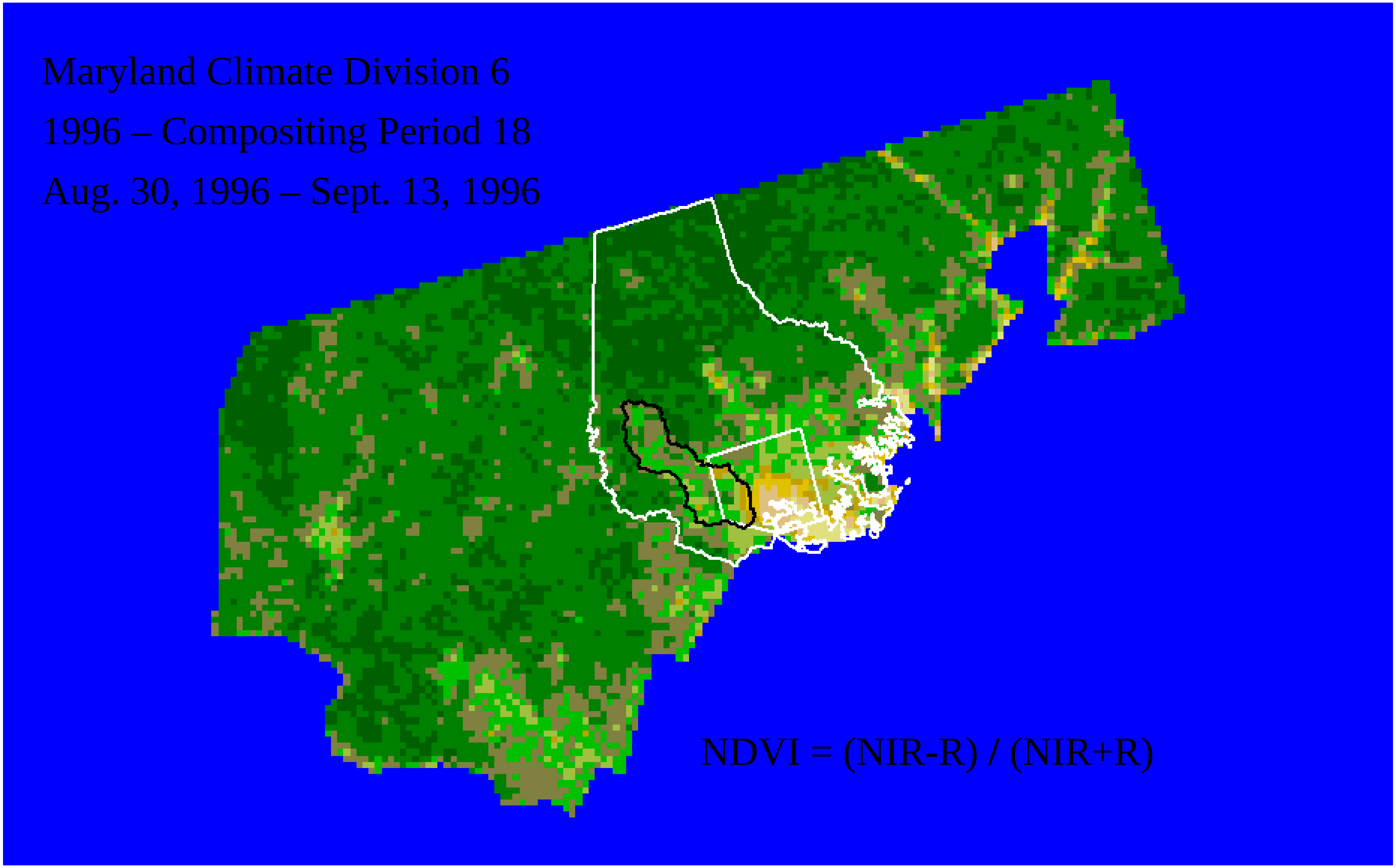


$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

NDVI [-1,1]

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

AVHRR Satellite Imagery - NDVI



MODIS Characteristics

Orbit: 705 km,

Time to cross equator: 10:30 a.m. descending node (Terra), 2:30 pm descending node (Aqua)

sun-synchronous, near-polar, circular

Sensor Systems: Across Track Scanning (‘Wiskbroom’)

Radiometric resolution: 12 bits

Temporal resolution: 1-2 days

Spatial Resolution:

250 m (bands 1-2)

500 m (bands 3-7)

1000 m (bands 8-36)

Design Life: 6 years

MODIS Bands

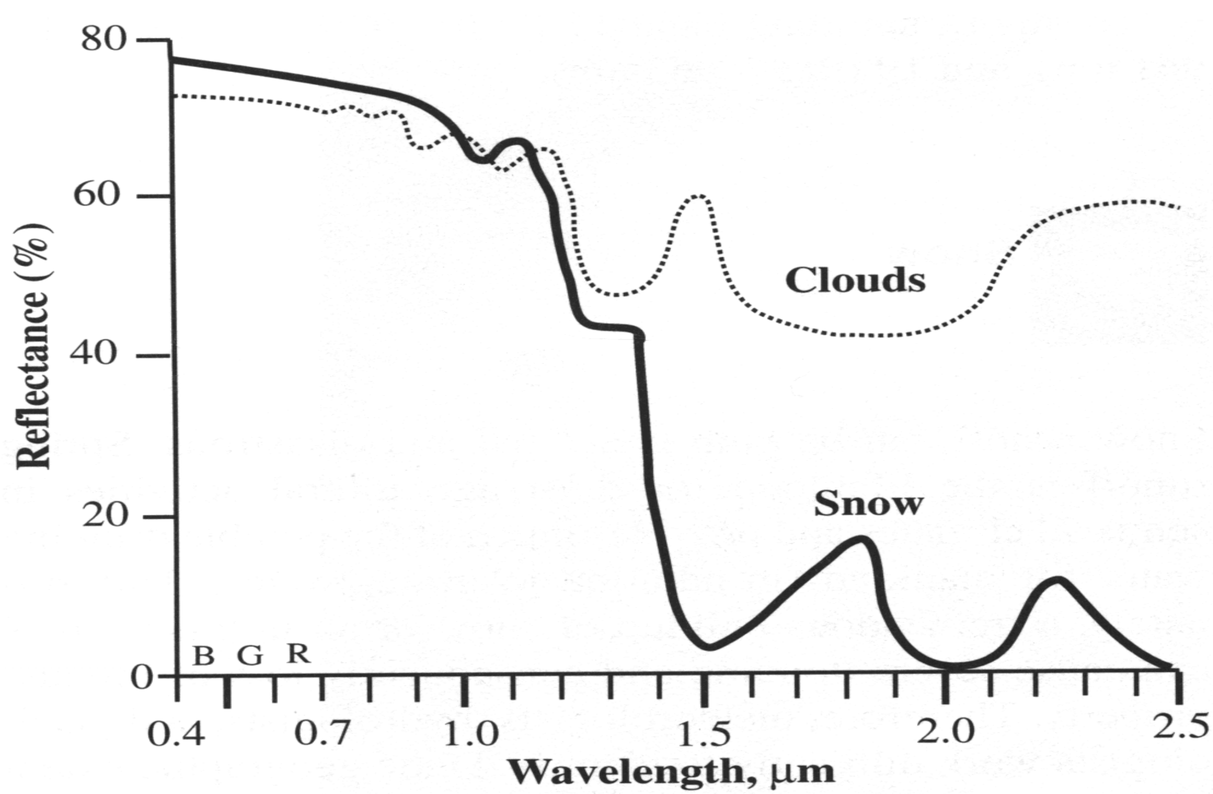
TABLE 6.14 MODIS Spectral Bands

Primary Use	Band	Bandwidth	Resolution (m)
Land/cloud boundaries	1	620–670 nm	250
	2	841–876 nm	250
Land/cloud properties	3	459–479 nm	500
	4	545–565 nm	500
	5	1230–1250 nm	500
	6	1628–1652 nm	500
	7	2105–2155 nm	500
Ocean color/ phytoplankton/ biogeochemistry	8	405–420 nm	1000
	9	438–448 nm	1000
	10	483–493 nm	1000
	11	526–536 nm	1000
	12	546–556 nm	1000
	13	662–672 nm	1000
	14	673–683 nm	1000
	15	743–753 nm	1000
	16	862–877 nm	1000
Atmospheric water vapor	17	890–920 nm	1000
	18	931–941 nm	1000
	19	915–965 nm	1000
Surface/cloud temperature	20	3.660–3.840 μm	1000
	21[a]	3.929–3.989 μm	1000
	22	3.929–3.989 μm	1000
	23	4.020–4.080 μm	1000
Atmospheric temperature	24	4.433–4.498 μm	1000
	25	4.482–4.549 μm	1000
Cirrus clouds	26[b]	1.360–1.390 μm	1000
Water vapor	27	6.538–6.895 μm	1000
	28	7.175–7.475 μm	1000
	29	8.400–8.700 μm	1000
Ozone	30	9.580–9.880 μm	1000
Surface/cloud temperature	31	10.780–11.280 μm	1000
	32	11.770–12.270 μm	1000
Cloud top altitude	33	13.185–13.485 μm	1000
	34	13.485–13.758 μm	1000
	35	13.785–14.085 μm	1000
	36	14.085–14.385 μm	1000

[a]Band 21 and 22 are similar, but band 21 saturates at 500 K versus 328 K.
[b]Wavelength out of sequence due to change in sensor design.

MODIS Applications - Snow

Spectral Properties of Clouds and Snow



In the **visible spectrum** clouds and snow look **very similar**. Thus, it is difficult to separate them with human eyes. But they are **very different in the mid-infrared**