EE 463 INTRODUCTION TO REMOTE SENSING

COURSE CONTENTS

1. Description and Application Fields of Remote Sensing
2. Characteristics of Digital Image Data
3. Spectral Ranges Used
4. Satellite Sensors
    - 4.1. Weather Satellite Sensors
    - 4.2. Earth Resource Satellite Sensors in the Visible and Infrared
5. Aircraft Scanners in the Visible and Infrared
    - 5.1. Thermal Infrared Multispectral Scanner (TIMS)
    - 5.2. Imaging Spectrometers
6. Microwave Image Data Sources
    - 6.1. Radars
        - 6.1.1. Airborne Radar
        - 6.1.2. Synthetic Aperture Radar
        - 6.1.3. Spaceborne Imaging Radars
        - 6.1.4. Aircraft Imaging Radar Systems
7. Spatial Data Sources
    - 7.1. Types and Formats of Spatial Data
    - 7.2. Geographic Information Systems (GIS)
    - 7.3. Image Processing and Analysis
8. Digital Image Data Scales Comparison
9. Error Correction and Registration of Image Data
    - 9.1. Atmospheric, Instrumental, Geometric Distortion
    - 9.2. Correction of Atmospheric, Instrumental, Geometric Distortion

10. Interpretation of Digital Image Data

10.1. Forms of Imagery for Photointerpretation

10.2. Computer Processing for Photointerpretation

10.3. Classification

10.3.1. Unsupervised

10.3.1.1. Clustering

10.3.2. Supervised

10.3.2.1.Maximum Likelihood Classification and Decision

10.3.2.2. Minimum Distance Classification

10.3.2.3. Table Look Up Classification

10.3.2.4. Multicategory Classification

10.4. Multispectral Space and Spectral Classes

10.5. Pattern Recognition

10.6. Pixel Vectors and Labelling

11. Enhancement Techniques

11.1. Radiometric Enhancement

11.1.1. Point Operations and Look Up Tables

11.1.2. Scalar and Vector Images

11.1.3. Image Histogram

11.1.4. Image Data Modification Methods

11.1.5. Histogram Equalization

11.1.6. Matching

11.2. Geometric Enhancement

11.2.1. Geometric Enhancement as a Convolution Operation

11.2.2. Image Domain versus Fourier Transformation

11.2.3. Image Smoothing

11.2.4. Shape Detection

12. Multispectral Transformations of Image Data

12.1. Mathematical Methods of Application

13. Fourier Transformation of Image Data

13.1. Special Functions

13.2. Sampling Theory

13.3. Discrete Fourier Transform and Discrete Spectrum of Image

13.4. Fast Fourier Transform

13.5. Spatial Frequency

13.6. Image Filtering

14. Feature Reduction

14.1. Separability Measures

14.2. Feature Reduction by Data Transformation

15. Statistical Methods

16. Knowledge Based Image Analysis

17. Hyperspectral Image Data

17.1. Data Volume, Redundency, Calibration

17.2. Spectral Analysis

17.3. Spectral Transformations

17.4. Compression

18. Examples of Remote Sensing Applications

MAIN REFERENCE BOOKS:

1. NAME : Remote Sensing Digital Image Analysis: An Introduction
AUTHORS : Xiuping Jia, John A. Richards, D. E. Ricken (Editor)
PUBLISHER : Springer Verlag
ISBN : 3540648607

EDITION : 3rd edition (June 1999)

2. NAME : Introductory Digital Image Processing: A Remote Sensing Perspective
AUTHOR : John R. Jensen
PUBLISHER : Prentice Hall
ISBN : 0132058405
EDITION : 2 edition (August 25, 1995)

GRADING:

1	MID TERM EXAM (IN CLASS)	: %40
1	FINAL EXAM (IN CLASS)	: %50
	ATTENDANCE	: %05
1	HW	: %05
	TOTAL	: %100

Important Note: 60% attendance in lactures is essential.

1. DESCRIPTION AND APPLICATION FIELDS OF REMOTE SENSING

See Additional Pages – 1, 1.a, 2, 3

Some Definitions of Remote Sensing:

- Group of Techniques for collecting image or other forms of data about an object from measurements made at a distance from the object and the processing and analysis of analysis of the data.

- Measurement and analysis of electromagnetic radiation reflected from, transmitted through, or absorbed and scattered by the atmosphere and by material at or near the land surface, for the purpose of understanding and managing Earth's resources and environment.

- The science and art of obtaining useful information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation.

Basic Elements of Remote Sensing:

1. Source of Energy (Illumination or Incident Energy): e.g. Sun, Laser, Microwave, Thermal Emission

2. Radiation Characteristics of the Source of Energy: e.g. Size, Power, Spectral Content, Coherence

3. Medium of Propagation: e.g. Atmosphere, Dielectric Material

4. Propagation Factors: e.g: Attenuation (Scattering, Absorption), Dispersion

5. Target or Object: e.g. Earth, Sea, Vegetation, Oil, Flood

6. Interaction of Energy with the Target: e.g. Reflection, Transmission, Absorption

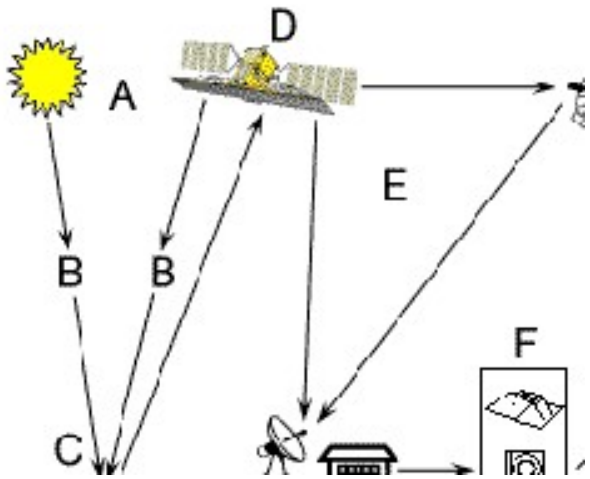
7. Remote Sensors: e.g. Aircraft, Satellite, Ground-based

8. Image Data Formation and Recording: e.g Photography, Digital Image

9. Image Data Processing: e.g: Eye-processing, Computer processing

10. Analysis of Processed Image for Specific Application: e.g. Visually, Electronically (Digital) extracting information about the target

An Example of a Remote Sensing Configuration



1, 2 ⇒ A

3, 4 ⇒ B

5, 6 ⇒ C

7, 8 ⇒ D, E

9, 10 ⇒ F, G

Some Applications of Remote Sensing

- Mapping
  - Planimetric (in x,y plane). e.g. general landscape information, urban mapping, transportation networks
  - Digital Elevation Model. e.g. integration into programming of cruise missiles to guide them over the terrain, route planning, telecommunications planning, volcanic inflation before eruption, relative earth movements caused by earthquakes
  - Topographic and Baseline Thematic. e.g. combination of interpretations of ground cover data and land use with topographic info (like elevation contours) and planimetry which becomes an optimal tool for resource management.

- Agriculture
  - Vegetation Type and Growth Observation (Both quality and quantity)
  - Crop Identification, Monitoring

- Weather
  - Forecast
  - Recording
  - Pollution Detection and Monitoring
  - Storm Forecast

- Hydrology, Oceans and Coastal
  - Flood Delineation
  - Soil Moisture
  - Ice Motion
  - Understanding Ocean Dynamics (e.g. fish stock assessment, ship routing)
  - Oil Spill Detection

- Forestry
  - Species Identification and Inventory
  - Fire Detection
  - Burn Delineation (Şeklini Çizmek)

- Geology
  - Structural Mapping and Terrain Analysis. e.g. mineral exploration, potential hazard monitoring and identification

- Others
  - Medical Applications
  - In the Sea Applications (Fish Mapping)
  - Micro Remote Sensing Applications

2. CHARACTERISTICS OF DIGITAL IMAGE DATA

- Remote sensing image data of earh's surface collected from aircraft or spacecraft is in digital format (if not then it is digitized into discrete data).

  Data is composed of:

  - **Spatially**: Dicrete picture elements, or pixels

  - **Radiometrically:** Quantised discrete brightness levels

- Characteristics of image is related to the wavelength band in which the measurement is taken. e.g:

  - Spatial disposition of reflected solar radiation in the ultraviolet, visible and near-to-middle infrared (passive system since the source is external)

  - Spatial distribution of energy emitted by the earth itself in the thermal infrared

- Measurements of relative energy returned from the earth's surface where the source in microwave is transmitted by the airplane (active system because the energy source is provided by the remote sensing platform)

- Important factors for Data Handling and Analysis:

  - Number of Spectral Measurements (spectral bands) by a particular sensor

  - Location of Spectral Measurements (spectral bands) by a particular sensor

- **Resolution:**

  - **Spatial resolution** is described by pixel size, in equivalent ground metres

  - **Radiometric resolution** (Dynamic range or signal-to-noise ratio) is described by the range and the number of discrete brightness values. Expressed as the number of binary digits or bits necessary to represent the range of brighness values. e.g. 8 bit radiometric resolution → 256 brightness levels
    4 bit radiometric resolution → 16 brightness levels

  - **Spectral resolution** describes the ability of a sensor to define narrow (fine) wavelength intervals. Finer the spectral resolution, narrower the wavelength range for a particular channel or band.

    e.g. Broad classes like water and vegetation can be separated using very broad wavelength ranges, visible and near infrared.
    However, more specific classes like different rock types require finer wavelength ranges to separate them

See Additional Page 3.A

  - **Temporal resolution** of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to the revisit period (length of time it takes for a satellite to complete one entire orbit cycle, usually several days).

    Temporal resolution is important in:
    i) imaging of short lived phenomena like floods, oil slicks or
    ii) imaging in cloudy weather conditions or
    iii) in observing vegetation growth

- **Volume of Data** received from a particular sensor which is **to be processed**, consists of:

  - Frame size of an image, in equivalent ground kilometres

  - Number of spectral bands

  - Radiometric resolution

- Spatial resolution

- Repeating measurements in time

3. Spectral Ranges Used

Frequency Spectrum:

See Additional Pages 4, 5

- Principally remote sensing systems can be in a wide spectral range. However limited due to:

  - Technical possibilities in general

  - Spectral reflectance characteristics (Reflectance versus wavelength) of the material of interest

See Additional Page 6

  - Atmospheric Scattering and Absorption

  - Significance of the data acquired at that frequency

- Some frequencies (wavelengths = λ= c / f) of interest::

  - Visible / infrared (λ= 0.4μm – 12 μm): Earth resources.e.g cellular structure and moisture content of vegetation, moisture contents of soil

  - Thermal infrared (far infrared) (5.5 μm – 5 mm): Heat capacity and other thermal properties of the surface and the nearby surface

  - Microwave (f = 1GHz – 10GHz) - Active imaging using radars: Surface roughness and electrical properties

  - 20GHz – 60 GHz: Atmospheric oxygen and water vapour

See Additional Pages 7, 8

- **Blackbody radiation**

See Additional Page 9, 9.a

- Real objects are not perfect blackbody radiators, they emit energy lower than blackbody rediation

- Emittance is proportional to (Object radiation / Blackbody Radiation) is wavelength dependent.

- **Systems are optimized for certain wavelength range based on the application**

Remote Sensing Satellites

Satellites are man made moons.

See Additional Page 10, 10A, 11, 12

Satellite Launch Vehicle

See Additional Page 13

List of Remote Sensing Satellites

See Additional Page 14

Some parameters of remote sensing satellites

- **Satellite Orbits**

See Additional Page 15,16

Orbit is the path traced out by by a satellite in space as it moves around the earth.

1. Circular orbit

- Orbit whose path is a circle centered around the center of earth
- Usually used in remote sensing
- Shape of circular orbits depend on two parameters:

  i) **Orbital altitude** – Height above the surface of earth

  ii) **Inclination Angle** – The angle between satellite's orbital plane and earth's equatorial plane.

  Inclination angle of an orbital plane also determines the observation area of the satellite on earth. E.g. inclination angle = 30° means observation area is bounded by +/- 30° latitude (i.e. the tropical region)

  Satellites with orbits of inclination angle less than 90° rotate around the world in the same sense as the earth itself rotates while inclination angle more than 90° means orbiting is in the opposite sense to earth's rotation

2. Low Earth Orbit (LEO)

- When a satellite circles close to Earth we say it's in Low Earth Orbit (LEO).
- Satellites in LEO have altitudes of 200 - 500 - 933 miles (320 - 800 - 1500 kilometres)

- Because they orbit so close to Earth, they must travel very fast so gravity won't pull them back into the atmosphere.

- Satellites in LEO speed along at 17,000 miles per hour (27,359 kilometres per hour). They can circle Earth in about 90 minutes.

- A Low Earth Orbit is useful because of its nearness to Earth. Satellites that observe our planet, like Remote Sensing and Weather satellites, often travel in LEOs because from this height they can capture very detailed images of Earth's surface.

3. Polar orbit

- Polar orbit's inclination angle is near 90° (near polar orbit)

- A Polar orbit is a particular type of Low Earth Orbit. The only difference is that a satellite in polar orbit travels a north-south direction (descending from north-south, ascending from south-north), rather than the more common east-west direction.

- Polar orbits are useful for viewing the planet's surface. As a satellite orbits in a north-south direction, Earth spins beneath it in an east-west direction. As a result, a satellite in polar orbit can eventually scan the entire surface

- Between successive orbits the Earth rotates 22.5° (In 24 hrs rotates 360° so in 1,5 hrs (in one orbit rotation) rotates 22.5°)

- Therefore 360°/22.5° = 16 orbits are required to scan totally the Earth's surface.

- For this reason, satellites that monitor the global environment, like remote sensing satellites and certain weather satellites are almost always in polar orbit.

- Tracking of these fast satellites by the ground stations has been a major obstacle which is now being overcome.

4. Geosynchronous orbit

- Has a fixed position relative to the surface of earth

- 35,786.1 km altitude

- Inclination angle is not zero

5. Geostationary orbit (GEO)

- It is geosynchronous orbit with zero inclination angle

- Satellite is fixed over one longitude at the equator. (In practice it moves slightly and requires periodic orbit adjustments

- Used in meteorlogy and communications (used in TV transmission, not effective in mobile communications
- No tracking from the ground station is needed

6. Sun synchronous orbit

- Inclination and altitude is such that a satellite passes over a given site always at the same local time

7. Elliptical orbit

- Moves in north-south direction
- Mostly for communications around the north and south pole areas

- **Period of satellites**

  Time spent for completion of one orbital revolution

- **Repeat Cycle**

  Number of revolutions around the orbit before the satellite passes over a given site

- **Dynamic Range**

  Number of bits representing the brightness levels

- **Bands, Channels**

  Spectral Band of frequencies (assigned to channels) used in sensing

- **Nadir Mode**

  Mode of measurement in which the the line of sight of a sensor points from the orbit downward to the earth's surface

- **Limb Mode**

  Mode of measurement in which the line of sight of a sensor points from the orbit tangentially into the earth's atmosphere

- **Field of View (FOV)**

See Additional Page 17,18

Scan angle (in degrees) either side of nadir over which data is recorded

In the range of 11° - 15° for landsat. In the range of 70° - 90° in aircraft scanning

- **Instantaneous Field of View (IFOV)**

See Additional Page 17, 18

Solid angle (in milliradians) extending from a detector to the area on the ground (ground pixel) it measures at any instant

- **Swath Width**

See Additional Page 17, 18

Width of the area scanned by the sensor

4. Satellite Sensors

See Additional Page 19

- Types of sensors used:

See Additional Page 20

- Wavelength Band of sensors used:

See Additional Page 21

- Optical Sensor Characteristics:

See Additional Page 22 (Two pages)

- Scanners:

  - Cross-track scanner See Additional Page 23 Fig(A)
  - Along-track scanner See Additional Page 23 Fig(C)

4.1. Weather Satellite Sensors

See Additional Page 24 (Two pages)

- Weather Satellites have almost the same band of frequencies as the Earth Resource Satellite Sensors

- Spatial Resolution of Weather Satellite Sensors (1 km x 1km) are coarser than Earth Resource Satellite Sensors' Spatial Resolution (< 100 m)

- Weather Satellite Sensors provide large areal coverage

- Performs weather monitoring and forecasting

- In near-polar orbits, providing repetitive coverage of global weather patterns

- Temporal resolutions are generally quite high, providing frequent observations of the Earth's surface, atmospheric moisture, and cloud cover, which allows for near-continuous monitoring of global weather conditions, and hence - forecasting. Here we review a few of the representative satellites/sensors used for meteorological applications:

GOES

- Latest is GOES 12

- The GOES (Geostationary Operational Environmental Satellite) System is designed by NASA for the National Oceanic and Atmospheric Administration (NOAA) to provide the United States National Weather Service with frequent, small-scale imaging of the Earth's surface and cloud cover.

- These satellites are part of a global network of meteorological satellites spaced at approximately 70° longitude intervals around the Earth in order to provide near-global coverage.

- Two GOES satellites, placed in geostationary orbits 36000 km above the equator

- Eeach view approximately one-third of the Earth.

- One is situated at 75°W longitude and monitors North and South America and most of the Atlantic Ocean.

- The other is situated at 135°W longitude and monitors North America and the Pacific Ocean basin.

- Together they cover from 20°W to 165°E longitude. This GOES image covers a portion of the southeastern United States, and the adjacent ocean areas where many severe storms originate and develop. This image shows Hurricane Fran approaching the southeastern United States and the Bahamas in September of 1996.

- The second generation of GOES satellites measure emitted and reflected radiation from which atmospheric temperature, winds, moisture, and cloud cover can be derived.

- With GOES-8 (launched 1994). They provide near-continuous observation of the Earth allowing more frequent imaging (as often as every 15 minutes). This increase in temporal resolution coupled with improvements in the spatial and radiometric resolution of the sensors provides timelier information and improved data quality for forecasting meteorological conditions.

- GOES-8 and the other second generation GOES satellites have separate imaging and sounding instruments.

- The imager has five channels sensing visible and infrared reflected and emitted solar radiation.

- The infrared capability allows for day and night imaging.

- Sensor pointing and scan selection capability enable imaging of an entire hemisphere, or small-scale imaging of selected areas. The latter allows meteorologists to monitor specific weather trouble spots to assist in improved short-term forecasting.

- The imager data are 10-bit radiometric resolution

- Image data can be transmitted directly to local user terminals on the Earth's surface.

- The following table describes the individual bands, their spatial resolution, and their meteorological applications.

GOES Bands

Band	Wavelength Range	Spatial Resolution	Application
1	0.52 - 0.72 (visible)	1 km	cloud, pollution, and haze detection; severe storm identification
2	3.78 - 4.03 (shortwave IR)	4 km	identification of fog at night; discriminating water clouds and snow or ice clouds during daytime; detecting fires and volcanoes; night time determination of sea surface temperatures
3	6.47 - 7.02 (upper level water vapour)	4 km	estimating regions of mid-level moisture content;tracking mid-level atmospheric motion
4	10.2 - 11.2 (longwave IR)	4 km	identifying cloud-drift winds, severe storms, and heavy rainfall
5	11.5-12.5 (IR window sensitive	4 km	identification of low-level moisture; determination of sea surface temperature; detection of airborne dust and volcanic ash

- Sixth band available on GOES-12(M) at 12.9 - 13.8 um (lower level (CO_2) temperature) at 8 km, useful for determination of cloud characteristics (such as cloud top pressure).

- The last image (from GOES-12) is a full disk (covering total world in one disc shape) from 25 September 2001

Sounders in GEOS

- Sounders measure the parameters like atmospheric temperature and moisture in the vertical atmospheric profile (imagers measure horizontally)

- The 19 channel sounder measures emitted radiation in 18 thermal infrared bands and reflected radiation in one visible band.

- These data have a spatial resolution of 2 km in the infrared and 1 km in the visible

- 13-bit radiometric resolution

- Sounder data are used for surface and cloud-top temperatures, multi-level moisture profiling in the atmosphere, and ozone distribution analysis.

NOAA AVHRR

- Meteorological, as well as other, applications.

- Sun-synchronous, near-polar orbits (830-870 km above the Earth)

- Provide complementary information to the geostationary meteorological satellites

- Two satellites, each providing global coverage, work together to ensure that data for any region of the Earth is no more than six hours old. One satellite crosses the equator in the early morning from north-to-south while the other crosses in the afternoon.

- The primary sensor on board the NOAA satellites, used for both meteorology and small-scale Earth observation and reconnaissance, is the Advanced Very High Resolution Radiometer (AVHRR).
- AVHRR sensor detects radiation in the visible, near and mid infrared, and thermal infrared portions of the electromagnetic spectrum

- Swath width of 3000 km.

NOAA AVHRR BANDS

Band	Wavelength Range	Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 -3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (thermal IR)	1.1 km	sea surface temperature, soil moisture
5	11.5 - 12.5 (thermal IR)	1.1 km	sea surface temperature, soil moisture

AVHRR DATA

Either
- Can be transmitted directly to the ground and viewed as data are collected

OR.
- Recorded on board the satellite for later transmission and processing

AVHRR Data Formats

AVHRR data can be acquired and formatted in four operational modes, differing in resolution and method of transmission.

Format	Spatial Resolution	Transmission and Processing
APT (Automatic Picture Transmission)	4 km	low-resolution direct transmission and display
HRPT (High Resolution Picture Transmission)	1.1 km	full-resolution direct transmission and display
GAC (Global Area Coverage)	4 km	low-resolution coverage from recorded data
LAC (Local Area Coverage)	1.1 km	selected full-resolution local area data from recorded data

- AVHRR sensors are widely used for weather system forecasting and analysis, also used for observation and monitoring of land features

Other Weather Satellites

- DMSP (Defense Meteorological Satellite Program)
- GMS satellite series
- Meteosat satellites.

4.2. Earth Resource Satellite Sensors in the Visible and Infrared

Landsat

- First satellite designed specifically to monitor the Earth's surface
- Combination of sensors with spectral bands tailored to Earth observation
- Functional spatial resolution
- Good areal coverage (swath width and revisit period).
- Near-polar, sun-synchronous orbits
- Later landsat satellites are at around 700 km and have revisit periods of 16 days
- Equator crossing times in the morning to optimize illumination conditions
- Landsat Sensors:

  i) Return Beam Vidicon (RBV) camera systems

ii) MultiSpectral Scanner (MSS) systems

iii) Thematic Mapper (TM) (Replaced MSS after Landsat 4 in 1992)

- Each of these sensors collected data over a swath width of 185 km, with a full scene as 185 km x 185 km.

TM (Thematic Mapper) sensor

See additional page 25

- In Landsat (Replaced MSS after Landsat 4 in 1992)
- Polar orbit
- Spatial resolution of TM is 30 m for all but the thermal infrared
- Spatial resolution of TM is 120 m for thermal infrared
- Swath width is 185 km
- All channels are recorded over a range of 256 digital numbers (8 bits)
- Uses an oscillating mirror which scans during both the forward (west-to-east) and reverse (east-to-west) sweeps of the scanning mirror
- 16 detectors for the non-thermal channels
- 16 scan lines are captured simultaneously for each non-thermal spectral band. İ.e. 16 scan lines x 30 m per line spacing = 480 meter strips are swept across the satellite path
- 4 scan lines are captured simultaneously for thermal spectral band.

TM Bands

Channel	Wavelength Range (μm)	Application
TM 1	0.45 - 0.52 (blue)	soil/vegetation discrimination; coastal mapping; cultural/urban feature identification
TM 2	0.52 - 0.60 (green)	green vegetation mapping (measures reflectance peak); cultural/urban feature identification
TM 3	0.63 - 0.69 (red)	vegetated vs. non-vegetated and plant species discrimination (plant chlorophyll absorption); cultural/urban feature identification
TM 4	0.76 - 0.90 (near IR)	identification of plant/vegetation types, health, and biomass content; water body delineation; soil moisture
TM 5	1.55 - 1.75 (short wave IR)	sensitive to moisture in soil and vegetation; discriminating snow and cloud-covered areas

TM 6	10.4 - 12.5 (thermal IR)	vegetation stress and soil moisture discrimination related to thermal radiation; thermal mapping (urban, water)
TM 7	2.08 - 2.35 (short wave IR)	discrimination of mineral and rock types; sensitive to vegetation moisture content

SPOT

- Earth observation imaging satellites
- Sun-synchronous, near-polar orbits at altitudes around 830 km above the Earth
- Orbit repetition every 26 days
- Equator crossing times around 10:30 AM local solar time
- First satellite to use along-track, or pushbroom scanning technology
- Twin high resolution visible (HRV) imaging systems, which can be operated independently and simultaneously.
- Each HRV is capable of sensing either in a high spatial resolution single-channel panchromatic (black-white) (PLA) mode, or a coarser spatial resolution three-channel multispectral (MLA) mode.
- Each along-track scanning HRV sensor consists of four linear arrays of detectors: one 6000 element array for the panchromatic mode recording at a spatial resolution of 10 m, and one 3000 element array for each of the three multispectral bands, recording at 20 m spatial resolution
- Swath width for both modes is 60 km at nadir

HRV Mode Spectral Ranges

Mode/Band	Wavelength Range (μm)
Panchromatic (PLA)	0.51 - 0.73 (blue-green-red)
Multispectral (MLA)	
Band 1	0.50 - 0.59 (green)
Band 2	0.61 - 0.68 (red)
Band 3	0.79 - 0.89 (near infrared)

- The viewing angle of the sensors can be adjusted to look to either side of the satellite's vertical (nadir) track, allowing off-nadir viewing which increases the satellite's revisit capability. This ability to point the sensors up to 27° from nadir, allows SPOT to view within a 950 km long swath and to revisit any location several times per week. As the sensors point away from nadir, the swath width varies from 60 to 80 km in width

- This not only improves the ability to monitor specific locations and increases the chances of obtaining cloud free scenes, but the off-nadir viewing also provides the capability of acquiring imagery for stereoscopic coverage

- By recording the same area from two different angles, the imagery can be viewed and analyzed as a three dimensional model, a technique of tremendous value for terrain interpretation, mapping, and visual terrain simulations.

Laser Fluorosensor

- Some targets fluoresce, or emit energy, upon receiving incident energy

- This is not a simple reflection of the incident radiation, but rather an absorption of the initial energy, excitation of the molecular components of the target materials, and emission of longer wavelength radiation which is then measured by the sensor

- Laser fluorosensors **illuminate the target with a specific wavelength** of radiation and are capable of detecting **multiple wavelengths of fluoresced radiation**

- Ocean applications, such as chlorophyll mapping and pollutant detection, particularly for naturally occurring and accidental oil slicks

Lidar (Laser Radar)

- Pulses of laser light are emitted from the sensor and energy reflected from a target is detected

- The time required for the energy to reach the target and return to the sensor determines the distance between the two

- Lidar is used effectively for measuring heights of features, such as forest canopy height relative to the ground surface and water depth relative to the water surface (laser profilometer)

- Lidar is also used in atmospheric studies to examine the particle content of various layers of the Earth's atmosphere and acquire air density readings and monitor air currents

5. Aircraft Scanners in the Visible and Infrared

- As with satellite image acquisition, as aircraft moves aircraft scanners provide along-tract scanning while a rotating mirror or a linear detector array provides sensing data in the across-track direction

Differences between airborn and satellite-born systems:

- Data volume can be substantially higher in a airborn scanners due to

  i) Large number of spectral bands or channels available in airborne (hundreds of bands)

  ii) Large number of pixels due to high spatial resolution (< 1 m)

- FOV (Field of View is large in airborne (70 º - 90 º as compared to 10 º - 15 º in spaceborne giving rise to significant distortion in image geometry at the edges of the scan

- Stability of aircraft is poor which can lead to excessive image distortion

5.1. Thermal Infrared Multispectral Scanner (TIMS)

- Typically between 8 - 12 μ m

- 6 channels

- Used to diagnose silicate rocks

5.2. Imaging Spectrometer

- Characterized by a multispectral scanner with **a very large number of channels (64-256 channels) with very narrow band widths**

- Basic scheme is almost the same as an optical mechanical scanner or pushbroom scanner.

See additional page 26

- Imaging spectrometer provides multiband imagery with a narrow wave length range

- Used for rock type classification and ocean color analysis

- Imaging spectrometers or "hyperspectral sensors" are remote sensing instruments that combine the spatial presentation of an imaging sensor with the analytical capabilities of a spectrometer.

- Up to several hundred narrow spectral bands with spectral resolution on the order of 10 nm or narrower

- Imaging Spectrometers produce a complete spectrum for every pixel of the image

See additional page 27

- Compare this to broad-band multispectral scanners such as Landsat Thematic Mapper (TM), which only has 6 spectral bands and spectral resolution on the order of 100 nm or greater.

See additional page 28

- Imaging spectrometer concept; hundreds of spectral images, thousands to millions of individual spectra

- With high spectral resolution of imaging spectrometers materials can be identified where with broad-band sensors only discrimination between materials is made.

Special Satellite Bands Used in Satellite-Ground Data Transmission:

L Band - 1.63 to 2.76 GHz
X-Band – 8.02 to 8.4 GHz downlink
Ku Band - 11.7 to 12.76 GHz Downlink
14 to 17.6 GHz Uplink
Ka Band - 18 to 31 GHz (Low Earth Orbit)
Rate of Data Transmission 150 Mbps in Landsat 7

Tracking the Satellites

- In order to record the data transmitted by the satellite, receiving antenna follows and continually points directly at the satellite. This is done as follows:

  i) Ephemeris data (tables of the predicted location of the satellite) are used to aim the antenna at the expected location (azimuth and elevation) of the satellite as it appears over the horizon

  ii) A computer moves the antenna, following along the predicted orbit of the satellite and searches for its X-band transmission

  iii) If a transmission with strong enough signal is detected then the computer will track the satellite using the X-band signal rather than the ephemeris data

Data Stream Handling at the Satellite Earth Receiving Station

See additional page 29

- The original X-band data at approximately 8GHz are received

- Data are converted to an intermediate frequency (IF) of 375 MHz by the downconverters located within the antenna structure

- The intermediate data stream are then converted (by a bit-synchronizer housed within the station building computer facility) into two different data streams:

  i) Data

  ii) Clock synchronization

- The resulting information is stored on special digital recording systems

- The digital data stream from a digital recording system is passed through a frame-synchronizer which prepares the data in "image" form

- The data is now fully compatible for conventional computer manipulation

- The digital image data are then stored on any type of computer storage medium, such as tape or compact disk

6. Microwave Image Data Sources

6.1. Radars (Radio Detection And Ranging)

- Controllable source of illumination (Active source)
- 0.3 GHz to 300 GHz (in wavelength from 1 m to 1 mm)
- Sees through cloud and rain
- Can operate day and night
- Images can be high resolution (3 - 10 m)
- Different features are portrayed or discriminated compared to visible sensors
- Following surface features can be seen better in radar images:
  - ice, ocean waves
  - soil moisture, vegetation mass
  - man-made objects, *e.g.* buildings
  - geological structures
- A Radar system has three primary functions:
  - Transmits microwave (radio) signals towards a scene
  - Receives the portion of the transmitted energy backscattered from the scene
  - Observes the strength (detection) and the time delay (ranging) of the return signals.

6.1.1. Airborne Radar

See additional page 30 (Two pages)

- Side looking Airborne Radar (SLAR)
- In SLAR, an electrical pulse in microwave frequency is radiated to the side of aircraft at an incidence angle of θ_i
- Some of this transmitted pulse energy is scattered from the ground and returned to the receiver at the aircraft
- Time delay between transmission and reflection identifies the slant distance to the target from the aircraft
- Strength of return contains information on the scattering cross-section of the target region of the Earth's surface

- Received signal from a single transmitted pulse consists of continuum of reflections from the complete region of ground that is illuminated by the radar antenna (range beamwidth of the antenna which is broad)

- Along-track (azimuth) beamwidth is chosen as small as possible so that the reflections from a single transmitted pulse can be regarded as coming to the aircraft from a narrow strip of terrain

- Forward velocity of aircraft is then arranged such that the next transmitted pulse illuminates the next strip of terrain along the swath

- Azimuth beamwidth of the antenna defines the spatial resolution in the azimuth direction (along-tract)

- Time resolution possible between echoes from two adjacent targets in the range direction (across-tract) defines the resolution in the slant direction

- Concerning the image, slant range resolution is not of interest, but ground range resolution (projection of slant range resolution onto the horizontal plane) is to be considered

- r_g = ground range size of a resolution element (pixel) = $c\,\tau / (2 \sin \theta_i)$ where τ is the pulse length, θ_i is the incidence angle

- As θ_i ↗ , r_g ↘ , i.e resolution gets better, i.e better ground range resolution on the far side of the swath

- r_a =azimuth size of the resolution element is related to the length (or aperture) of the transmitting antenna in the azimuth direction, d as $r_a = R_0 \lambda / d$ where R_0 is the range between the aircraft and target

- As length (or aperture) of the transmitting antenna in the azimuth direction = d ↗ r_a ↘ , i.e resolution gets better. This is the starting point for SAR (Synthetic Aperture Radar)

6.1.2. Synthetic Aperture Radar (SAR)

Concept of Synthetic Aperture

See additional page 31(Two pages)

- A side-looking radar system which makes a high-resolution image of the Earth's surface (for remote sensing applications)

- Continuous strips of the ground surface are "illuminated" parallel and to one side of the flight direction.

- The **across-track dimension** is referred to as "**range**". Near range edge is closest to nadir (the points directly below the radar) and far range edge is farthest from the radar.

- The **along-track dimension** is referred to as "**azimuth**"

- In a radar system, resolution is defined for both the range and azimuth directions

- Higher resolution than achieved by conventional radar

- Measurement and resolution are achieved in synthetic aperture radar in the same manner as most other radars: Range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target and, in the simplest SAR, range resolution is determined by the transmitted pulse width, i.e. narrow pulses yield fine range resolution

- **It is the ability of SAR to produce relatively fine azimuth resolution that differentiates it from other radars.**

- To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam

- The sharpness of the beam defines the azimuth resolution

- Since SARs are operating in microwave fine SAR resolutions require an antenna physically larger than can be practically carried by an airborne platform: antenna lengths several hundred meters long are often required

- However, an airborne radar could collect data while flying this distance and then process the data as if it came from a physically long antenna

- The distance the aircraft flies in synthesizing the antenna is known as the synthetic aperture

- A narrow synthetic beamwidth results from the relatively long synthetic aperture, which yields finer resolution than is possible from a smaller physical antenna

- Achieving fine azimuth resolution may also be described from a doppler processing viewpoint:

    - A target's position along the flight path determines the doppler frequency of its echoes

    - Targets ahead of the aircraft produce a positive doppler offset

    - Targets behind the aircraft produce a negative offset

    - As the aircraft flies a distance (the synthetic aperture), echoes are resolved into a number of doppler frequencies

    - The target's doppler frequency determines its azimuth position

Sensor resolution of SAR

See additional page 32(Two pages)

- Resolution of a SAR sensor is different than pixel spacing which results from sampling done by the SAR image processor.

- **Sensor resolution** has two dimensions (i.e yields 2-D image):

i) Range resolution

- Range resolution depends on the length of the processed pulse
- Shorter pulses result in “higher” resolution
- Radar data are created in the slant range domain, but usually are projected onto the ground range plane when processed into an image.

ii) Azimuth resolution

- Real aperture radar has azimuth resolution determined by the angular beam width of the terrain strip illuminated by the radar beam
- For two objects to be resolved, they must be separated in the azimuth direction by a distance greater than the beam width on the ground
- A synthetic aperture radar (SAR) the azimuth resolution to much shorter
- than the antenna length
- SAR gets its name from the azimuth processing and using signal processing to refine azimuth resolution, it can achieve an azimuth resolution which may be hundreds of times smaller than the transmitted antenna beam width

Microwave Radar Operating Frequencies

- Most remote sensing radars operate at wavelengths between .5 cm to 75 cm
- Microwave frequencies are arbitrarily assigned to bands identified by letter

BAND	WAVELENGTH	FREQUENCY	APPLICATION	VEHICLE USED
X-band	2.4 to 3.75 cm	12.5 to 8 GHz	Military reconnaissance and commercially for terrain surveys	CV-580 SAR (Environment Canada)
C-band	3.75 to 7.5 cm	8 to 4 GHz		Spaceborne SARs, such as ERS-1 and RADARSAT
S-band	7.5 to 15 cm	4 to 2 GHz		Almaz
L-band	15 to 30 cm	2 to 1 GHz		SEASAT and JERS-1
P-band	30 to 100 cm	1 to 0.3 GHz		NASA/JPL AIRSAR

- The capability to penetrate through precipitation or into a surface layer is increased with longer wavelengths
- Radars operating at wavelengths greater than 2 cm are not significantly affected by cloud cover
- However, rain does become a factor at wavelengths shorter than 4 cm

Choice of Radar Frequency

Application factors:

– Radar wavelength should be matched to the size of the surface features that we wish to discriminate

  – *e.g.* Ice discrimination, small features, use X-band

  – *e.g.* Geology mapping, large features, use L-band

  – *e.g.* Foliage (bitki, yeşillik) penetration, better at low frequencies, use P-band

- In general, C-band is a good compromise

System factors:

– Low frequencies:

  - More difficult processing
  - Need larger antennas and feeds
  - Simpler electronics

– High frequencies:

  - Need more power
  - More difficult electronics
  - Good component availability at X-band

- Note that many research SARs have multiple frequency bands

  – *e.g.* JPL AIRSAR, SIR-C, Convair-580

Polarization

See additional page 33

- Polarization is the orientation of the electric vector of an electromagnetic wave.
- Radar system antennas can be configured to transmit and receive either horizontally or vertically polarized electromagnetic radiation
- When polarization of the transmitted and received waves is in the same direction, it is referred to as like-polarized
- HH refers to horizontally transmitted and received waves
- VV refers to vertically transmitted and received waves

- When polarization of the transmitted waves is orthogonal to the polarization of the received radiation, it is referred to as cross-polarized; *e.g.* HV refers to horizontal transmission and vertical reception; VH for vertical transmission and horizontal reception

- When the radar wave interacts with a surface and is scattered from it, the polarization can be modified, depending upon the properties of the surface. This modification affects the way the scene appears in polarimetric radar imagery, and the type of surface can often be deduced from the image

Choice of Polarization

- Basic or operational SARs usually have only one polarization for economy, *e.g.* HH or V V

- Research systems tend to have multiple polarizations, *e.g.* all of HH, HV, V V, VH (quad pol)

- Multiple polarizations help to distinguish the physical structure of the scattering surfaces:

  – Alignment with respect to the radar (HH *vs.* V V)

  – Randomness of scattering (*e.g.* vegetation - HV)

  – Corner structures (*e.g.* HH V V phase angle)

  – Bragg scattering (*e.g.* oceans – V V)

Radar shadows in imagery

See additional page 34

- Areas on the ground surface not illuminated by the radar

- Since no return signal is received, radar shadows appear very dark in tone on the imagery

- Information about the scene, such as an object's height, can also be obtained from radar shadows.

Fading and speckle

See additional page 35

- Noise-like processes which degrade image quality in a coherent imaging system.

- Fading is due to variation in the echo phase delay caused by multiple targets in a resolution cell with range variations differing by less than a wavelength.

- Local constructive and destructive interference appears in the image as bright and dark speckles, respectively

- Using independent data sets to estimate the same ground patch, by average independent samples, can effectively reduce the effects of fading and speckle

Surface roughness

See additional page 36

- Influences the reflectivity of microwave energy and thus the brightness of features on the radar imagery

- Horizontal smooth surfaces reflect nearly all incident energy away from the radar and are called specular (meaning mirror) reflection

- Specular surfaces, such as calm water or paved highways, appear dark on radar imagery

- Microwaves incident upon a rough surface are scattered in many directions. This is known as diffuse or distributed reflectance

See additional page 37

- Vegetation surfaces will cause diffuse reflectance and result in a brighter tone on the radar imagery.

- In general, scenes observed by a SAR consist of two kinds of reflecting surfaces; distributed scatterers and discrete scatterers

- **Discrete scatterers** are characterized by a relatively simple geometric shape, such as a building. The classic element used to represent discrete scattering is a corner reflector, a shape as is formed when all sides intersect at (nearly) right angles such as the intersection of a paved road and tall building

- **Distributed scatterers** consist of multiple small areas or surfaces from which the incident microwaves scatter in many different directions. Distributed scattering is produced from a forest canopy or cultivated fields.

- Radar measures that component of the scattered energy which returns along the same path as the incident beam.

- Surface roughness of a scattering surface is determined relative to radar wavelength and incident angle

- A surface is considered smooth if surface height variations $<< \lambda$

- In terms of a single wavelength, a given surface appears rougher as incident angle increases

- Rough surfaces will usually appear brighter on radar imagery than smoother surfaces composed of the same material

- Rough surface can be defined as having a height variation of about half the radar wavelength

Corner Reflectors

See additional page 38

- Small objects may appear extremely bright on radar imagery. This is dependent on the geometric configuration of the object

- The side of a building or a bridge, combined with reflection from the ground is an example of a corner reflector

- When two surfaces are at right angles and open to the radar, a dihedral corner reflector is formed. The return from a dihedral corner reflector is strong only when the reflecting surfaces are very nearly perpendicular to the illumination direction

- Strong reflections are caused by a trihedral corner reflector. These are formed by the intersection of three mutually perpendicular plane surfaces open to the radar

- Researchers often place corner reflectors at various ground locations to act as reference points on the radar imagery

Volume scattering

See additional page 39

- Related to multiple scattering processes within a medium, such as the vegetation canopy of a corn field or a forest

- Multiple scattering can also occur in layers of very dry soil, sand, or ice

- Important as it influences the backscatter observed by the radar

- Radar will receive backscatter from both the surface and the volume

- The intensity of volume scattering depends on:

  i) The physical properties of the volume variations especially in the dielectric constant

  ii) Characteristics of the radar (wavelength, polarization and incident angle)

- The presence of moisture increases a material's complex dielectric constant

- The dielectric constant influences the ability of a material to absorb, reflect and transmit microwave energy.

- The moisture content of a material can change its electrical properties. This affects how a material appears on the radar image

- Identical materials can vary in appearance at different times or different locations according to the amount of moisture they contain

- The reflectivity, and hence image brightness, of most natural vegetation and surfaces is increased with increasing moisture content

- Microwaves may penetrate very dry materials, such as desert sand. The scattering which results, is affected by both surface and subsurface properties

- In general, the longer the radar wavelength, the deeper into the material the energy will penetrate.

Advantages of satellite SARs (RADARSAT)

– More coverage per second (Km^2/s)
– Lower operating costs ($/$Km^2$)
– Not constrained by flying conditions or airport proximity
– Wider area views
– Somewhat simpler signal processing (no motion compensation)

Disadvantages of satellite SARs (RADARSAT)
– More expensive to design, build and launch
– More difficult to provide multiple polarizations & frequencies
– Cannot be flown anywhere on demand
– Lower resolution in general

Imaging Modes of RADARSAT-1

See additional page 40 (Two pages)

Comparison of Imaging Geometries of Spaceborne SAR and Airborne SAR

See additional page 41

7. Geospatial Data and GIS (Geographical Information Systems)

GIS is a "computer system for capturing, managing, integrating, manipulating, analysing and displaying data which is spatially referenced to the Earth.

GIS differs from other forms of information systems (like databases and spreadsheets) since GIS deals with spatial information.

GIS has the capability to relate layers of data for the same points in space, combining, analysing and, finally, mapping out the results.

Spatial information uses location, within a coordinate system, as its reference base.

The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude.

Major areas of application of GIS

- Different streams of planning

- Urban planning, housing, transportation planning, architectural conservation, urban design, landscape

- Street network based application

- Vehicle routing and scheduling: location and site selection and disaster planning

- Natural Resource Based Applications like management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, forests and wildlife

- Hazardous or toxic factories siting and ground water modelling

- Wild life habitat study and migrational route planning

- Land parcel based zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance

- Facilities Management

- Locating underground pipes and cables for maintenance, planning, tracking energy use

- Tool for crime analysts in many police departments

One of the advantages of GIS is its ability to integrate information from a variety of sources into one user interface which allows for spatial analyses that would either not have been possible or very difficult prior to the advent of GIS.

- Water supply companies use GIS as a spatial database of pipes and manholes

- Municipalities can use GIS to manage and update property boundaries, emergency operations and environmental resources

- GIS can be used to map out the provision of services, such as health care and primary education, taking into account population distribution

- GIS is being used to assist businesses in identifying their potential markets and maintaining a spatial database of their customers

- GIS data are usually stored in more than one layer in order to overcome the technical problems caused by handling very large amounts of information at once

- It is easier to work with complex spatial problems one layer at a time

- Working with layers of geographical information is known as data integration and this is a fundamental aspect of GIS

- For example, GIS of a region may consist of several layers of data:

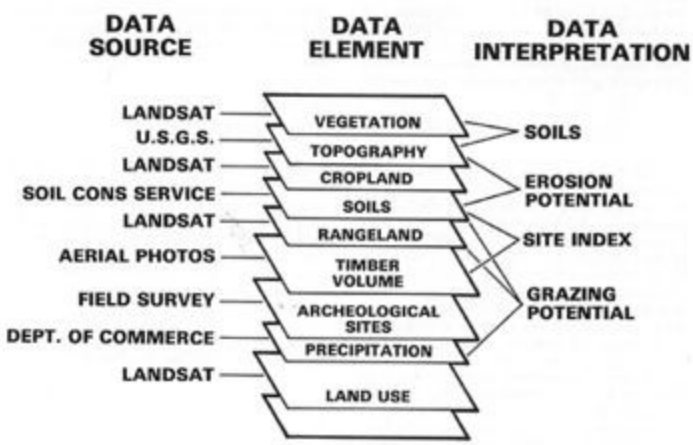
    - Layer 1: Property boundaries and land use types (as area maps)

    - Layer 2: Road and railway networks (as line maps)

    - Layer 3: Terrain characteristics (as spot-height or contour maps)

    - Layer 4: Hospital, school ..etc. locations (as point maps)

- Spatial data is represented in one (or both) of the two following formats:
  - Vector model, as geometric objects like points, lines, polygons
  - Raster model, as image files composed of pixels
- Data Elements and Models
  - The interrelations among variables are usually very complex
  - **GIS Example:** To control the crop production process, a model is formulated for the crop growth that accounts for the dynamic interactions and cause-effect responses of the appropriate factors
  - Model establishes the functions, sequences, and feedback effects of the determining variables



(Otlatma Potansiyeli)

  - In the above diagram, information is taken from:
    - i) Various conventional sources
    - ii) Data from Landsat or similar Earth-observing satellites
  - Information is combined to produce data elements
  - From data elements interpretation maps and other output types are produced
  - These outputs become parts of environmental resource planning, site selection, and other desired applications
    - Interpretative maps are derivatives (i.e., they result from decisions to produce new object categories, originating from combinations of several others)
    - E.g: A map may contain the likelihood of erosion, which can deduced from maps showing:

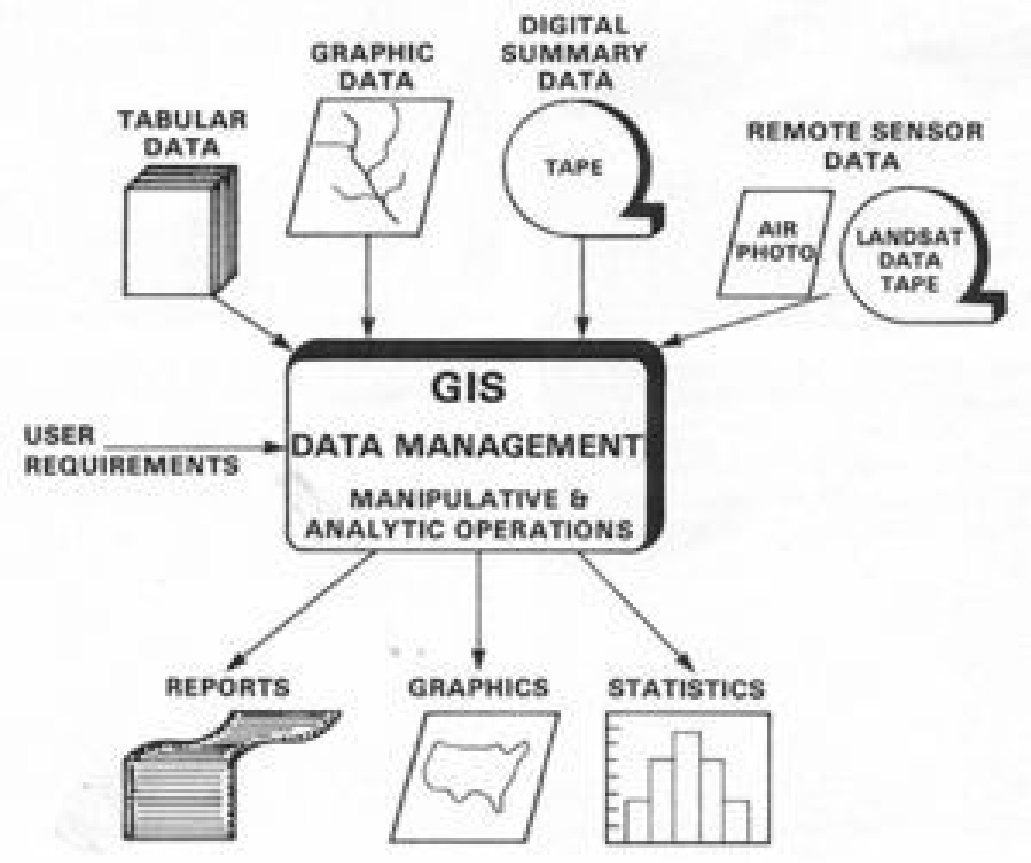
i) Soil properties

ii) Topography

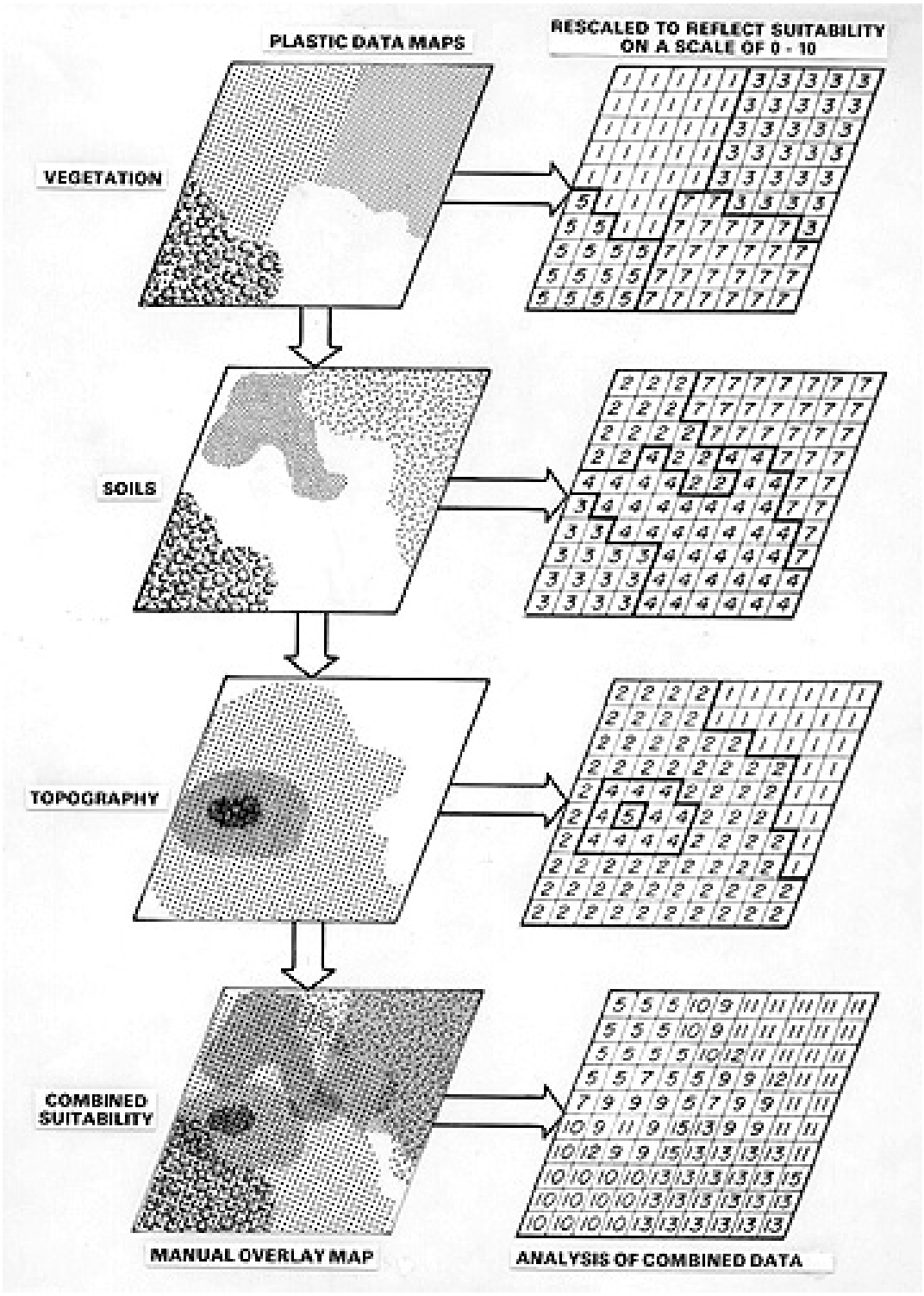
iii) Rainfall

iv) Stream patterns

v) Other related factors



- **GIS Case Study - 1** and the thinking behind the steps in a site-suitability analysis



- Suppose that three factors or variables, among the attributes that describe a geographic area under consideration, are essential in determining best sites for a land development venture:

  i) Vegetation

  ii) Soils

  iii) Topography

- A data element on a map represents each variable

- In this case the map shows the characteristics and distribution of the members or classes within the element theme, e.g., different types of soils and their properties

- Usually one map, often a cartographic map (maps representing spatial distributions over various areas of the earth) is designated as the base, over which the other maps are laid

- Each map then constitutes a data layer either manually or digitally

- Some soils, vegetation cover types, and elevations are more favorable than others in specifying their role in the site-selection process

- Thus, for a certain intended use, we prefer high areas over low areas

- So, numerical ratings, say from 1 to 5 are assigned to relative heights

- Soils with optimum drainage can be marked by higher numbers in a scale of 1 to 8

- Then a data element map is subdivided into pixels

- Each cell is assigned a value based on its thematic rating

- Other kinds of data can be incorporated, e.g., tables representing some condition in the pixels, provided there is some spatial connection

- When the maps sharing the same pixels are combined, each comprising a data layer, the values of **sum** for each pixel, ranging from:

  (lowest numbers = worst suited) to (highest = best suited)

- In GIS, this is usually done digitally

- The outcome is a map, in which the areas with the highest resultant scores are judged the most favorably suited

- The numerical data and their values need to be assigned to each cell. This is called encoding

GIS Case Study - 2

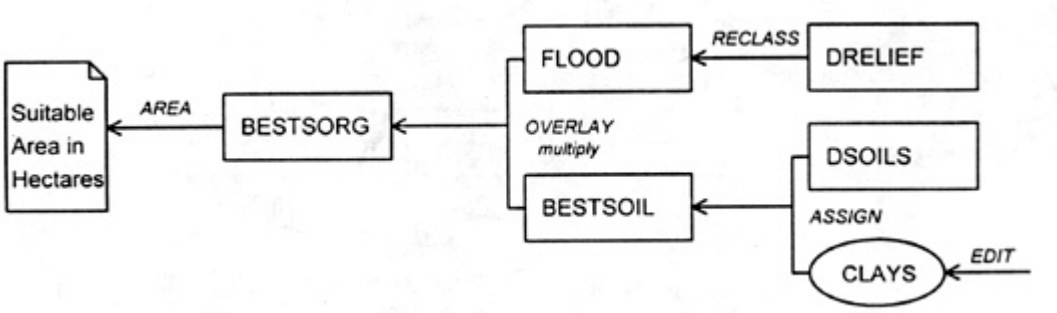
- Simplified example contains only a few of the many data elements that is normally considered in the model

- In order to easily manipulate the data, ranking mode within each element is reduced to acceptable (1) or not-acceptable (0)

- The problem is identifying the best areas for planting a cereal crop (sorghum) within a valley along a River

- Among the many applicable agricultural factors, here only the key factors, such as, soil types, relief (range of elevations) and periodic flooding (which promotes sorghum growth) are considered

- Below flow chart outlines the sequence of steps for using GIS to automate the decision about suitable areas for sorghum planting:



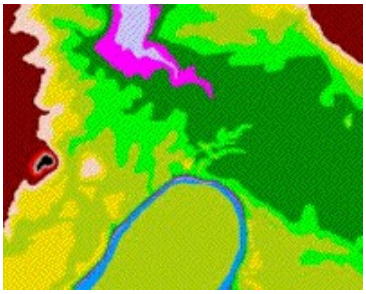
- In this flow chart, annotations are from the IDRISI software program used for GIS applications

- The first factor is the elevation variations or relief

- Field surveys have led to a digital elevation model (DEM) data set

- From DEM data set, general topographic map image with 3-meter contour interval (file name DRELIEF) is produced

RELIEF (ELEVATION) IMAGE



- The sequence of increasing elevations, as color-coded is: blue (lowest, associated with the river), medium gray, purple-red, dark green, medium green, olive, yellow, tan, brown, red, darker gray and black
- The relief or range of elevations is 33 m

- Gentle hills occur in the west and northeast sections

- Lowlands extends across the river

- An unusual lower area (a gully, i.e. a flood bed) is present in the north center of the image

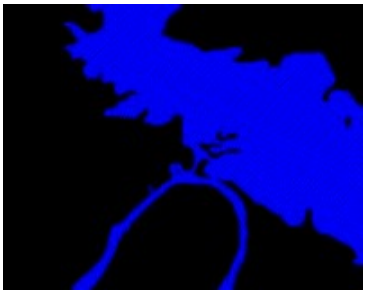
- This depression controls the location and retention of water (keeping water) during floods that take place routinely during the rainy season

- Flood stages can reach 9 m above the normal stream level

- Using this elevation range of 9 m as a constraint, RECLASS routine of IDRISI is used

- RECLASS routine gives boolean algebra values of 0 and 1 to produce the below image (named FLOOD) that defines the area of flooding (in blue)

FLOOD IMAGE



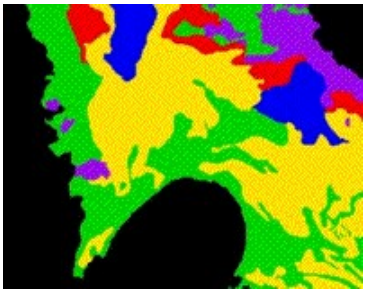
- In the above FLOOD image, 1 is assigned to all elevation values (in blue) less than 9m, i.e., region having tendency for flooding, and 0 to all values above this level (black in the image)

- Soil types in the region differentially absorb floodwaters; some retain enough over the long term to provide a continuing supply of moisture during the growing season

- Thus, soil type is another critical factor

- Below is a map (DSOILS) of the distribution of five soils within the region:

SOIL IMAGE

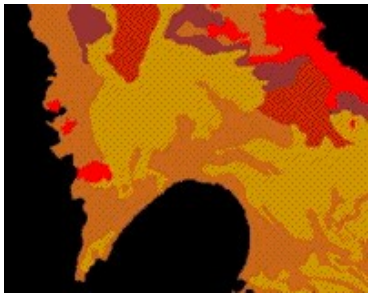


- In the above Soil Image; blue = heavy soils (1), yellow = clays (2), red = sandy clays (3), green = levee soils (4), purple = stony soils (5)

- IDRISI software allows to give each soil a suitability ranking, as follows: best (5) = clays, then in decreasing quality, levee soils (4), sandy clays (3), heavy clays (2) and worst, stony soils (1). The black areas are not considered further

- Then, a map (SORGSUIT) is produced in which the soils are rated by suitability, using the IDRISI ASSIGN program

SORGSUIT (SORGHUM CROP SUITABILITY) MAP



- In this map, red = 1 (least suitable); brown = 2; dark brown = 3; light brown = 4, yellow = 5 (most suitable); black (not considered)

- Above Sorgsuit map has the same distribution pattern as the soils image above, but now, the computer is instructed to give each soil a numerical value

- This numerical value is an attribute that represents its productiveness for growing this crop), instead of a soil-type name

- Next step is to generate a map that shows the location and sizes of patches of clay soil (in green) that constitute the best soil (named BESTSOIL) for growth

BEST SOIL IMAGE



- Final step in the flow chart is to combine the information in the FLOOD and BESTSOIL maps as an OVERLAY to generate a decision end product map, called BESTSORG

- Again, Boolean algebra is used

- On each of the intermediate maps (FLOOD and BESTSOIL), there are just two themes or patterns, one in color and the other in black, representing the idea of "good" or "appropriate" (flooded, optimum soil) and "not suitable" respectively

- Let "acceptable" = 1 and "not suitable" = 0

- Each data cell (the grid is implicit in the above maps but is not shown) for each map then has either a 1 or a 0 within it

- Since the two intermediate maps are at the same scale and projection, they fit or register in the overlay process

- An analog process can be used, i.e., transparencies of the two maps are made and visually overlay them on a lighted table

- Te same result can also be produced digitally, by combining data in the grid cells for each map

- Following this map-algebra operation:

FLOOD		BESTSOIL	BESTSORG
0	X	0	0
0	X	1	0
1	X	0	0
1	X	1	1

- Thus, only those cells that are colored (1) in both maps make a product score of 1

- These form continuous patches, colored red, in the BESTSORG map produced by OVERLAY shown below:

BESTSORG MAP



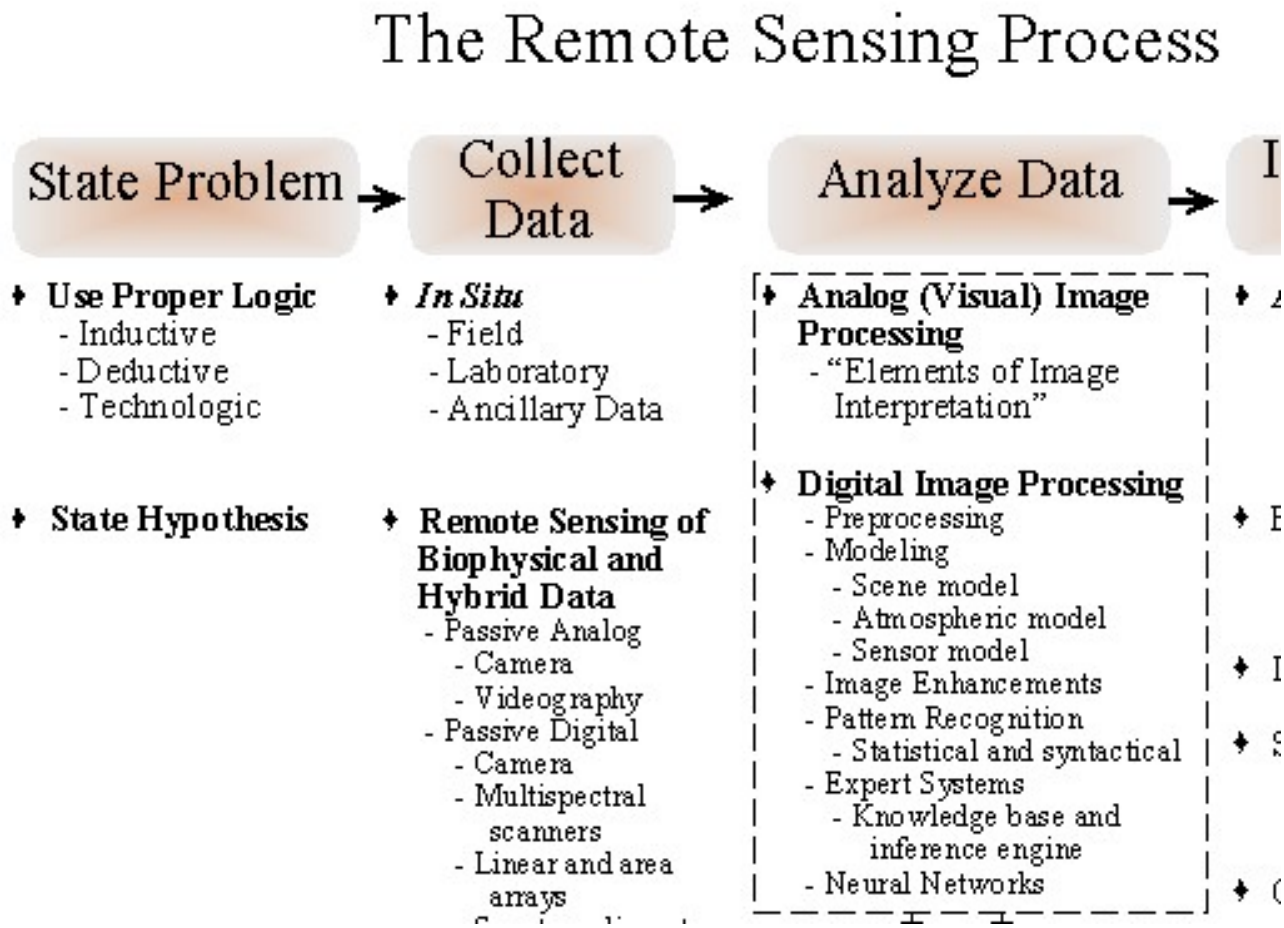
- Since the area of each pixel is known, the total area associated with suitable conditions is just the product of the number of pixels times the unit area. In IDRISI, the two programs GROUP and AREA do this

- Many other attributes and thematic factors in a real suitability case can be included like access (roads, etc.), Market Requirements, Fertilizer Needs, Manpower Availability, etc.

- Some of these factors can be expressed as maps and others as data that we may organize into value tables. These data can be integrated in GIS models that add to the scores in each pixel

- Also as shown in the Site Suitability illustration above, one could apply a different system of ranking, in which a range of rankings can be associated, say, from 1 to 10 (rather than just 0s and 1s), with each pixel, and then sum them for all the data elements.

7.3. Image Processing and Analysis



- Remotely sensed data is analyzed using various image processing techniques and methods including both of the

  i) Visual (or analog) processing techniques applied to hard copy data such as photographs or printouts

  ii) Application of digital image processing algorithms to the digital data

- One of the purposes of applying both analog and digital techniques to remotely sensed data is to enable the analyst see the data in several ways

- The goal of image processing is to allow the researcher to examine their data from all possible angles, to place entire images in context with their surroundings and to allow the relationships of individual scene elements to be discovered

Analog Image Processing

- Scientific visualization is the process of exploring data visually to gain an intimate knowledge and insight about the data

- Elements of Image Interpretation:

  • **Shape** – Outlines of objects (e.g. Specific building)

- **Size** – In context of image scale (e.g. Houses / Industrial buildings)
- **Pattern** – Spatial arrangement of objects (e.g. trees in an orchard (fruit garden) versus forest tree stands)
- **Tone** – Relative brightness or colour of objects (e.g. Light toned and Dark toned soils, Deciduous Trees which lose their leaves inwinter versus Coniferous Trees which do not lose their leaves in winter)
- **Texture** – Smoothness or Coarseness of image features (green grass vs. green tree)
- **Shadows** – E.g. Shadows of Trees bridges help in their identification
- **Site** – Geographic location (e.g. Crops in well-drained vs. poorly drained sites)
- **Association** – Context of occurrence (e.g. Barn in an agricultural area)

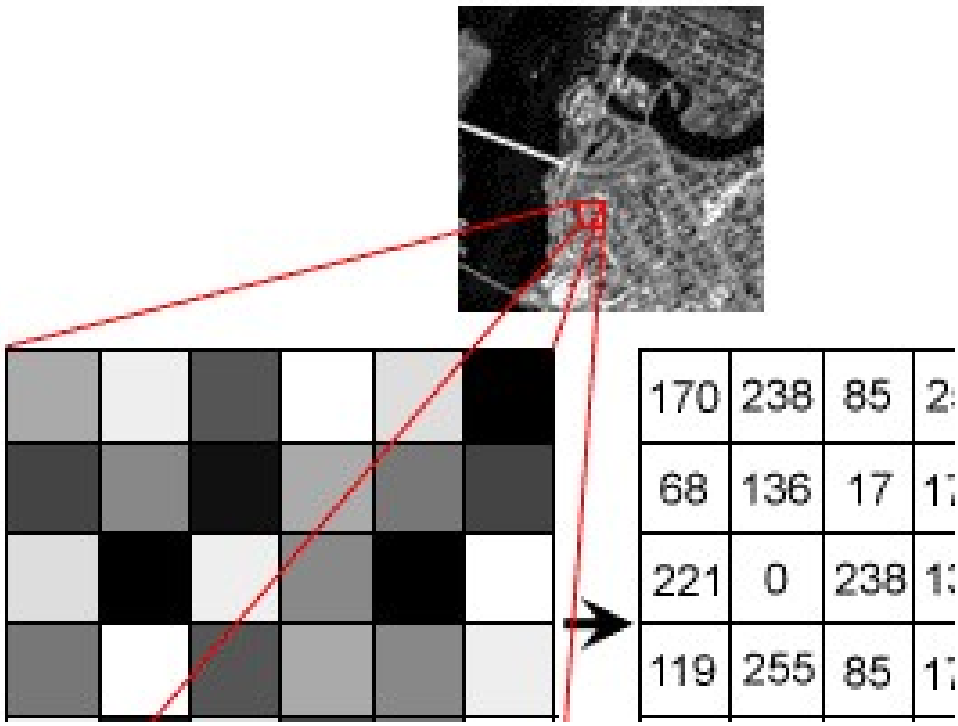
- Everyone continually processes images in daily life
- As you walk down the street you see cars, other people, take note of the weather, etc.
- All these images are passed to our brain where all of our experiences and learning are used to extract the most pertinent information
- Similarly, you apply collateral data and personal knowledge to the task of image processing
- This, combined with the multi-concept of examining remotely sensed data:
  - In multiple bands of the electromagnetic spectrum (multispectral)
  - On multiple dates (multitemporal)
  - At multiple scales (multiscale)
  - In conjunction with other scientists (multidisciplinary),
- Eventually a judgement is made what the object is and its significance

- Other tasks performed in analog image processing include Optical Photogrammetric techniques allowing for precise measurement of height, width, location, etc. of an object

Digital Image Processing

- The ultimate goal of digital image processing is to extract information from an image that is not readily apparent or is not available in its original form
- Image is in digital format
- Image is composed of pixels representing digital numbers for brightness (e.g. from 0 (representing black) to 255 (representing white) in an 8 bit radiance resolution)

• Because of digital pixel structure, remote sensing inputs fit well into Raster GIS models.



Digital Image Processing Functions

1) Image Preprocessing

- Concerned with removal of errors in Data – sensor and platform related
- Correction for velocity, altitude and earth curvature (carried out at ground receiving stations)
- Radiometric pre-processing (for missing scan lines, de-striping)
- Geometric corrections (for geo-referencing)
- Radiometric corrections (using multi-temporal images)
- Atmospheric corrections (haze removal)

2) Image Enhancement

- Usually done to more effectively display or record the data for subsequent visual interpretation.
- Contrast stretching
- Filtering

- Edge enhancement

3) Image Transformations

- Arithmetic operations done to combine and transform the original bands into "new" images which better display or highlight certain features in the scene

4) Image Classification and Analysis

- To categorize all pixels in an image into land cover classes or themes
- Multi-spectral data are used to perform classification
- Spectral patterns present within data used as numerical basis for categorization

Comparison of Analog (Visual) and Digital Image Processing

Analog (Visual) Image Processing	Digital Image Processing
• Uses all available elements	• Relies mainly on the tone and color of image pixels
• Traditional: intuitive	• Recent: requires specialized training
• Simple, inexpensive equipment	• Complex, expensive equipment
• Uses brightness (limited grey levels) and Spatial content of the image	• Relies chiefly upon brightness and spectral content (detection of subtle spectral differences) , limited spatial
• Usually single channel data or three channels at most	• Frequent use of data from several channels.
• Subjective, concrete, qualitative	• Objective, abstract, quantitative

- Digital image processing is also applied with expert systems and neural networks which attempt to enable the computer to mimic the ways in which humans interpret images
- **Expert systems** accomplish this through the compilation of a large database of human knowledge gained from analog image interpretation which the computer draws upon in its interpretations
- **Nueral networks** attempt to 'teach' the computer what decisions to make based upon a training data set. Once it has 'learned' how to classify the training data succesfully, it is used to interpret and classify new data sets.

Information Output of Image Processed Data

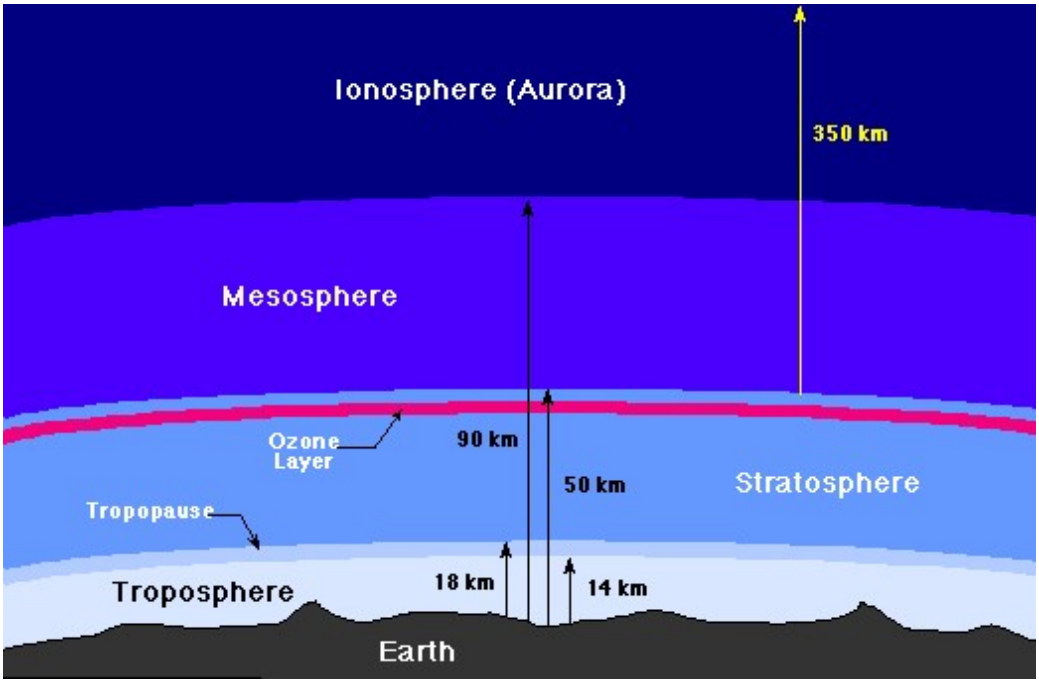
- After the remotely sensed data is processed, it must be placed into a format that can effectively transmit the information it was intended to. This can be done in a variety of ways including:

  - Printout of the enhanced image itself
  - Image map
  - Thematic map
  - Spatial database
  - Summary statistics and/or graphs

9. Error Correction and Registration of Image Data

Atmospheric, Geometric, Radiometric Distortion and Correction

ATMOSPHERE



CONTENT AND BASIC PROPERTIES OF THE ATMOSPHERE

Composition of the Atmosphere

- Composition of the atmosphere is important to understand the role which the atmosphere plays in remote sensing and in interactions with electromagnetic radiation

- Atmosphere is to a large extent a mixture of gases, some with fairly constant concentrations, others that are variable in space and time

- Additionally there are suspended particles (e.g. aerosol, smoke, ash etc.) and hydrometeors (e.g. cloud droplets, raindrops, snow, ice crystals, etc)

- About 99% of the mass lies below an altitude of 30km. Table 1 below shows the composition of the atmosphere below 100km.

Constituent	% by volume	Variable constituents	
Nitrogen (N2)	78.08	Water vapour	0
Oxygen (O2)	20.95	Ozone	0
Argon (Ar)	0.93	Ammonia (NH3)	0
Carbon dioxide (CO2)	0.033	Sulphur dioxide (SO2)*	0
Neon (Ne)	18.2 x 10^-4	Nitrogen dioxide (NO2)*	0
Helium (He)	5.2 x 10^-4	other gases	t
Krypton (Kr)	1.1 x 10^-4	aerosols, dust, gases	h
Xenon (Xe)	0.089 x 10^-4		
Hydrogen (H2)	0.5 x 10^-4		
Methane (CH4)	1.5 x 10^-4		

- Above table shows the main constituents of the earth's atmosphere (* denotes concentration near the earth's surface)

- Nitrogen, oxygen and argon account for about 99.99% of the permanent gases

- Carbon dioxide can be variable in concentration on a localised basis at low levels

- Water vapour content may vary from about 0 to 4%

- Ozone concentrations also vary

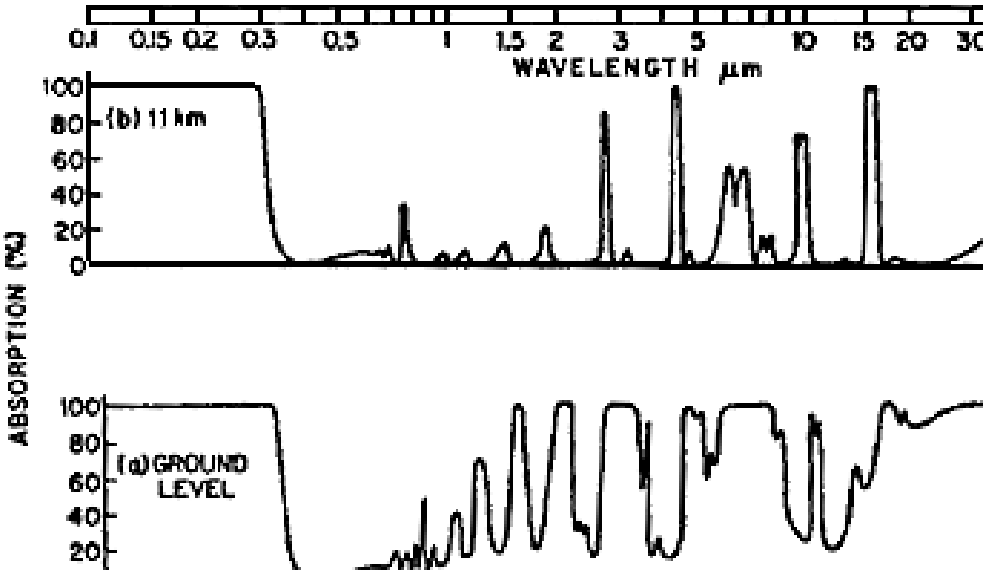
- In addition to these variable constituents there are also aerosols and hydrometeors which can vary widely in space and time

- Atmospheric gases critically affect the earth's global energy balance through absorption and re-emission

- Solar radiation reaching the earth's surface is determined by atmospheric gases

- E.g. harmful UV radiation is blocked by the ozone layer

- Below figure shows atmospheric absorption for solar radiation for the layer of atmosphere above 11km and at the ground level



Absorber	Symbol	Spectral Reg
Carbon dioxide	CO2	13.5-16.5 um (center a
		4.2-4.4 um (center at 4
		10.4, 9.4, 5.2, 2.7, 2.0
		1.4 um; also a series of
		in the 0.78-1.24 um re
Molecular oxygen	O2	1.07 and 1.27 um, a ser
		between 50-70 GHz, on
		118.75 GHz; also weak b
		visible, with centres be
		5384 and 7621Å
Water vapour	H2O	5.5-7.5 um (centre at 6
		2.6-3.3 um (several cer
		1.4, 1.1, 0.94, 0.81, 0
		22.24 and 183.31 GHz,
		at frequencies higher tha
		that extend all the way t
		a few weak bands in the
Ozone	O3	14.1, 9.6, 9.0, 5.75, 4.
		3.27, 2.7um, 18 lines be
		and 43.65 GHz, lines at
		101.74 and 118.36GHz,
		lines between 160 and 3
		1800-3400 A (centre a
		3200-3600 A, 4400-7
Methane	CH4	3.3 and 7.7 um
Nitrous oxide	N2O	4.5, 7.8, 17.0 um, plus
		50, 25 GHz

- Above table gives the main atmospheric gases which absorb radiation along with their absorbing regions, at ultraviolet (UV), visible, infrared (IR) and microwave wavelengths

- Also, the main spectral regions for which atmospheric absorption is small **("windows)** allow ground-based measurements of celestial objects, and satellite-based measurements of the earth's surface or clouds for remote sensing applications. Windows are indicated in the above table

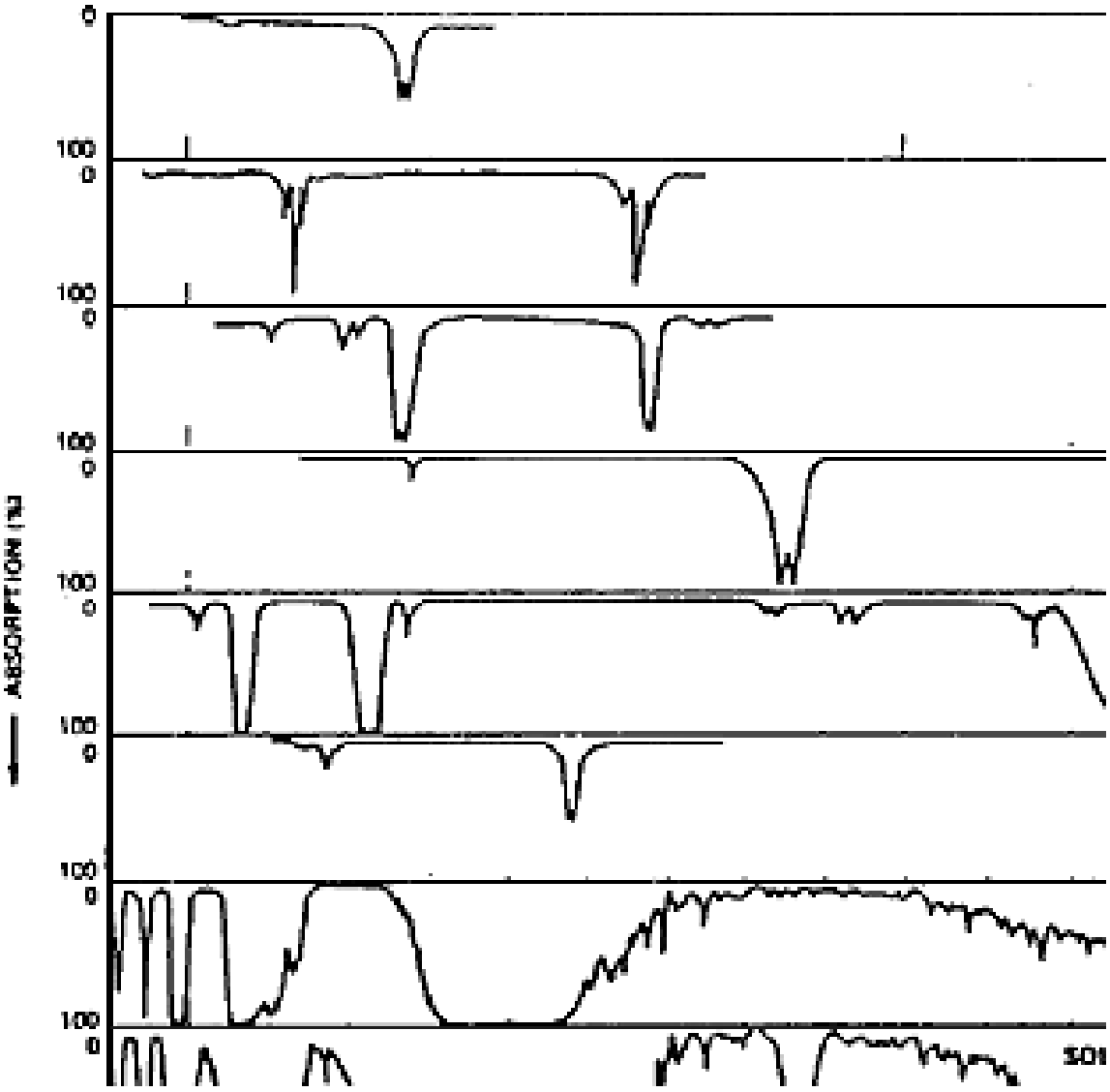
- Atmosphere is relatively transparent from about 8 to 13 microns. This region is referred to is an atmospheric window and is commonly used by IR imaging sensors on meteorological satellites

- In a clear atmosphere without clouds and aerosols, a large portion (about 50%) of solar energy transmits through the atmosphere and is absorbed by the earth's surface

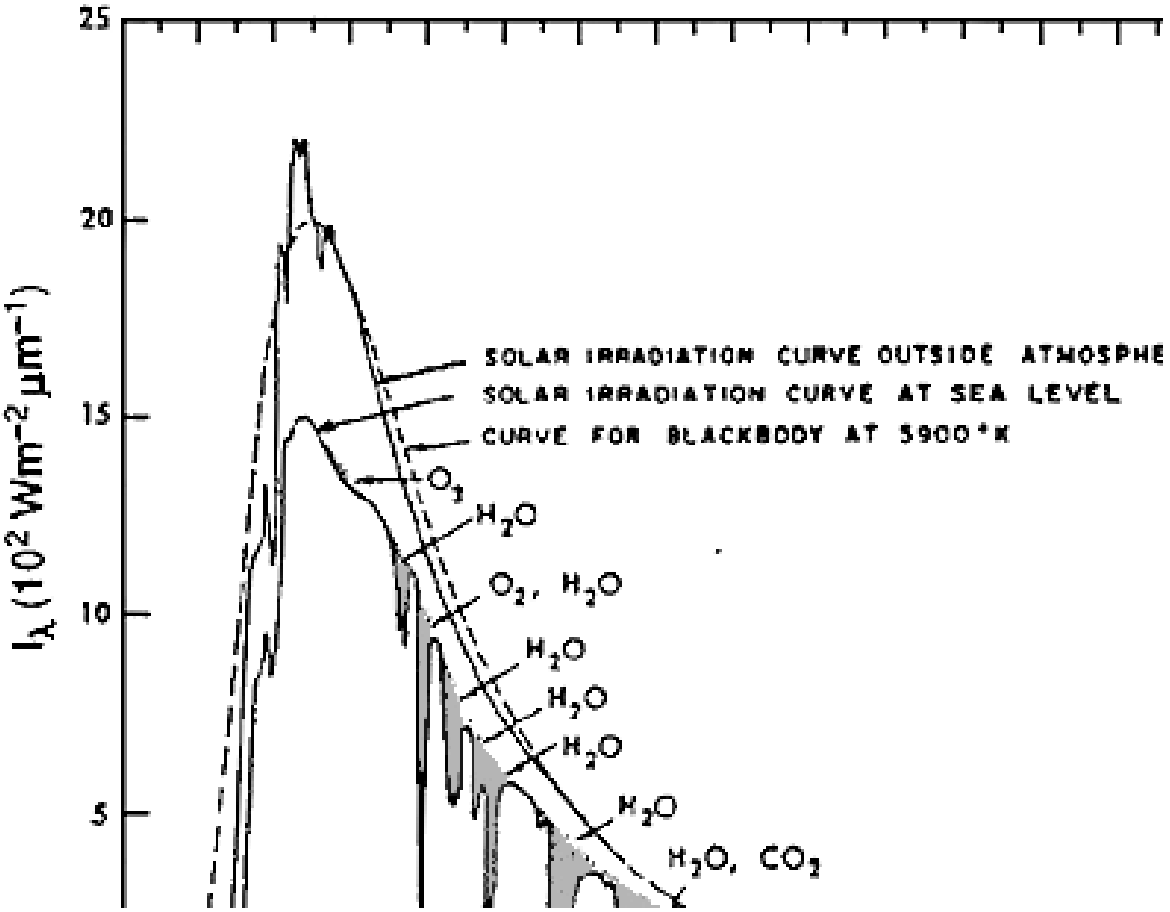
- Energy emitted from the earth, on the contrary, is absorbed largely by carbon dioxide, water vapour, and ozone in the atmosphere

- Trapping of thermal infrared radiation by atmospheric gases is called the greenhouse or atmospheric effect

- Atmospheric absorptivity as a function of wavelength is shown in the below Figure for visible and IR wavelengths for separate gases.



- Below figure shows solar radiation at the top of the atmosphere and the actual radiation at sea level which has been reduced due to absorption by atmospheric gases
- The dashed curve is a blackbody at 5900K for comparison with the solar curve outside the earth's atmosphere
- Shaded areas indicate absorption by atmospheric gases
- Intensity scale is in the order of mWatt or Watt



Atmospheric scattering

- Much of the visible radiation which reaches our eyes is scattered rather than direct

- E.g. light from the sky or from clouds is scattered sunlight
- Atmospheric Scattering is a fundamentally significant process in which incident electromagnetic radiation may be affected by the presence of a particle upon which it is incident

- The particle effectively removes energy from the incoming radiation and reradiates that energy in all directions

- Particles in the atmosphere which are important in scattering are:

  - Gas molecules (size about 1 nm)

  - Solid aerosols (sizes 0.1 to 1.0 μ m)

  - Cloud water droplets (1 to 10 μ m)

  - Cloud ice crystals (1 to 100 μ m)

  - Hail (dolu) (up to 10 cm).

- The directional dependence of the scattering depends very strongly on the ratio of the scattering particle size to the wavelength of the incident radiation

- Isotropic scattering is characterised by a scattering pattern which is symmetrical about the direction of the incoming radiation

- A very small particle tends to scatter light equally in the forward and backward directions relative to the direction of incoming radiation

- Larger particles tend to concentrate most of the scattered radiation in the forward direction

- Several cases to consider:

  1) Rayleigh scattering: Occurs when the scattering particle size << λ

  In Rayleigh scattering, the intensity of light is scattered in a particular direction by air molecules is inversely proportional to λ^4

  Rayleigh scattering explains the scattering of sunlight (eg visible and IR wavelengths) by air molecules

  Much of the incoming solar radiation is at visible wavelengths

  The amount of scattering of sunlight at dark blue wavelengths (about 0.47 micron) > for red light (about 0.64 micron) by a factor of $(0.64/0.47)^4 = 3.4$

  This is the reason why the sky appears blue (greater Rayleigh scattering at short visible wavelengths)

  Rayleigh scattering also applies to microwave scattering by raindrops
  Thus used in understanding and interpreting weather radar observations

  2) Mie scattering: Occurs when scattering particle size is comparable to or > λ

  Scattering from small suspended particles in the atmosphere (aerosols) like haze, dust, smoke, soot, bacteria, virus, sea salt crystals

  3) Geometric Optics: Describe angular distribution of scattered radiation when the scattering particle size >> λ

  Non selective scattering where the scattering is not very dependent on wavelength.

  E.g. to non-selective scattering is scattering of sunlight by atmospheric constituents such as **large** aerosols, cloud droplets or ice crystals. This is why the clouds appear as white or grey

- Consider the size parameter α

  $\alpha = 2 \pi r / \lambda$

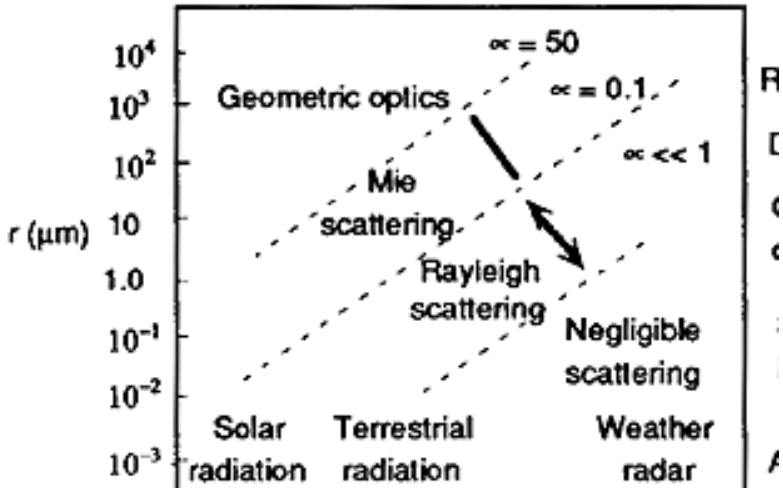
  where r is particle radius

Note that α is a dimensionless size parameter which relates the particle size to wavelength of radiation

The ranges of α corresponding to various scattering theories are shown below

α	Scattering
α > 50	Describe angular distr
	of scattered radiation
	geometric optics i.e. n
	selective scattering
0.1 < α < 50	Mie regime

Below figure shows for various values of scattering particle radius r and wavelength λ



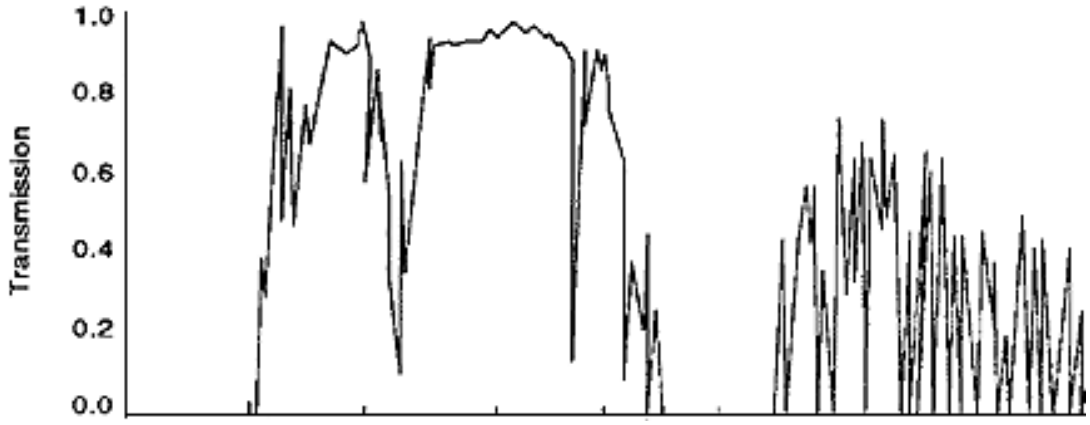
- Scattering of visible radiation in the atmosphere can be significant

- However, scattering of terrestrial (long wave-far inrared) radiation with wavelength >4λ is of secondary importance compared to absorption and emission

- Below Table summarises the main types of atmospheric scattering in the order of importance:

Theory	Particle size	Type of particle	Com
Rayleigh	$\lambda < 0.1$	Gas molecules	Scattering inverse
			to fourth power of
			Result: blue sky,
			sunrise; haze in p
Mie	$>= \lambda$	Small cloud droplets,	Generalised theor
		dust, fumes etc	Affects long visibl
Non-selective	$>> \lambda$	Cloud droplets, dust etc	Applies to scatteri
			clouds. Scattering
			independent of λ .
			whitish colour of

- A detailed view is given in the below figure in the form of measured transmittances over the range 5 to 25 microns for the entire atmosphere. This shows that even window regions may be affected by attenuation.



Radiometric Correction of Remotely Sensed Data

- Radiometric correction of remotely sensed data involves the processing of digital images to improve the brightness value magnitudes (as opposed to geometric correction which involves improving the relative spatial or absolute locational aspects of image brightness values)

- The main purpose for applying radiometric corrections is to reduce the influence of errors or inconsistencies in image brightness values that may limit one's ability to interpret or quantitatively process and analyze digital remotely sensed images

- Radiometric errors and inconsistencies can be referred to as "noise", which could be considered any undesirable spatial or temporal variations in image brightness not associated with variations in the imaged surface

- The sources of radiometric noise and therefore, the appropriate types of radiometric corrections, partially depend on the sensor and mode of imaging used to capture the digital image data

- Several types of imaging systems are utilized for generating digital remotely sensed data, each having their own characteristic sources of radiometric noise

    1) Scanned aerial photography

    2) Optical scanners

    3) Optical linear arrays

    4) Optical framing arrays

    5) Scanning microwave radiometers

    6) Side-looking radars

- Radiance measured by any given system over a given area is influenced by several factors (Some sources of radiometric noise):

    - Spatial variations in illumination quantity and quality

    - Temporal variations in illumination quantity and quality

    - Atmospheric conditions

    - Viewing geometry

    - Instrument response characteristics

    - Sensor-related effects

    - Terrain and surface properties

- Some of these effects are greater with aircraft sensors than with Satellite systems

- Need to apply certain types of corrections depends on the particular application of interest

- In the application of radiometric corrections to digital remotely sensed data:

    - Relative correspondence of image brightness magnitudes may be desired for pixels:

        1) Within a single image (e.g., orbit segment or image frame)

        2) Between images (e.g. adjacent, overlapping frames)

        3) Between spectral band images

        4) between different dated images

- Absolute quantification of brightness values of the pixels are required

- Objective in radiometric correction are:

  - Brightness value inconsistencies caused by the sensor and environmental noise factors are balanced or "normalized" across and between image coverages and spectral bands

  - Retrieval of surface energy properties such as spectral reflectance or surface temperature, which requires absolute radiometric processing

- **Sun corrections**

  - In case regional mosaics using different date images are required or the changes in the ground reflectance are studied, it is necessary to apply corrections for different seasonal positions of the sun

    e.g. Earth - sun distance correction is applied to normalize for the seasonal changes in the distance between the earth and the sun

    Earth - sun distance is usually expressed AU (in astronomical unit = 1.496×10^8 km)

    Irradiance of the sun decreases as the square of the earth-sun distance and expressed as:

    $I_s = (I_0 \cos \theta) / d^2$ where I_s = Normalized solar irradiance, θ is the zenith angle (angle between the line joining the pixel with the sun and the line perpendicular to earth), I_0 is the solar irradiance at $\theta = 0$, d is the distance between the sun and the earth

- **Radiometric Restoration types**

  - **Destriping**

    - Striping or banding occurs if an individual detector used for a particular band goes out of adjustment

    - This brings systematic noise in an image that results from variation in the response of the a detector

    - Result is that the detector provides readings that are consistently greater than or less than the other detector's readings for the same band over the same ground area

    - In the case of MSS (Multispectral Scanner) data, there are 6 detectors per band which scan in a side to side motion

    - If one of the detectors is miscalibrated, then horizontal banding occurs on each 6th line

- Similarly, in the case of TM data with 16 detectors per band, each 16th line in the image will be affected

- Multispectral SPOT data have a pushbroom scanner with 3000 detectors for each band, one detector for each pixel in a row

- Since detectors in a pushbroom scanner are arranged in a line perpendicular to the satellite orbit tack, miscalibration in SPOT detectors produces vertical banding

- Procedure that corrects the values in the bad scan lines is called destriping

- Destriping involves the calculation of the mean (or median which is the value that divides the data values into two equal parts) and standard deviation {$\sigma = [\Sigma (x_i - \upsilon)^2]^{1/2}$ where υ is the mean value and the summation is from i=1 to N} for the entire image and then for each detector separately

- Some software packages offer an option for applying a mask to the image to exclude certain areas from these calculations (for example, clouds and cloud shadows should be excluded)

- Also, sometimes only a portion of the image, usually a homogeneous area, such as a body of water, is used for these calculations

- Then, depending on the algorithm employed by a software system, one of the following adjustments is usually made:

    - The output from each detector is scaled to match the mean and standard deviation of the entire image. In this case the value of each pixel in the image is changed

    - The output from the problem detector is scaled to resemble the mean and standard deviation of the other detectors. In this case the values of the pixels in normal data lines are not altered.

Destriping Example:

- In this exercise, destriping technique with a certain SPOT data will be explored

- The data set includes three multispectral bands (B1, B2,B3) with 20 x 20 m resolution

- Two false color composites will be created

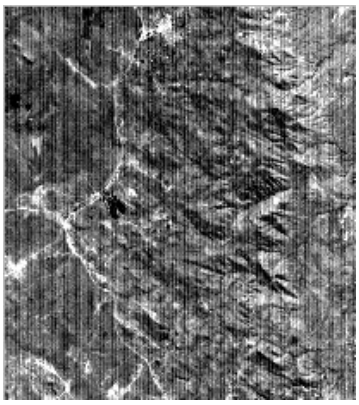
    - First, using the raw bands

    - Second, using destriped bands

- Comparison of these two images will show how efficient destriping techniques can be for the removal of systematic noise in the data

Procedure:

5) Examine the below B2 (red band) image (vertical stripes are noticed)



6) Create a false color composite image using NJOLOV1 as the blue band, NJOLOV2 as the green band, and NJOLOV3 as the red band

   Specify a linear stretch with 0.5 % saturation. Call the output image NJOLOVFC

   As seen below the stripes are even more clear



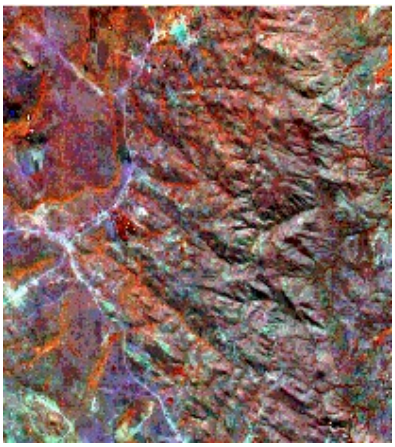
7) Through a software algorithm, apply destriping procedure to each of the three raw bands

8) Create a false color composite image using the three destriped images, destiped B1 as the blue band, destriped B2 as the green band and the destriped B3 as the red band

   Specify a linear stretch with 0.5 % saturation

   Resultant false color composite image is displayed below

   For comparison, false color composite of the raw bands is also shown below





Line dropout

- Data error that occurs when a detector in a satellite scanner either:

  Completely fails to function, or

  Temporarily misfunctions during a scan

- The result is a line, or partial line, of data with incorrect data files

- Thus the values create a horizontal streak until the detector(s) recovers

Signal noise

- Noise refers to any unwanted or extraneous energy detected by the sensor which will disturb the image

- Noise is the result of limitations in the sensing, signal digitization or data recording

- Noise can either degrade or totally mask the true radiometric information content of a digital image

- It is expressed by the signal-to-noise ratio (SNR)

- SNR directly affects the ability to detect small radiometric differences in the data

Atmospheric effects

- İncoming and outgoing radiation interact with the atmosphere which produce errors in the brightness values

- These errors are not similar to sensor errors because atmospheric events appear as part of the detected radiance

- Quite often it is important to remove or reduces these unwanted atmospheric effects

- Atmosphere affects radiance at any given point on the image in two ways:

1) Attenuates the energy that illuminates the ground object.

2) Acts as a reflector itself, adding a scattered, extra path radiance to the signal detected by the sensor.

- Scattering factor introduces haze into the image

- Scattering effect can be minimizes using haze compensation routines

Haze compensation

- Procedures are developed to compensate for the effects of scattering or haze which are designed to minimize the influence of path radiance effects

- These procedures are usually applied uniformly over the entire scene

- Most widely used procedures are:

  - **Dark pixel removal** - Studies areas with zero reflectance, like water, to see what brightness shifts have occurred.

  - **Linear regression** - Statistically compares the scattering in two bands, usually the blue (most scatterering) and mid ir (least scattering)

Radar Despeckling

- Radar imagery is particularly susceptible to the introduction of image noise called speckle (that occurs due to random interference of microwaves) which is responsible for the "grainy" appearance of SAR imagery

- Variety of image filters are used to remove these unwanted speckle effects

Radiance Conversion

- Pixel values in commercially available satellite imagery represent the radiance of the surface in the form of Digital Numbers (DN), (e.g. 256 levels) which are calibrated to fit a certain range of values

- DN are referred to as the brightness values

- Conversion of DN to **absolute radiance** values is a necessary procedure for comparative analysis of several images taken by different sensors (for example, Landsat-2 versus Landsat-5)

- Since each sensor has its own calibration parameters used in recording the DN values, the same DN values in two images taken by two different sensors may represent two different radiance values

- Usually, detectors are calibrated so that there is a linear relationship between DN and spectral radiance

- This linear function is described by three parameters:

- The range of DN values in the image. Mostly, the data is in 8-bit format corresponding to 256 DN levels

- The lowest (L_{min}) radiances measured by a detector over the spectral bandwidth of the channel

- The highest (L_{max}) radiances measured by a detector over the spectral bandwidth of the channel

- L_{min} is the spectral radiance corresponding to the minimum DN value (usually, value of 0)

- L_{max} is the radiance corresponding to the maximum DN (usually, value of 255)

- **Not only each sensor, but each band within the same sensor, has its own Lmin and Lmax**

- The specifications about sensor calibration parameters (L_{min} and L_{max}) are usually supplied with the data or is available elsewhere (e.g., Landsat Data User's Handbook)

- The equation relating DN in remotely sensed data to radiance is:

  $$\mathbf{L = (L_{max} - L_{min})/255*DN + L_{min}},$$ Eq. (1)

  where L is the the radiance expressed in (W m^{-2} sr^{-1})

- In this exercise two MSS images taken by different satellites will be compared

- At first, one image will be subtracted from another

- The resulting image will have values represented in DN

- Then, these images will be converted into absolute radiance images and perform image differencing on them

- The resulting image will have values represented in radiance units

- Finally, two difference images will be compared to see how the radiance conversion influences the results of change analysis.

<u>The Data Set</u>

- The data set consists of two infrared bands (0.8-1.1 micrometers) of MSS imagery

- First image, BAND475, was taken by Landsat-2 on December 12, 1975

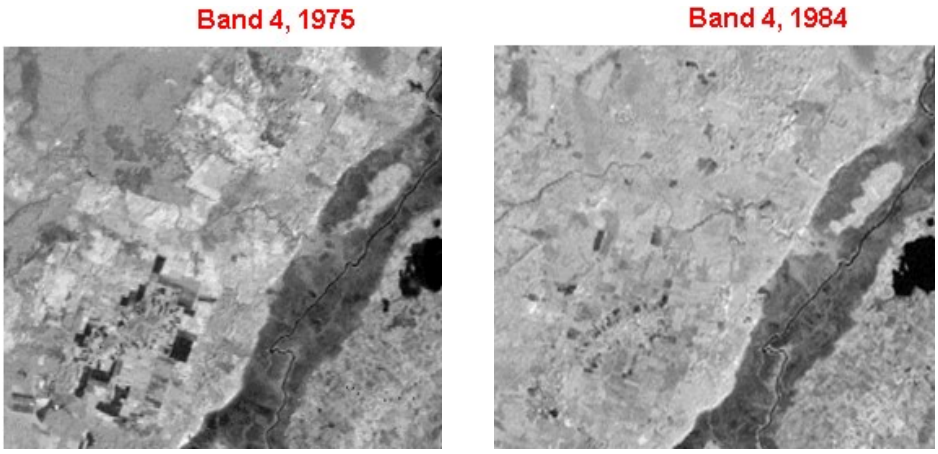
- The second, BAND484, by Landsat-5 on November 11, 1984

- Both images are georegistered and have the resolution of 60x60 meters

- The DN values in both images range from 0 to 255

Procedure

1) Simultaneously display BAND475 and BAND484 images



2) Subtract BAND484 from BAND475

The value of any pixel in this image corresponds to the difference in DN values for this pixel in BAND475 and BAND484

Calculate the mean value of the difference image

Now convert the DN values in the two bands into radiance units

For conversion, values of L_{min} and L_{max} for the satellites should be known

The following table lists these values for MSS band 4 for the two satellites:

Sensor	L_{min}	L_{max}
Landsat-2 MSS (on or after 07/16/75)	0.6	15.2
Landsat-5 MSS (on or after 11/9/84	0.3	12.3

Using these values in the conversion equation (1) above, absolute radiance values for each pixel in the two images can be calculated

For the first image (BAND475) the equation will be in this form:

$L_1 = (15.2-0.6)/255*BAND475 + 0.6$ Eq. (2)

i.e.

$L_1 = 0.0572549 * BAND475 + 0.6$ Eq. (3)

Similarly, for the second image (BAND484) the equation can be written as:

L_2= (12.3-0.3)/255 * BAND484 + 0.3 Eq. (4)

i.e.

L_2 = 0.0470588 * BAND484 + 0.3 Eq. (5)

3) Using equations (3) and (5), convert BAND475 and BAND484 into radiance images RAD475 and RAD484

4) Examine the range of values in RAD475 and RAD484 images which represent the absolute radiance values

   Notice that the radiance values are real numbers, while the DN values in BAND475 and BAND484 are integers.

5) Subtract RAD484 from RAD475

   Calculate the mean value of this image (difference of the radiance)

Observations

- Mean value in both difference images is not zero
- This suggests that there is an overall change between the two dates
- In the case of the difference image between the DN images, the mean is less than zero (-10.3086) suggesting that there was an overall negative change in reflectance values in the area
- In the case of the difference image between the radiance images, however, the mean is above zero (0.2303) suggesting that there was an overall positive change in reflectance values in the area
- So, which of the two conclusions correspond to reality? The latter, because it is based on the comparison that takes into account the difference in calibration parameters of the satellites, while the former assumes no difference in satellites between the two time periods.
- Conclusion: This example illustrates that conversion of DN values to absolute radiance is an important step in quantitative analysis of change when satellite data from different time periods are employed

Geometric Correction of Remotely Sensed Data

- Geometric errors in the digital images collected from airborne or spaceborne sensors:
  - Systematic geometric errors
  - Unsystematic geometric errors

- **Systematic Errors:**

- Scan Skew: Caused by the forward motion of the platform during the time required for each mirror sweep. The ground swath is not normal to the ground track but is slightly skewed, producing cross-scan geometric distortion

- Mirror-Scan Velocity Variance: The mirror scanning rate is usually not constant across a given scan, producing along-scan geometric distortion

- Platform Velocity: If the speed of the platform changes, the ground track covered by successive mirror scans changes, producing along-track scale distortion

- Earth Rotation: Earth rotates as the sensor scans the terrain. This results in a shift of the ground swath being scanned, causing along-scan distortion

- **Nonsystematic Errors**

  - Altitude Variance: If the sensor platform departs from its normal altitude or the terrain increases in elevation, this produces changes in scale

  - Platform Attitude: One sensor system axis is usually maintained normal to Earth's surface and the other parallel to the spacecraft's direction of travel. If the sensor departs form this attitude, geometric distortion results

- Errors like scan skew, mirror-scan velocity variance, platform velocity can be corrected by using ephemeris (any tabular statement of the assigned places of a celestial body for regular intervals. E.g., the solar ephemeris provides the exact location of the sun at any given time of the day or year) of the platform and known sensor distortion characteristics

- Altitude Variance and Platform Attitude Errors can be corrected by matching image coordinates of physical features recorded by the image to the geographic coordinates of the same features collected from a map or global positioning system (GPS)

Definition of some geographic correction terms

- Ground Control Point (GCP): A specific pixel on an image or location on a map whose geographic coordinates are known. GCP's are used to correct geometric distortion in an image by matching image coordinates with map coordinates. Image and map coordinates are used to compute the transformation matrix for use in rectifying the image

- Linear Transformation: The transformation of coordinates from one system to another (image to map) using a linear algebraic (1st order polynomial) formula

- Non-Linear Transformation: The transformation of coordinates from one system to another (image to map) using a non-linear algebraic (n^{th} order polynomial) formula

- Rectification: The process by which the geometry of an image is made planimetric

- Registration: The process of geometrically aligning two or more sets of image data such that resolution cells for a single ground area can be digitally or visually superimposed

- Resampling: The process of extrapolating data values to a new grid. Resampling is the step in rectifying an image that calculates pixel values for the rectified grid from the original data grid

- Root Mean Square Error (RMS):The RMS Error is the error term used to determine the accuracy of the transformation from one coordinate system to another

Image to Ground Geocorrection

The correction of digital images to ground coordinates using ground control points collected from maps or ground GPS recognaisance.

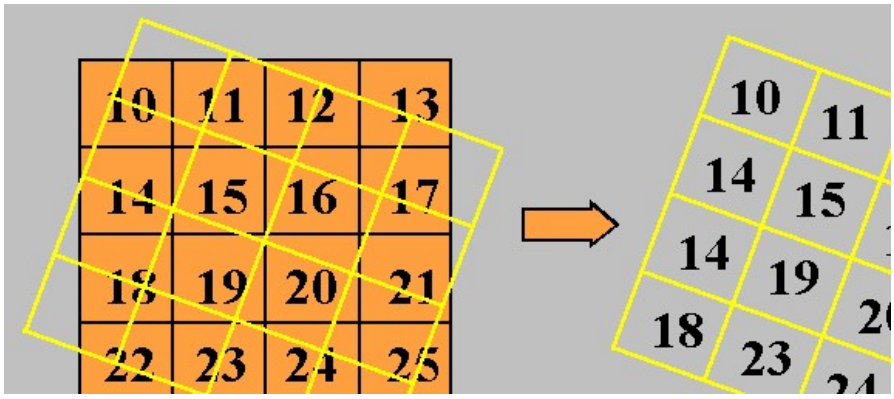
Image to Image Geocorrection

Image to Image correction involves matching the coordinate systems of two digital images with one image acting as a reference image and the other as the image to be rectified.

<u>Image Resampling Methods:</u>

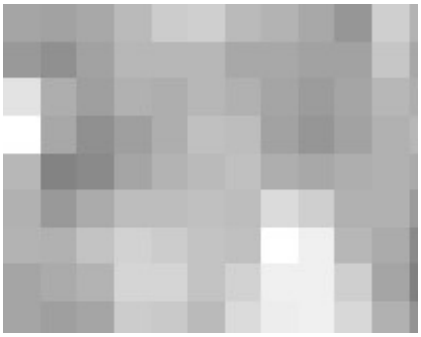
1. Nearest Neighbour Resampling Method

- Nearest neighbour approach uses the value of the closest input pixel for the ouput pixel value. An example:

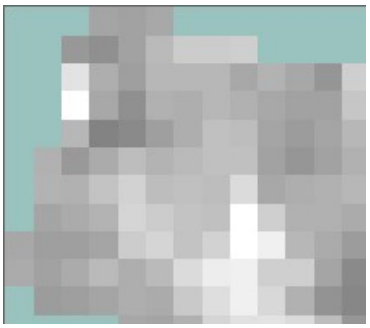


In the above figure:

- Input file (orange) is superimposed with the output file (yellow)
- Input values closest to the center of each output cell are sent to the output file to the right
- Notice that values 13 and 22 are lost while values 14 and 24 are duplicated
- This loss of data may result in breaks in linear features such as roads, streams, and boundaries



Unrectified raster image



Rectified using nearest neighbour resampling

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	66

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0				55	59	63							
1			56	54	60	69	73	73	69				
2			81	64	61	67	65	62	59	60	58	58	75
3			85	60	56	64	62	66	64	60	57	59	73
4			61	51	57	60	63	72	69	61	56	57	67
5		62	62	70	71	66	69	70	70	61	58	61	66
6		66	69	74	75	68	70	69	83	65	65	63	67
7		60	63	69	75	72	71	71	95	76	61	63	64
8	58	58	58	61	71	75	72	74	95	85	64	61	58
9	58	59	61	62	61	68	74	79	81	71	71	58	52
10		58	57	59	61	63	70	80	81	76	66	59	53

Brightness value matrix of nearest neighbour resampled image





- To determine the nearest neighbor, the algorithm uses the inverse of the transformation matrix to calculate the image file coordinates of the desired geographic coordinate

- The pixel value occupying the closest image file coordinate to the estimated coordinate will be used for the output pixel value in the georeferenced image

Advantages of Nearest Neighbour Resampling Method:

- Output values are the original input values. Other methods of resampling tend to average surrounding values

- Easy to compute, thus fastest to use

Disadvantages of Nearest Neighbour Resampling Method:

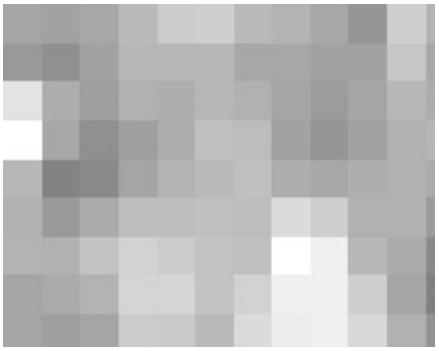
- Produces a choppy, "stair-step" effect. The image has a rough appearance relative to the original unrectified data

- Data values may be lost, while other values may be duplicated

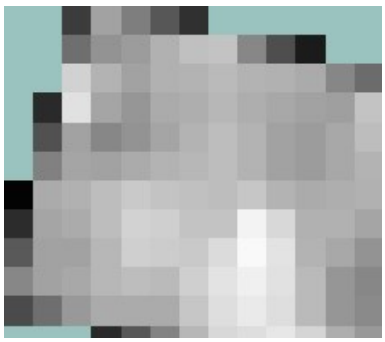
2. Bilinear Interpolation Resampling Method

- Bilinear interpolation approach uses the weighted average of the nearest four pixels to the output pixel

- İ.e. the brightness values from four pixels (those to the right, left, above and below the spot where the new pixel is to be created) are added, then the sum is divided by four to create the new brightness value



Unrectified raster image



Rectified using nearest Bilinear Interpolation

- Notice the dark edge cells created by averaging zero values located around the perimeter of the ouput file into real data values

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	66

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0			21	56	47	33	17						
1			40	55	58	65	70	68	45	26	9		
2			74	66	61	65	65	63	61	60	59	50	41
3		14	76	60	58	62	62	66	62	60	57	59	71
4		28	58	54	59	62	66	70	66	60	56	59	69
5		46	63	66	67	66	68	70	67	61	60	63	66
6	1	62	68	73	73	70	70	69	74	69	65	64	65
7	16	60	64	71	75	73	71	72	89	78	62	63	61
8	31	58	59	66	73	73	73	77	87	80	63	60	55
9	46	59	60	63	66	67	72	77	81	76	65	56	52
10	25	41	55	60	62	63	69	78	80	78	68	58	55

Brightness value matrix of Bilinear Interpolation resampled image





Advantages of bilinear interpolation resampling:

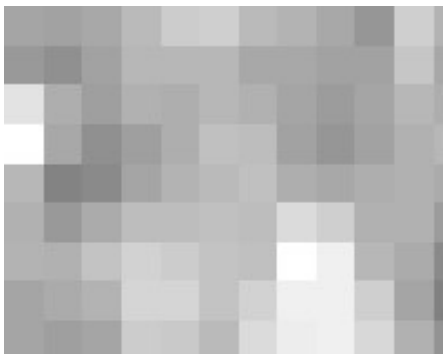
- Stair-step effect caused by the nearest neighbor approach is reduced
- Image looks smooth

Disadvantages of bilinear interpolation resampling:

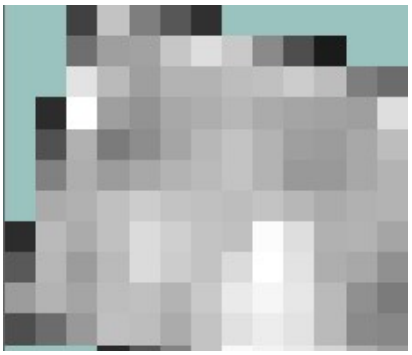
- Alters original data and reduces contrast by averaging neighboring values together
- Computationally more expensive than the nearest neighbour

3. Bicubic Convolution Resampling Method

- In the bicubic convolution case, **a distance-weighted average** of the 16 nearest old cells is assigned to the new cell
- The corresponding brightness values are added and then averaged
- Averaging can also be on weighted basis giving preference for the predominant brightnesses
- The output is similar to bilinear interpolation, but the smoothing effect caused by the averaging of surrounding input pixel values is more dramatic



Unrectified raster image



Rectified using bicubic convolution resampling

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	68

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0			23	66	47	33	17						
1			41	60	60	74	81	69	45	25	9		
2			79	68	61	65	65	64	65	68	64	48	41
3		14	86	58	57	62	62	65	61	61	57	59	82
4		26	63	51	57	62	67	72	66	59	55	59	70
5		45	67	65	67	67	68	71	66	59	59	63	67
6		62	69	74	75	70	70	68	73	70	65	64	66
7	16	67	63	72	76	73	71	71	93	81	62	63	62
8	30	65	58	67	76	73	72	77	92	80	61	61	54
9	52	65	60	64	66	66	71	77	81	79	64	53	49
10	27	41	55	67	68	64	68	78	81	80	67	55	54

Brightness value matrix of bicubic convolution resampled image





Advantages of the bicubic convolution resampling method:

- Stair-step effect caused by the nearest neighbor approach is reduced. Image looks smoother

Disadvantages of the bicubic convolution resampling method:

- Alters original data and reduces contrast by further averaging neighboring values
- Computationally more expensive than nearest neighbor or bilinear interpolation

Geometric Restoration Exercise:

1) Merging Data with Varying Resolutions

- Merging of different data sets is often used in digital image processing to improve the visual and analytical quality of the data
- It may be needed to merge different types of data, such as:
  - Satellite imagery from the same sensor but with different resolution (e.g. SPOT 10x10 m panchromatic (black,white) data with SPOT 20x20 m multispectral data)
  - Satellite imagery from different sensors with varying resolution (e.g. Landsat 30x30m TM data and Landsat 79x79m MSS data)
  - Digitized aerial photography and satellite imagery (e.g. aerial photography with 15x15m resolution and SPOT 20x20 m multispectral data)
  - Satellite imagery with ancillary information (e.g. Landsat 30x30 m TM color composite and 70x70 m Digital Elevation Model)
- Before merging can be done, the initial data need to be processed to have:
  i) The same reference system
  ii) The same resolution
  iii) The coverage of the same geographical area (the same minimum and maximum x and y-coordinates)

- First, the images have to be accurately georegistered to the same reference system and to one another

- Then the common geographical area between the two images has to be determined and extracted (windowed) from the original images so that the resulting windows have the same minimum and maximum X and Y coordinates

- Finally, the images have to be transformed to have the same dimensions and resolution

- This usually can be done via resampling

- In cases when the ratio between the number of rows (columns) in one image and the number of rows (columns) in the other image is an integer number, then the image with coarser resolution can be expanded by this integer number to match the dimension of the other image

- Both resampling and the latter procedure will automatically calculate the new cell resolution

- Some of the other alternatives for data merging:

  - Color space transformation and substitution method
  - Simple band substitution
  - Principle component substitution
  - Band-by-band merging (via addition)

Geometric Restoration Exercise:

2. Image-to-Image Geocorrection

- Geometric correction is used for a variety of operations like:

  - Referencing an unreferenced or arbitrarily referenced image to a universally recognized coordinate reference system such as Lat/Long or Universal Transverse Mercator (UTM)
  - Co-registering multiple images that were collected at different times or from different sources for the purpose of change analysis
  - Making non-integer changes in the resolution of an image.

<u>Image rectification and registration procedure:</u>

1. Identify x, y-coordinates of several pairs of points (called ground control points) that represent the same places within both the old and new coordinate systems

   The coordinates of the new system may be taken from:
   - A map
   - Another already georeferenced image

- A vector file
- Through surveying either with traditional instruments or with GPS

2. Solve the equations that describe the relationship between the two coordinate system (using the ground control points information) to produce two equations for the conversion of the X and Y coordinates from the "old" reference system to the "new" one

3. Using these equations, convert the entire image to the new reference system through transformation process including both:

   - Spatial interpolation (e.g., coordinate transformation) and

   - Intensity interpolation (e.g., pixel brightness transformation).

The Data Set

- In this exercise, one satellite image will be registered to another

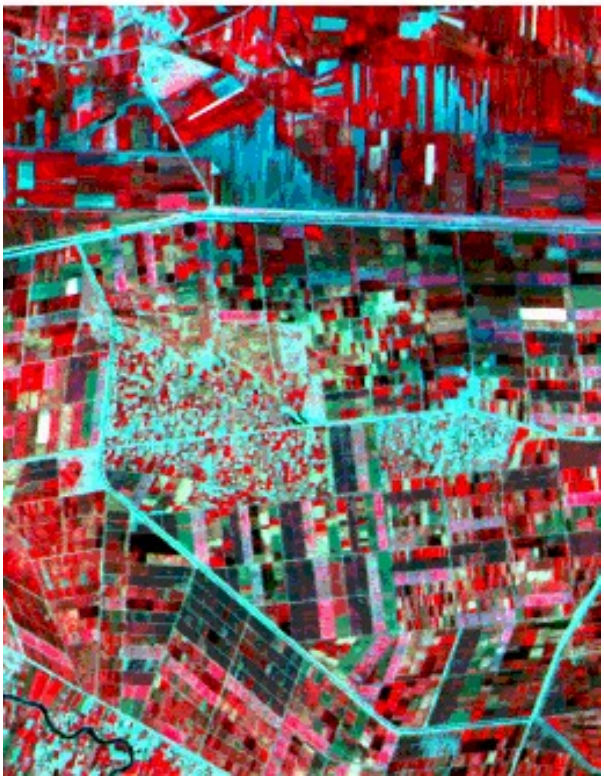
- Both of the images are false color composite images derived from SPOT multispectral images. The images are MAY (taken on May 10, 1986) and JUNE (June 13, 1986)

Procedure

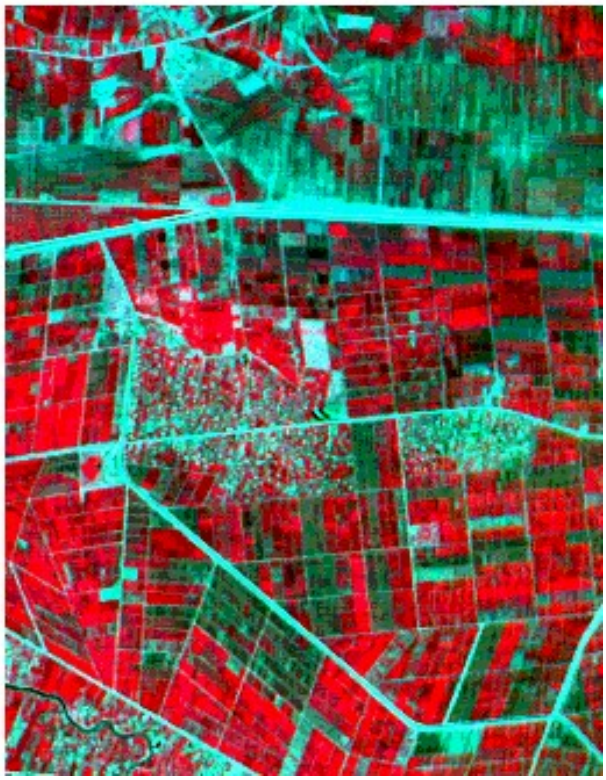
1. Examine the images JUNE and MAY simultaneously

   Select a prominent road intersection and examine its x and y coordinates on both images

May image



June image



- You will notice that the images differ slightly in position and orientation. To be able to analyze changes between these images, first we have to make sure that the corresponding pixels of each image actually describe the same location on the ground

- Registering these images is done using a process known as rubber sheet resampling

- Consider the JUNE image to be the reference image and register the MAY image to it

- As the first step in the registration procedure, find the points that can be easily identified within both images

- Places that make good control points include road and river intersections, dams, airport runways, prominent buildings, mountain ridges or any other obvious physical feature

- x, y-coordinates of these points in the JUNE image will be the "new" coordinate pairs while the coordinates from the MAY image will be the "old" coordinate pairs

- Two issues are critical during this phase of the process:

  i) Obtaining a good distribution of control points

  - Points should be spread evenly throughout the image because the equation that describes the overall spatial fit between the two reference systems will be developed from these points

  - If the control points are clustered in one area of the image then the equation will only describe the spatial fit of that small area and the rest of the image will not be accurately positioned during the transformation to the new reference system

  - A rule of thumb is to try to find points around the edge of the image area

  - However, if you are only interested in part of the image then you may concentrate all the points in that area and then window out that area during resampling

  ii) Recording the confidence of positional accuracy

  - While locating points, draw a small sketch of the area, mark each control point position on the sketch with an identifier and record your level of confidence in the positional accuracy of each of the points (e.g., poor, fair, good)

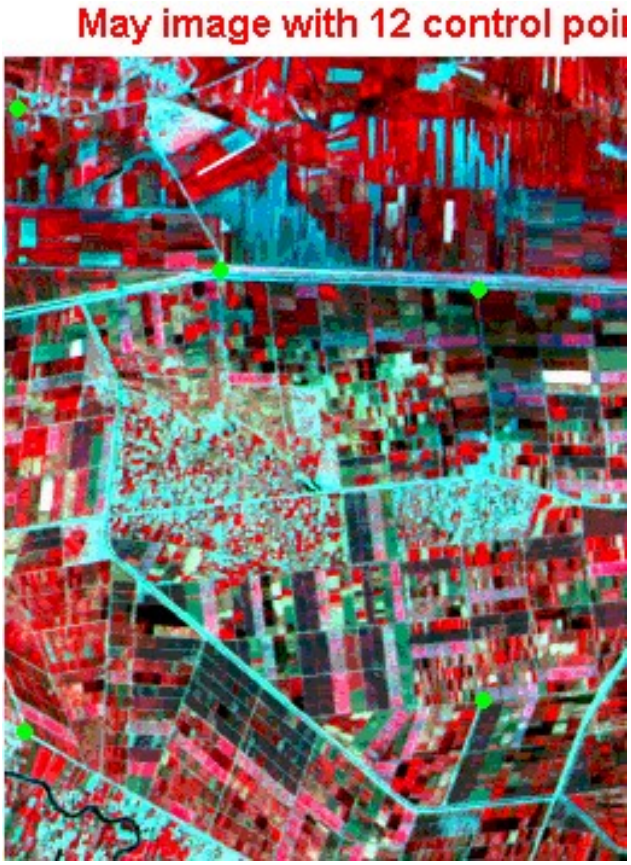
  - In the resampling process, it will be possible to omit points from the equation that don't fit the equation well

  - In order to retain a good distribution and high confidence in the remaining control points, remember their positions in the image and their relative positional accuracy

2. Find 10 -12 control points that may be precisely located and are well distributed around the image

Record the x and y-coordinates of each control point in both images

3. Display the MAY image and overlay the control points on top of the image (as seen below the control points are uniformly distributed around the image)

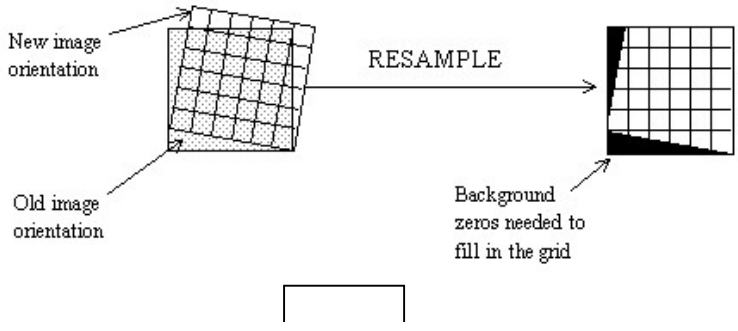


In the next step, the best fit equation between the two images will be calculated.

4. Apply resampling. Specify MAY as the input image to be resampled

5. Specify 0 as background value

A background value is necessary because after fitting the MAY image to the JUNE image, the actual shape of the data may be angled. In this case, some value needs to be put in as a background value to fill out the grid. The value zero is a common choice. This is illustrated in the below Figure



6. Select the geographic region that covers the output image

   To define the area of interest, specify the bounding rectangle by fixing minimum and maximum x and y's which are taken from the JUNE image as:

   Min x = 3840
   Max x =10240
   Min y = 1220
   Max y = 9620

7. Determine the number of columns and rows for the output image

   In some cases it is assumed that the cell resolution will remain the same and the number of rows and columns are calculated automatically

   In other cases, the resolution of the output image is changed and the number of rows and columns are found accordingly

   Number of columns for the new image is calculated using the following equation:

   # Columns = (Max x - Min x) / Resolution

   In this exercise, 20 meter resolution for the output image will be kept

   Thus # columns in the new image = (10240 - 3840) / 20 = 320.

   Similarly, the number of rows for the new image is found as

   # Rows = (Max y - Min y) / Resolution = 420

8. Apply resampling, either bilinear and nearest neighbor resampling

   Process of image-to-image registration is like laying the new image in its correct orientation on top of the older image

   Values are then estimated for each new cell by looking at the corresponding cells underneath it in the old image

   One of following three basic logics can be used for the estimation:

   i) Nearest neighbour rule: The nearest old cell (based on cell center position) is chosen to determine the value of the new cell. Nearest neighbor resampling should be used when the data values cannot be changed, e.g, with categorical data or qualitative data such as soils types

   ii) Bilinear interpolation: A distance weighted average of the four nearest old cells is assigned to the new cell. The bilinear interpolation is appropriate for quantitative data such as remotely sensed imagery

   iii) Bicubic convolution: A distance weighted average of the 16 nearest old cells is assigned to the new cell. Bicubic convolution is appropriate for quantitative data such as remotely sensed imagery

9. Fix the order of polynomial fit desired for the mapping function:

   - Linear (first order) or,
   - Quadratic (second order) or,
   - cubic (third order)

   For this exercise select the linear function

   The linear mapping function is commonly used with images about this size or smaller

   Higher-order mapping functions (quadratic and cubic) are used with larger images

   A minimum number of control points are required for each of the mapping functions:

   - 3 for linear
   - 6 for quadratic
   - 10 for cubic

   In this exercise, the number of points found (12) better reflects the quantity that should be found for the surface area of MAY with the linear mapping function

10. Calculate the total root mean square (rms) error of the control points and the individual residual errors of each control point

    These residuals express how far the individual control points deviate from the best fit equation

    Best fit equation describes the relationship between the image's reference system and the new reference system into which it will be resampled

    This relationship is calculated from the control points. A point with a high residual suggests that the point's coordinates were ill chosen, in either the "old" system, the "new" system, or both

    Total rms describes the typical positional error of all the control points in relation to the equation. It describes the probability that a mapped position will vary from the true location

    According to some map accuracy standards, the rms for images should be less than 1/2 the resolution of the input image

    In this case, rms should be less 10 m

11. View the residual errors of all the control points

    Some points have higher residuals than the others which is not unexpected or uncommon

It is not always easy to know which pixel to pick for a control point or whether to pick the cell center or one of its edges

Bad points can be omitted, a new equation can be calculated

Before omitting points, maintain a good distribution of points and retain those points in which you have the highest confidence

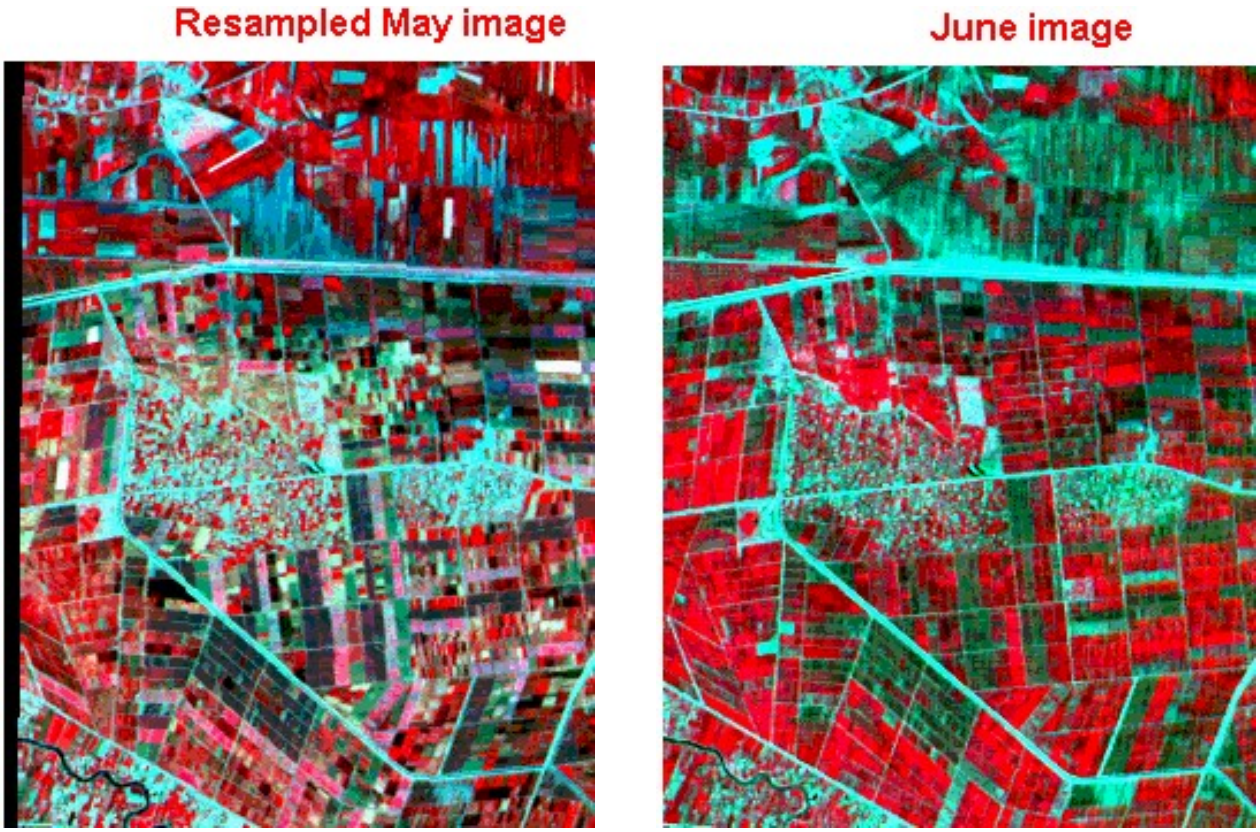
While those points with a very high rms value tend to be poor, this is not always the case

Few bad points in another part of the image can "pull" the equation and make one good point appear bad

12. When the setting of control points and the overall rms (less than 10) are satisfactory, calculate the transformation equation and complete the resampling process

    Transform the entire image into the new reference system according to the equation

13. Display and examine the resampled MAY image as a false color composite image



Now these two images (Resampled MAY image and JUNE image - are coregistered and can be used for any type of change analysis.

Resampling can be time-consuming, however, the level of care with which it is done affects subsequent analyses that use the registered data