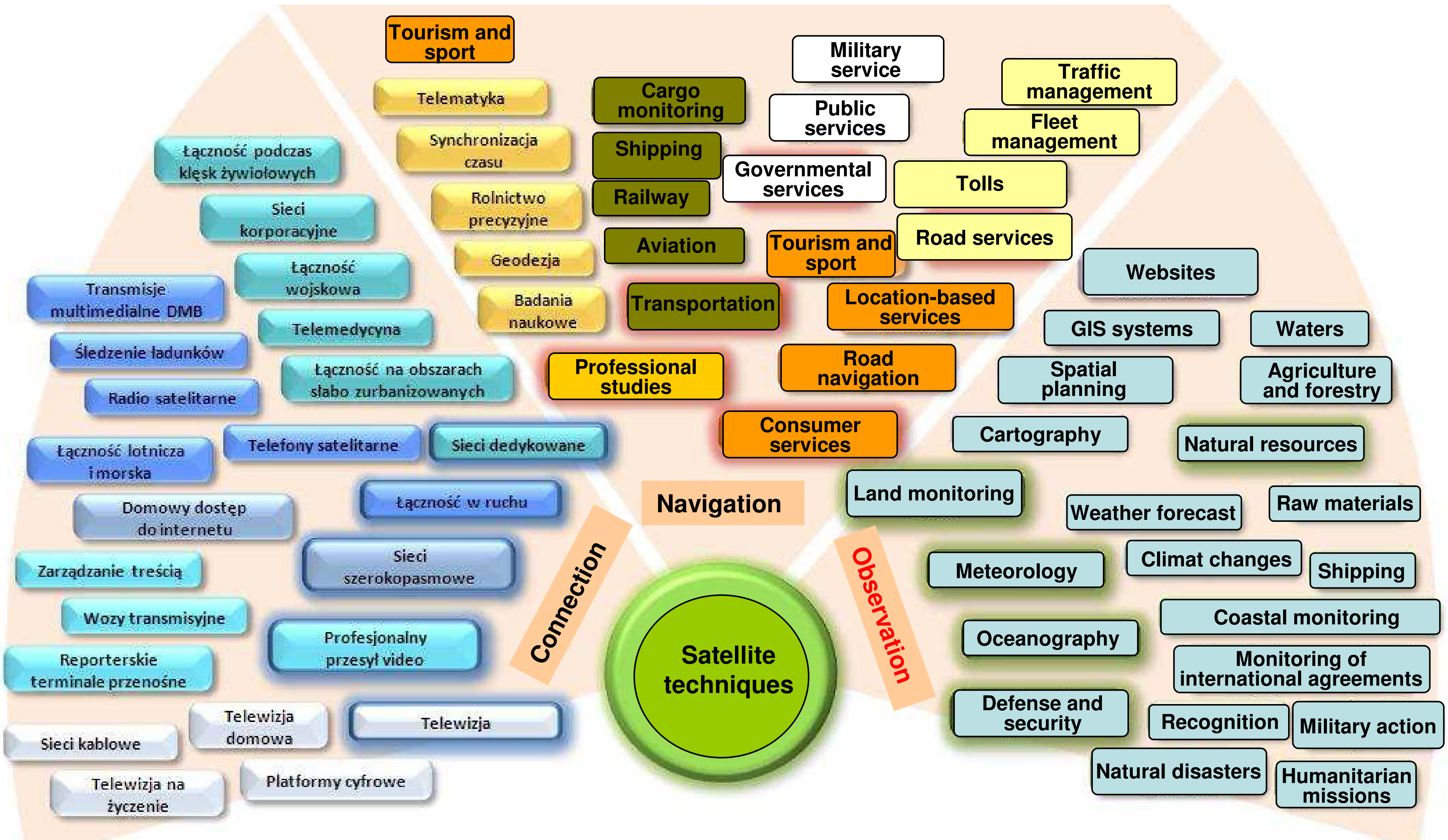
Remote Sensing
Multi & Hyperspectral Systems

Multispectral Remote Sensing systems



Treść i układ za opracowaniem Euroconsult 2008 ze zmianami

Multispectral Remote Sensing systems

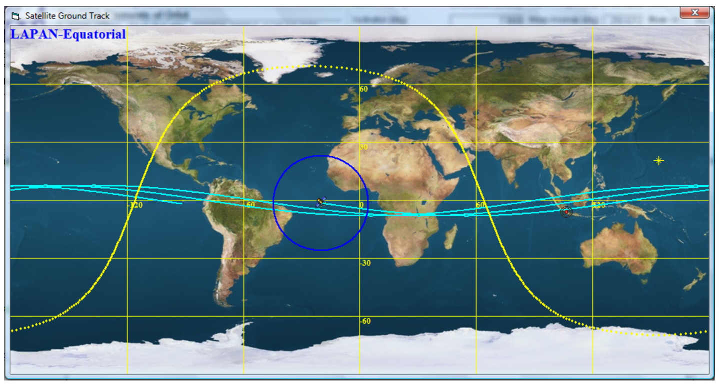
Earth satellite orbits

LEO – low Earth orbit
160 – 2000 km above the Earth's surface

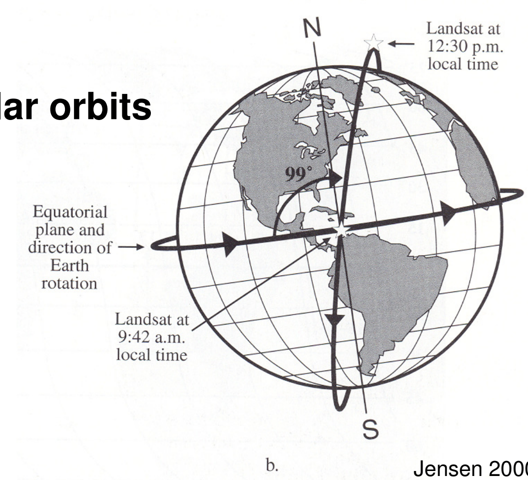
MEO – medium Earth orbit
from 2 000 to 35 786 km

Geostationary Orbit
35 786 km

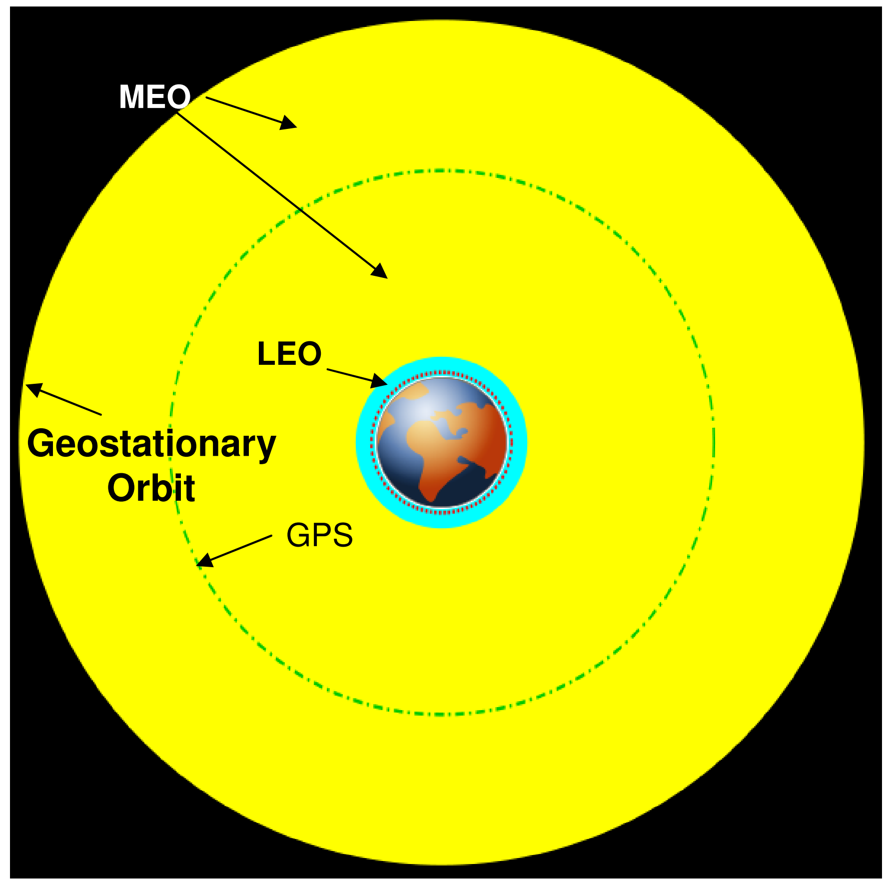
Equatorial low Earth orbits (ELEO)
Low Inclination LEO



Polar orbits



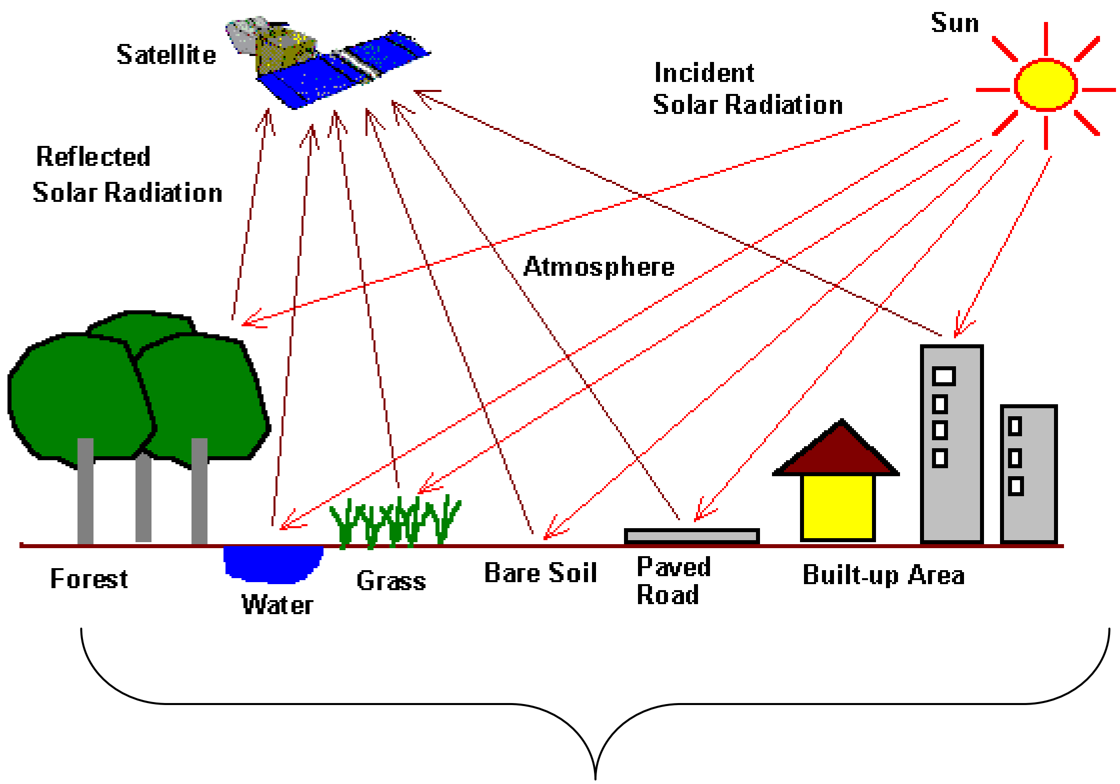
Jensen 2000



Aronoff 2005

Multispectral Remote Sensing systems

Multispectral Remote Sensing – collection of reflected, emitted or backscattered energy from an object and area of interest in multiple bands (regions) of the electromagnetic spectrum.



Objects

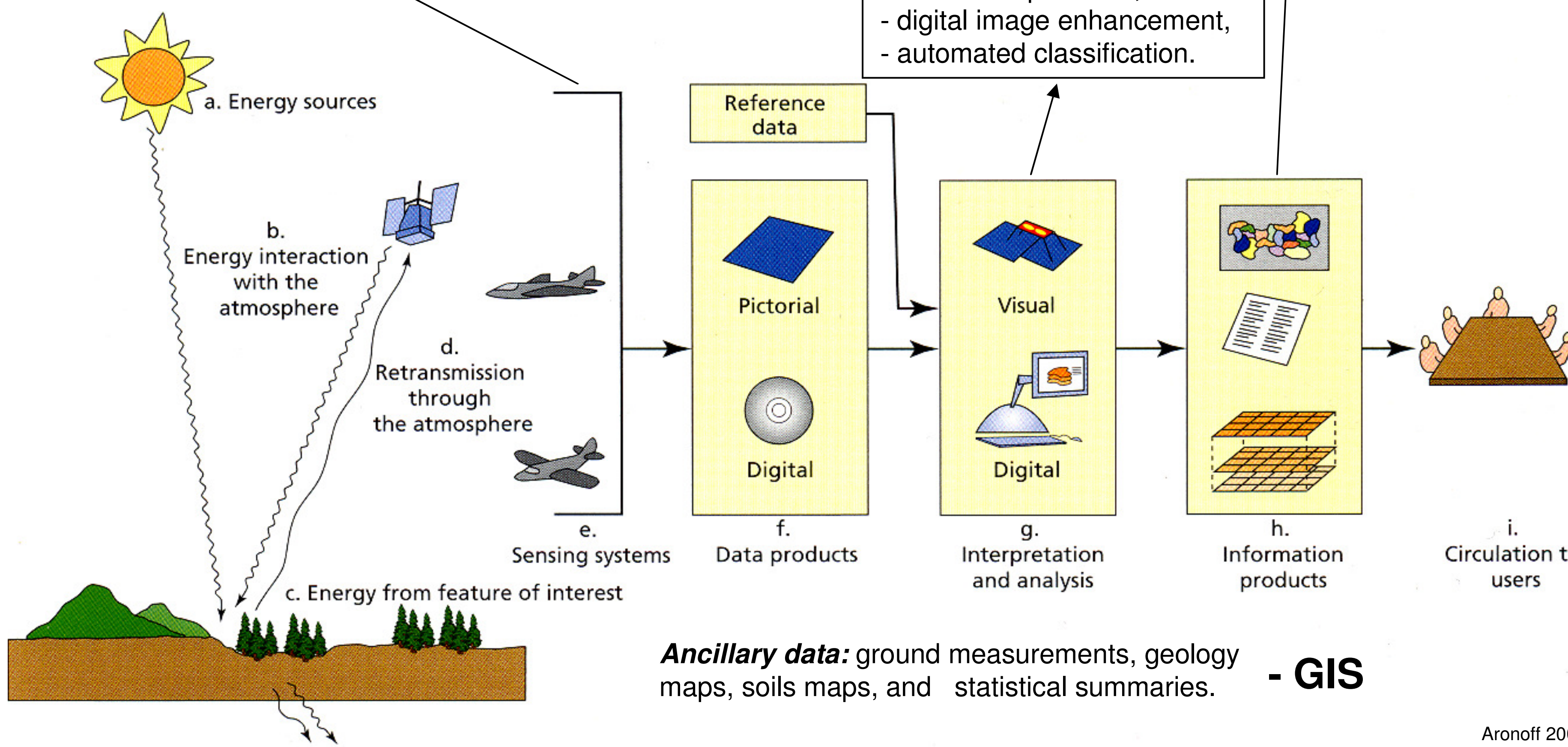
categorized by: - class or type, - substance, - spatial distribution

Multispectral Remote Sensing systems

Sensor systems:
- film (photography),
- electronic detectors (scanners, digital cameras, etc.),
- antennae (radar).

Information products:
- photographic images,
- digital images,
- image mosaics (multiple images combined to cover areas larger than a single image),
-and image maps.

Analysis techniques:
- visual interpretation,
- digital image enhancement,
- automated classification.

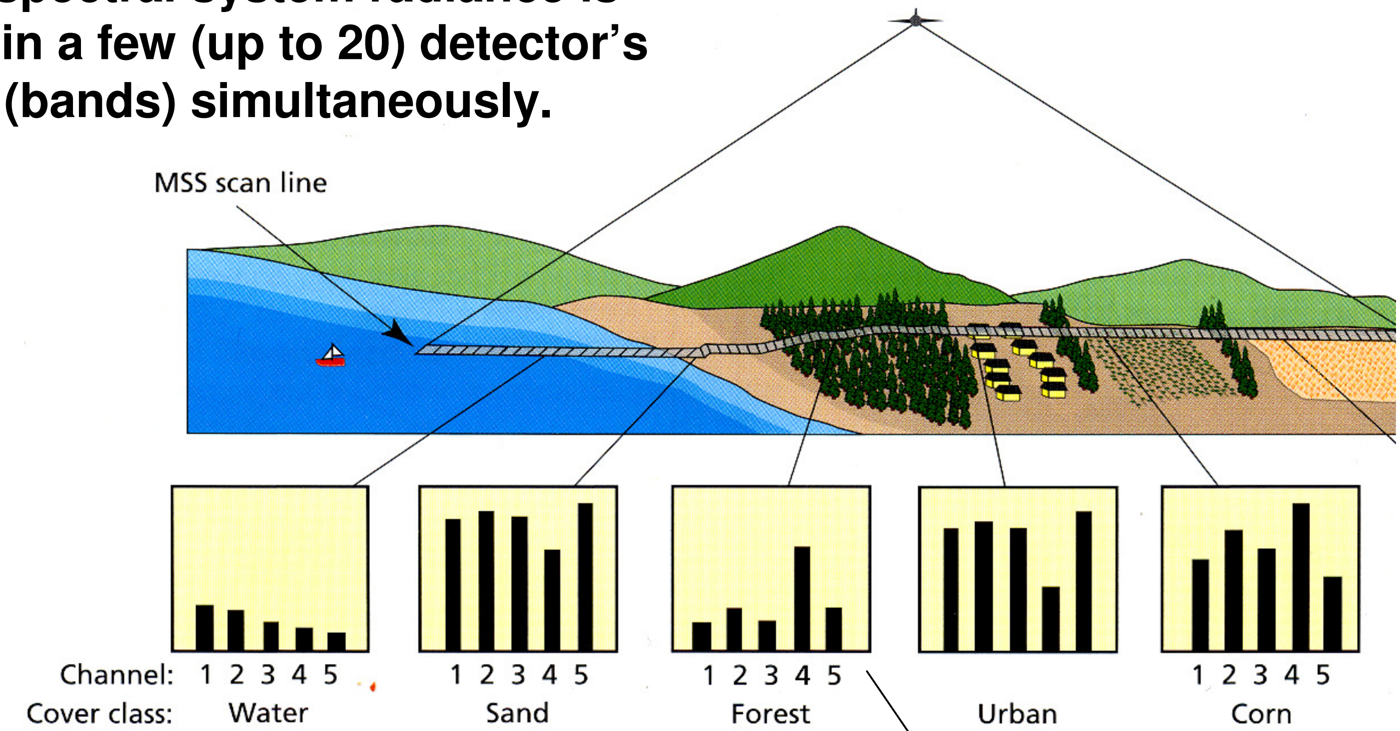


Ancillary data: ground measurements, geology maps, soils maps, and statistical summaries. **- GIS**

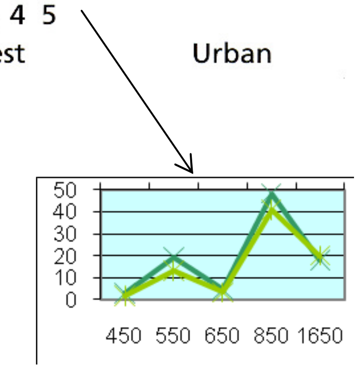
Aronoff 2005

Multispectral Remote Sensing systems

In a multispectral system radiance is recorded in a few (up to 20) detector's channels (bands) simultaneously.

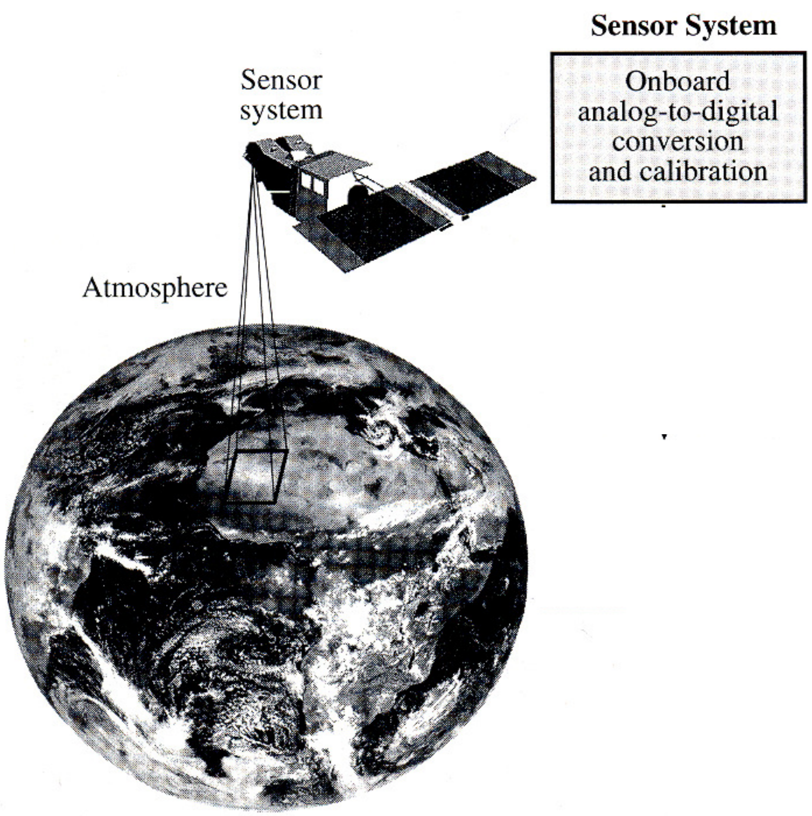


Channels: 1 – blue (420 – 460 nm)
2 – green (490 – 530 nm)
3 – red (650 – 760 nm)
4 – near-infrared (780-1300 nm)
5 – thermal



Aronoff 2005

Multispectral Remote Sensing systems



Jensen 2000

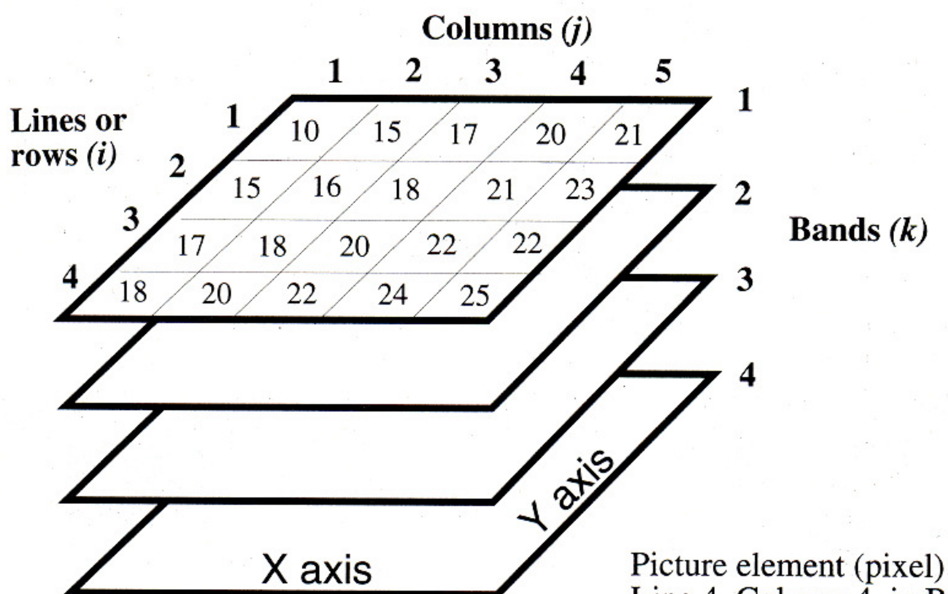
Multispectral Remote Sensing systems

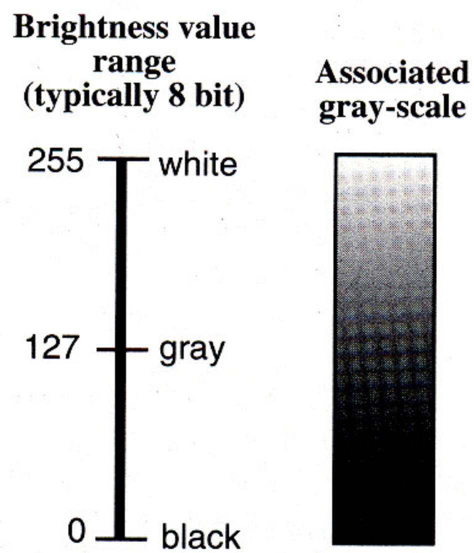
Pixel - a two-dimensional picture element that is the smallest non-divisible element of a digital image.

Quantization - the analog-to-digital conversion which creates pixels with various brightness values.

8 bits: brightness values 0 - 255

12 bits: 0 - 1023

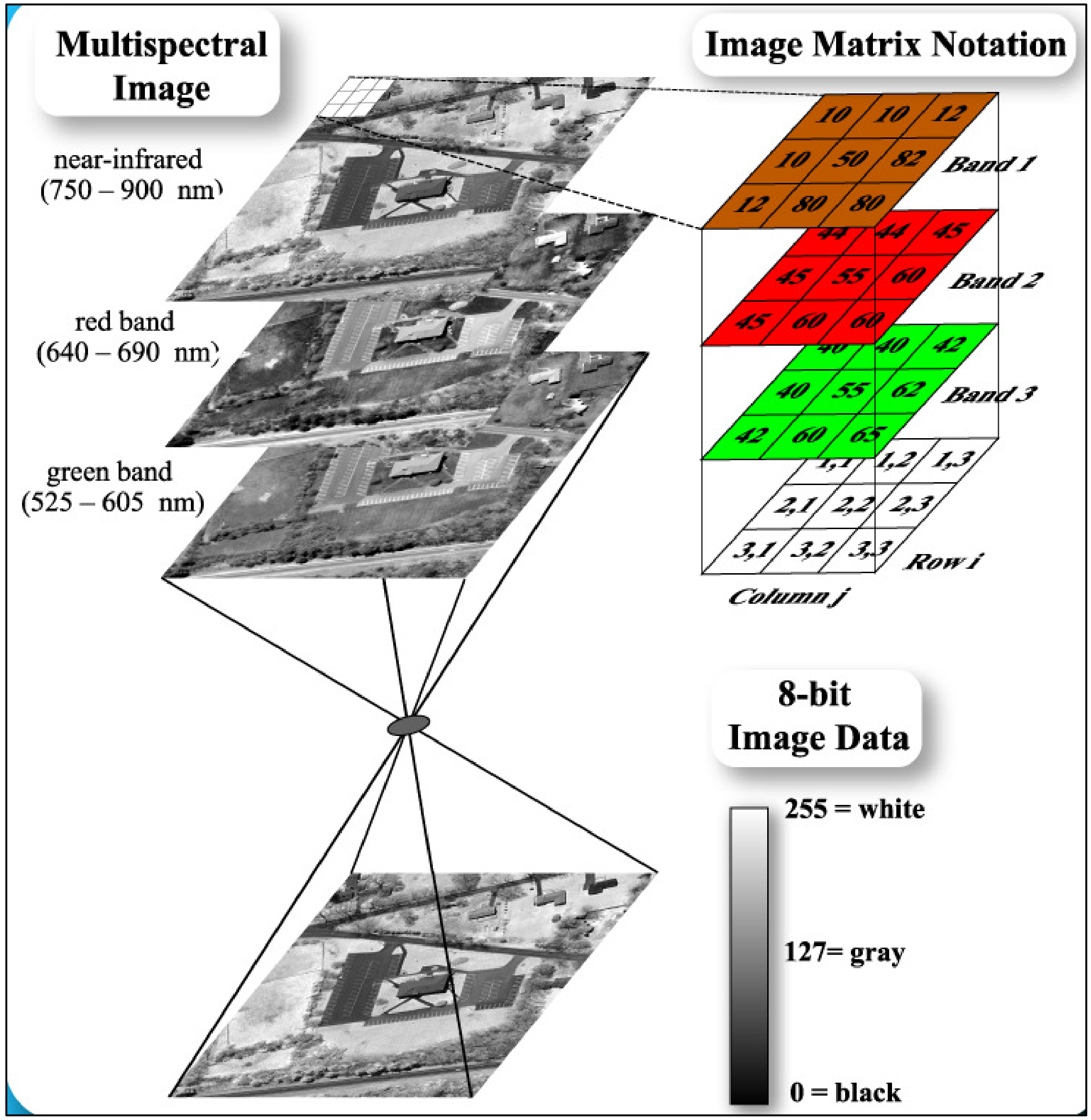




Picture element (pixel) at location Line 4, Column 4, in Band 1 has a Brightness Value of 24, i.e., $\mathbf{BV}_{4,4,1} = \mathbf{24}$.

Jensen 2000

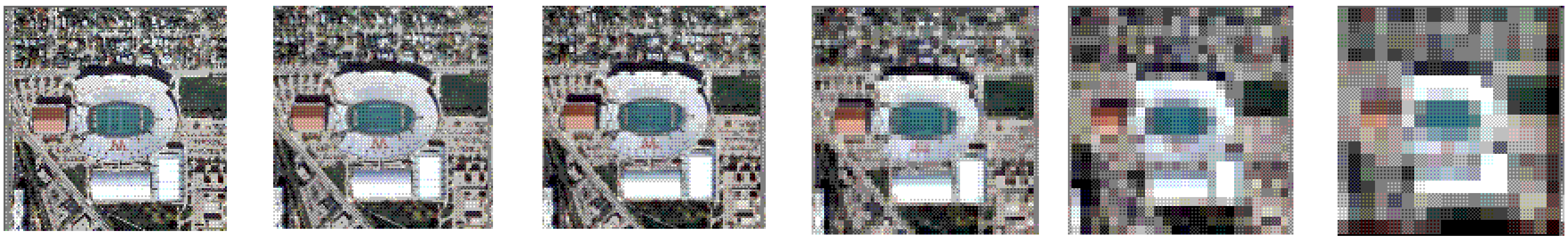
Multispectral Remote Sensing systems



Multispectral Remote Sensing systems

Detector characteristics: resolutions

Spatial resolution is a measure of the smallest object that can be resolved by the sensor, or the linear dimension on the ground represented by each pixel or grid cell in the image



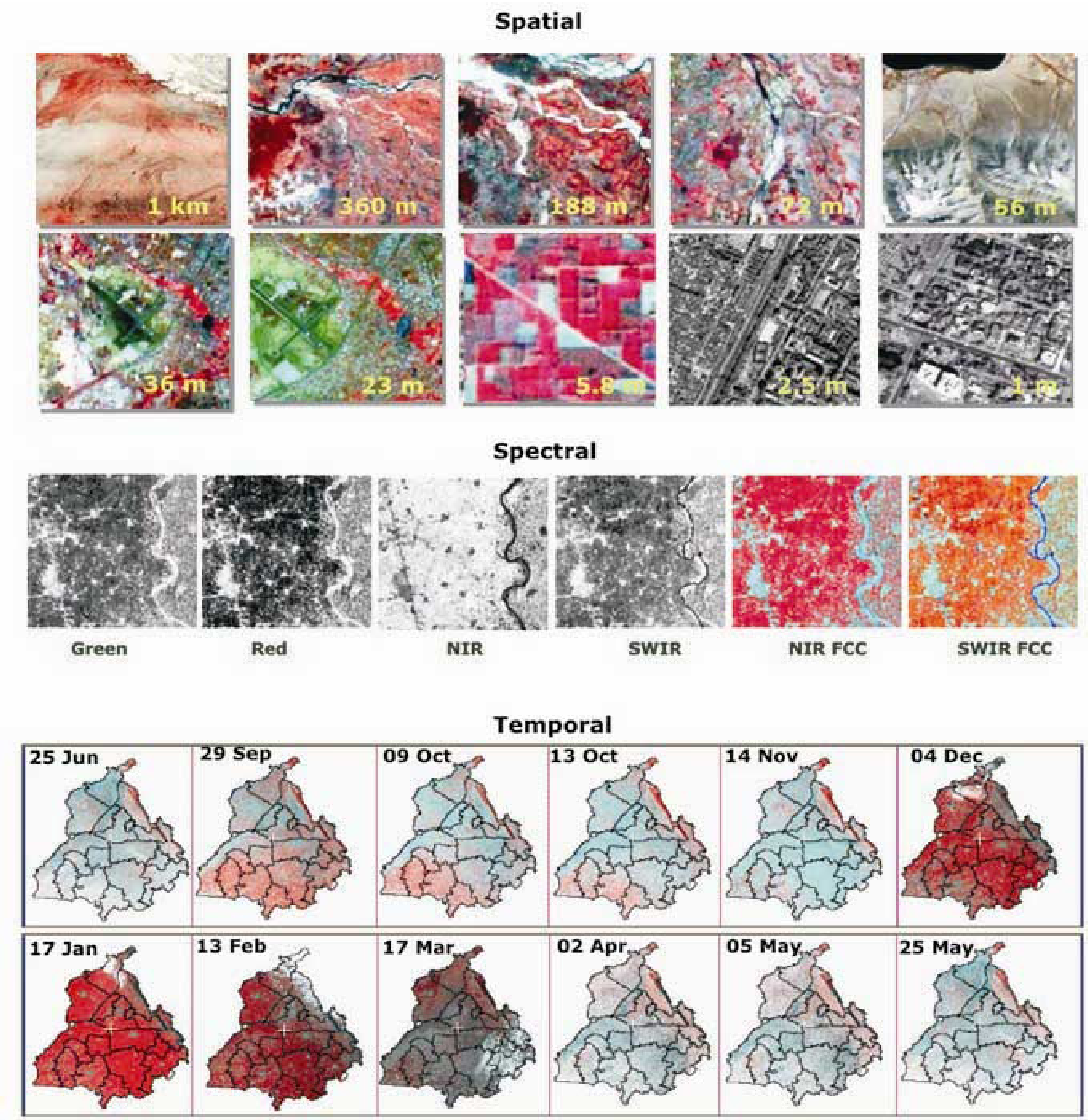
1 m 2 m 5 m 10 m 20 m 30 m

Spectral resolution describes the specific wavelengths that the sensor can record within the electro-magnetic spectrum (e.g. MSS band 1 420-460 nm – spectral resolution=40 nm.

Temporal resolution is a description of how often a sensor can obtain imagery of a particular area of interest (mostly in days).

Radiometric resolution refers to the number of possible brightness values in each band of data and is determined by the number of bits into which the recorded energy is divided. In 8-bit data, the brightness values can range from 0 to 255 for each pixel (256 total possible values). In 7-bit data, the values range from 0 to 127.

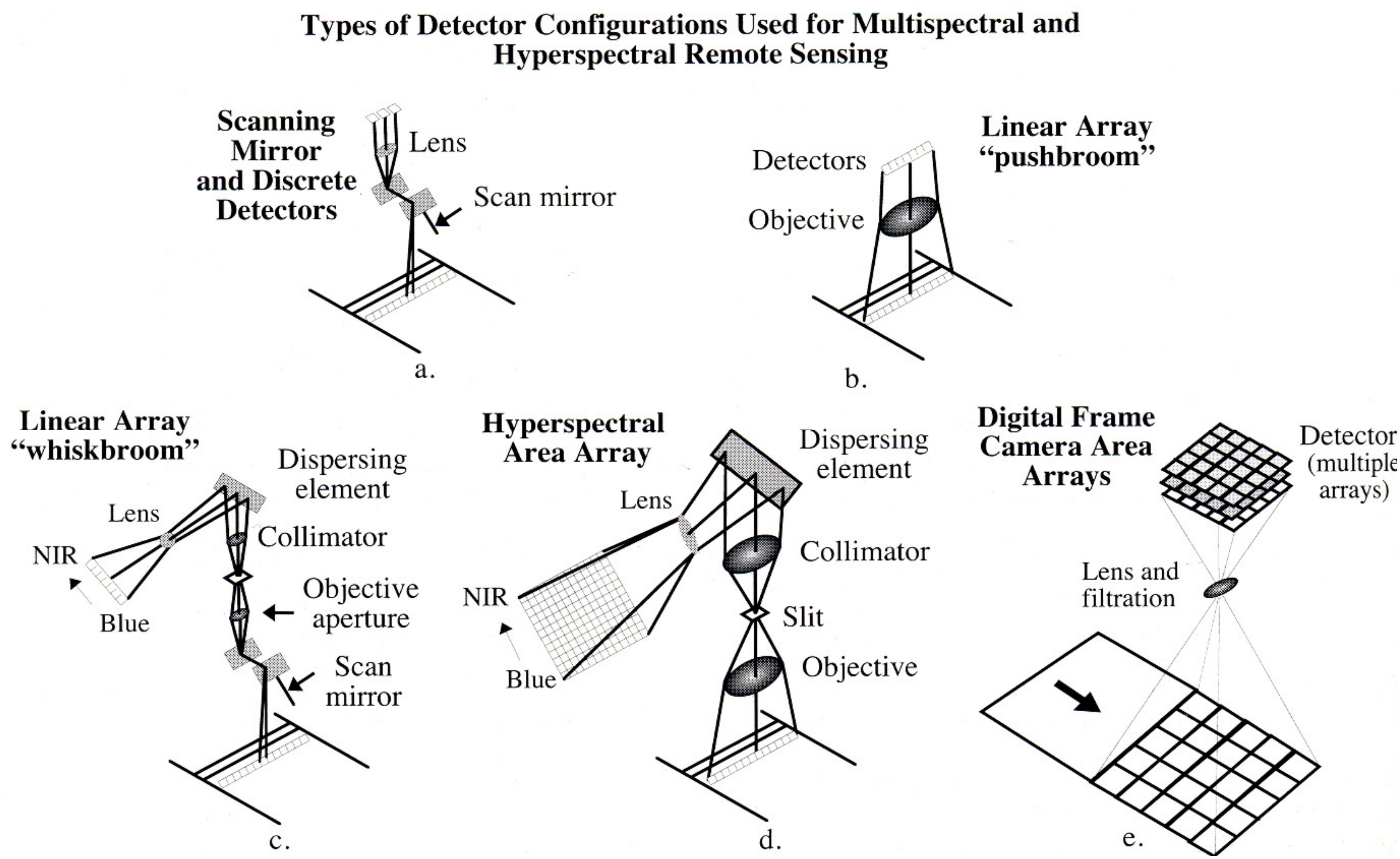
Multispectral Remote Sensing systems



There are four principal characteristics of signatures to identify an object:

- ***Spectral variations***: changes in the reflectance or emittance as a function of wavelength.
- ***Spatial variations***: variations in the reflectance/ emittance determined by the shape, size and texture of the target
- ***Temporal variations***: diurnal and/or seasonal changes in reflectance or emittance
- ***Polarization variations***: changes in the polarization of the radiation reflected or emitted by an object.

Multispectral Remote Sensing systems



Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

Landsat Multispectral Scanner (MSS)
Landsat Thematic Mapper (TM)
Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

National Atmospheric and Oceanic Administration (NOAA) Multispectral Scanner Sensors

NOAA Geostationary Operational Environmental Satellite (GOES)
NOAA Advanced Very High Resolution Radiometer (AVHRR)

ORBIMAGE, Inc., and NASA and Sea-viewing Wide Field of view Sensor (SeaWiFS)

Aircraft Multispectral Scanner (AMS) Daedalus, Inc.,

Daedalus, Inc.,
NASA Airbome Terrestrial Applications Sensor (ATLAS)

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

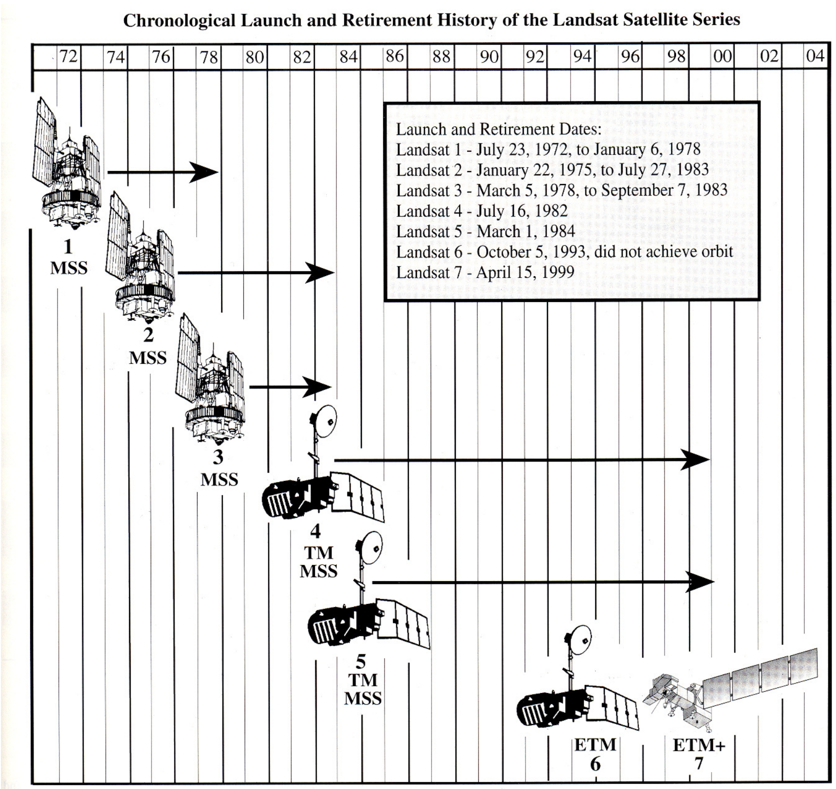
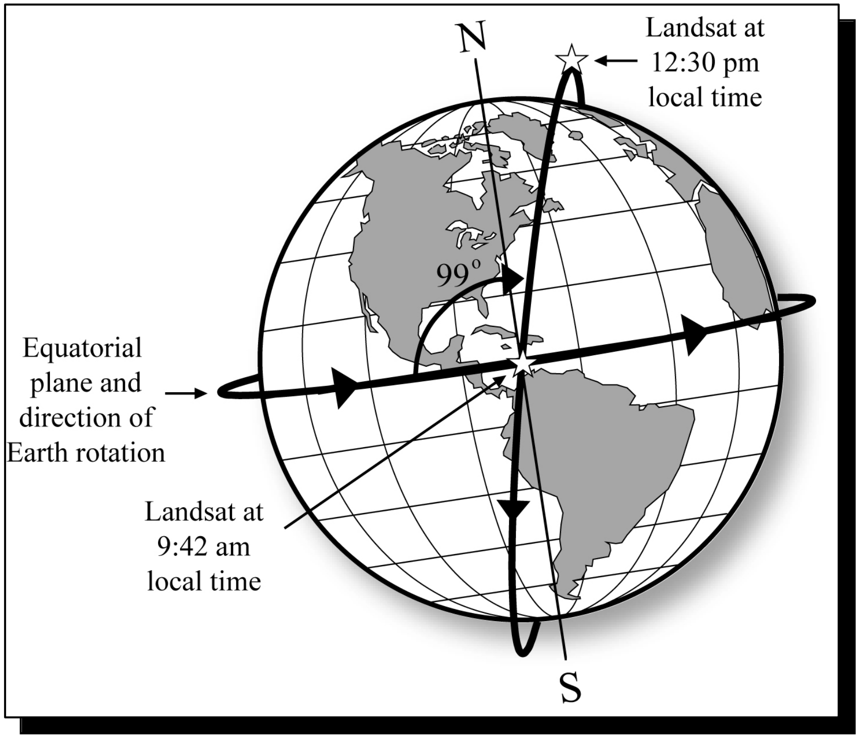


Figure 7-4 Chronological launch and retirement history of the Landsat series of satellites (1 through 7) from 1972 to 1999.

National Aeronautics and Space Administration (NASA)



Jensen 2000

Instatenous Field of View (IFOV):

Landsat MSS – 79x79m for bands 4-7

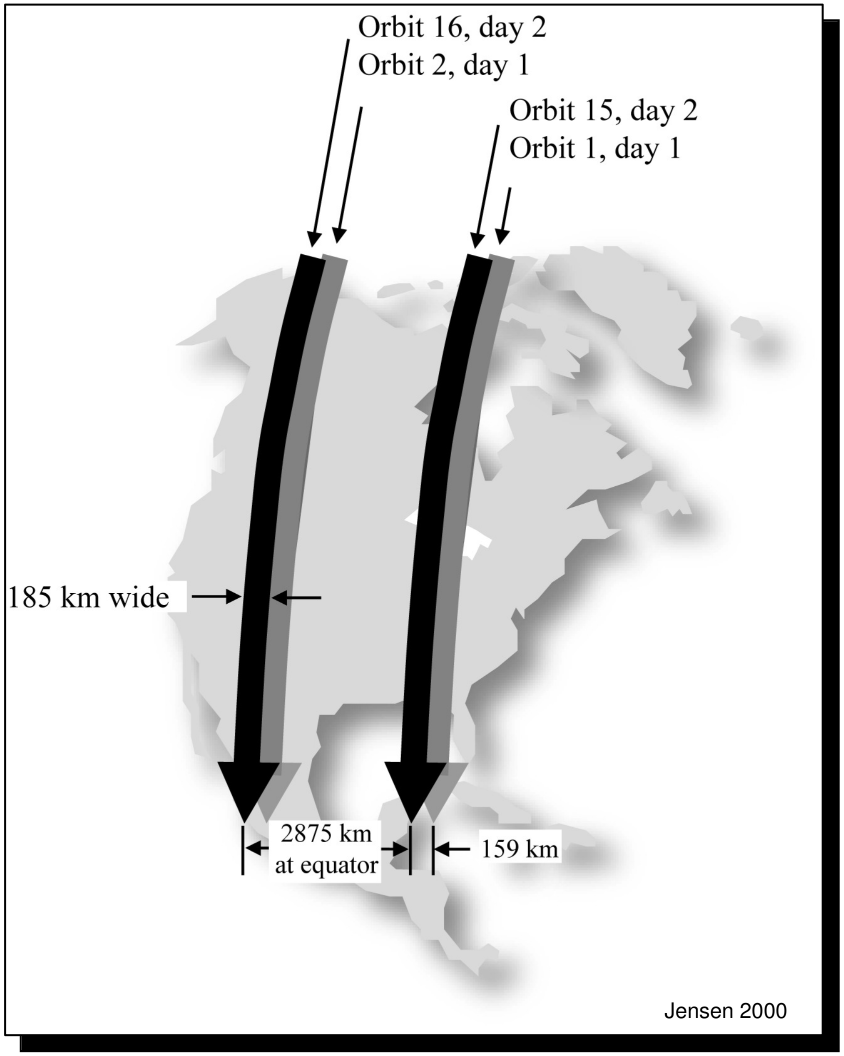
- 240x240 m for band 8

Landsat 4 & 5 TM – 30x30 m for bands 1-5 & 7

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems



Landsat Satellite Series

Sun-synchronous orbit - orbital plane precessed around Earth at the same angular rate at which Earth moved around the Sun

↓

In a ***sun-synchronous*** *orbit* the satellite passes over the same part of the Earth at roughly the same local time each day

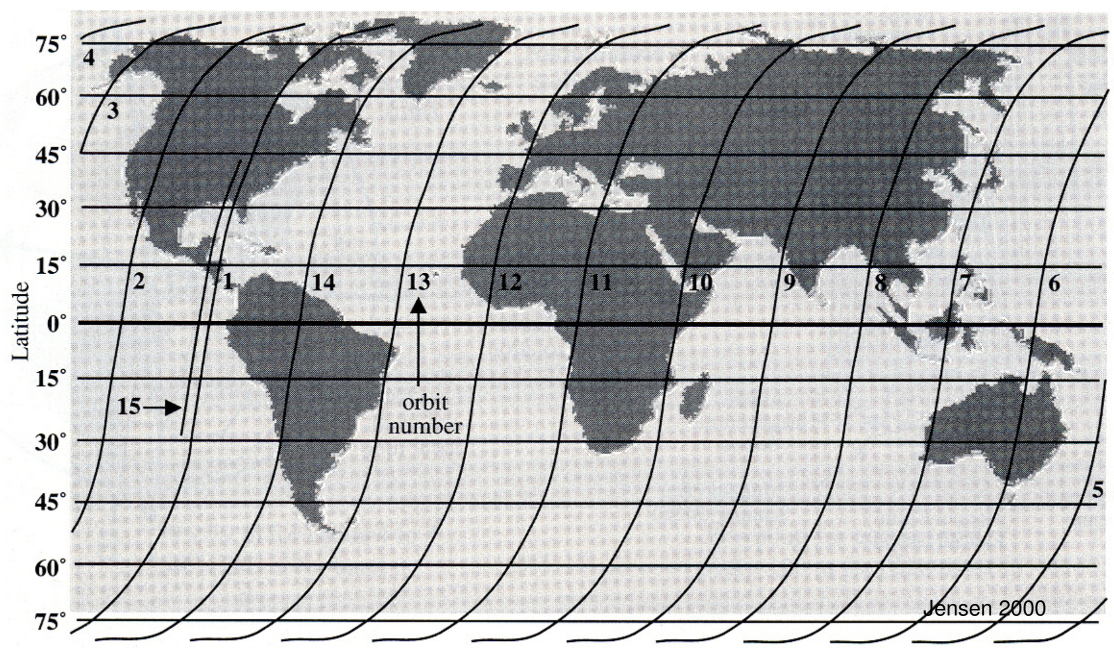
9:30 to 10:00 a.m. at equator on the illuminated side of Earth

1 orbit = 103 minutes
14 orbits per day

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems



Orbital tracks of Landsat 1, 2, or 3 during a single day of coverage

Landsat 1, 2, and 3

Orbit 252 fell over orbit 1 again after 18 days

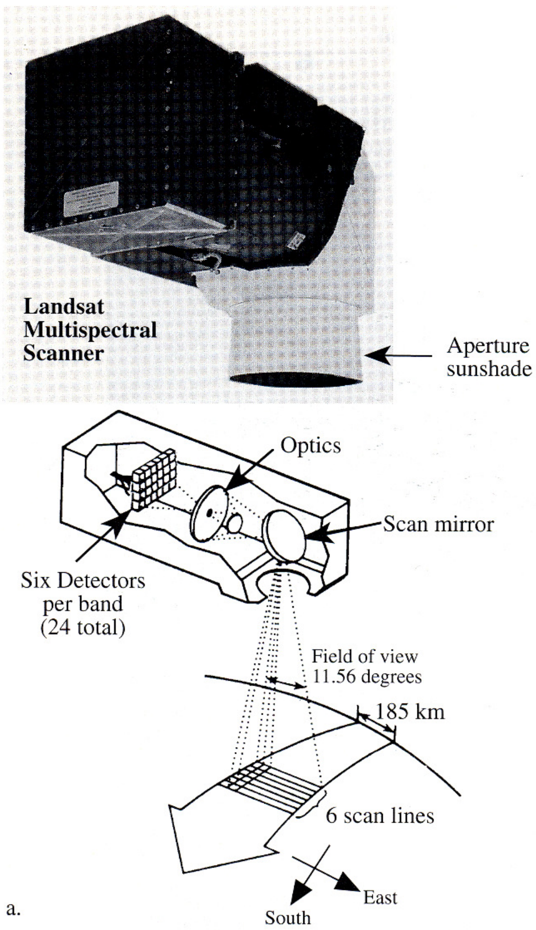
Revisit: - every 18 days,
- 20 times a year.

Multispectral Remote Sensing systems

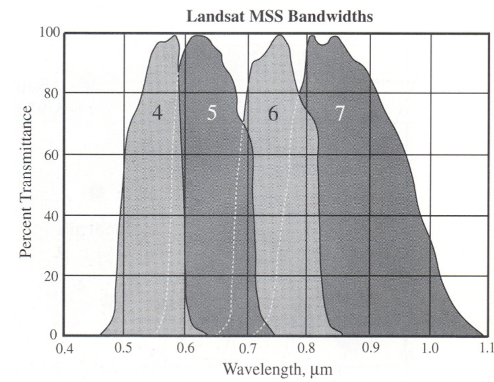
Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

SENSORS: Landsat Multispectral Scanner (MSS)



Band	Spectral Resolution (μm)
4^b	0.5 – 0.6
5	0.6 – 0.7
6	0.7 – 0.8
7	0.8 – 1.1
8^c	10.4 – 12.6



IFOV at nadir	79 × 79 m for bands 4 through 7 240 × 240 m for band 8
Data rate	15 Mb/s
Quantization levels	6 bit (values from 0 to 63)
Earth coverage	18 days Landsat 1, 2, 3 16 days Landsat 4, 5
Altitude	919 km
Swath width	185 km
Inclination	99°

Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

a.

Terrestrial images acquired by the engineering model of Landsat MSS

MSS band 4 detectors

(500 – 600 nm green)

MSS band 6 detectors

(700 - 800 nm near-infrared)

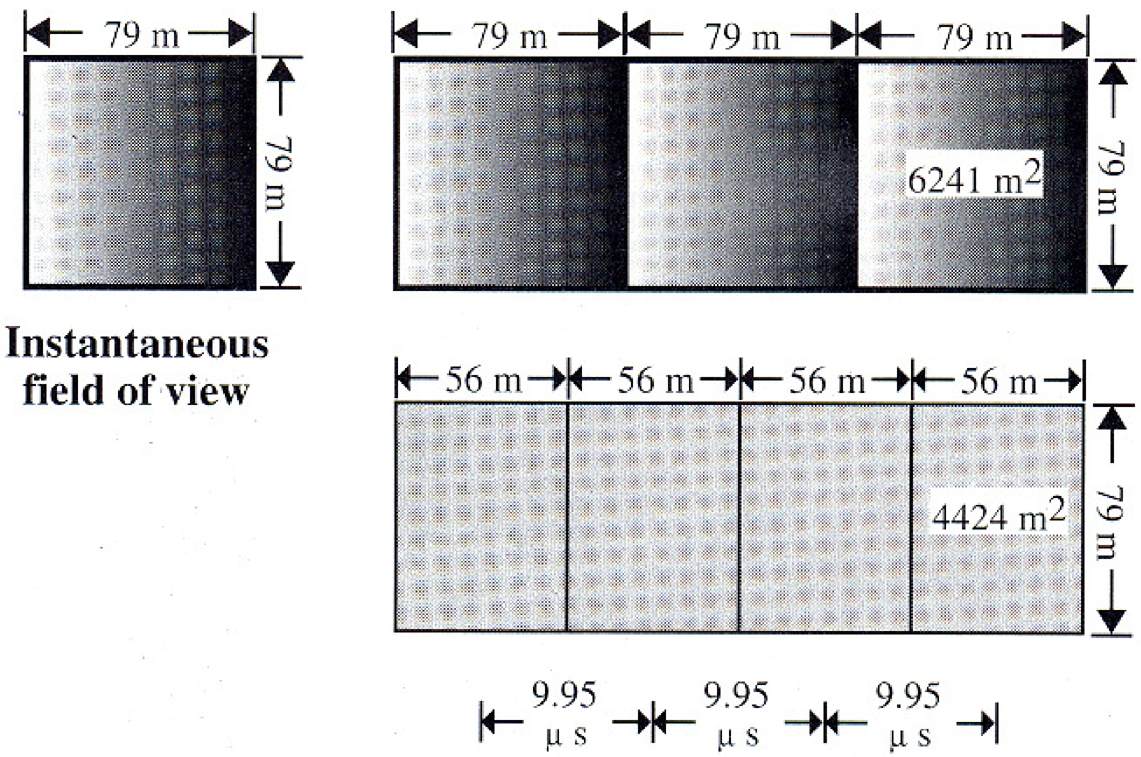
Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

IFOV (Instantaneous Field of View) - A measure of the spatial resolution of a remote sensing imaging system.



Relationship between the original 79 x 79 m IFOV of the Landsat MSS and the rate at which It was resampled (every 9.95 µs)

Landsat 1, 2, and 3

- 6 bits with a range of values from 0 to 63 rescaled to 7 bits (0 to 127).

- measurement of landscape brightness was made from a 6241 m^2 to 4424 m^2 area

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Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

	Landsat MSS	Landsat TM
IFOV at nadir	79 × 79 m for bands 4 through 7 240 × 240 m for band 8	30 × 30 m for bands 1 through 5, 7 120 × 120 m for band 6
Data rate	15 Mb/s	85 Mb/s
Quantization levels	6 bit (values from 0 to 63)	8 bit (values from 0 to 255)
Earth coverage	18 days Landsat 1, 2, 3 16 days Landsat 4, 5	16 days Landsat 4, 5
Altitude	919 km	705 km
Swath width	185 km	185 km
Inclination	99°	98.2°

-general vegetation inventories
-geologic studies

4[b]	0.5 – 0.6
5	0.6 – 0.7
6	0.7 – 0.8
7	0.8 – 1.1
8[c]	10.4 – 12.6

1	0.45 – 0.52
2	0.52 – 0.60
3	0.63 – 0.69
4	0.76 – 0.90
5	1.55 – 1.75
6	10.40–12.5
7	2.08–2.35

- water penetration,
- discrimination of vegetation type and vigor,
- plant and soil moi-sture measurement,
- differentiation of clouds, snow, and ice,
-identification of hydrothermal alter-ation in certain rock types

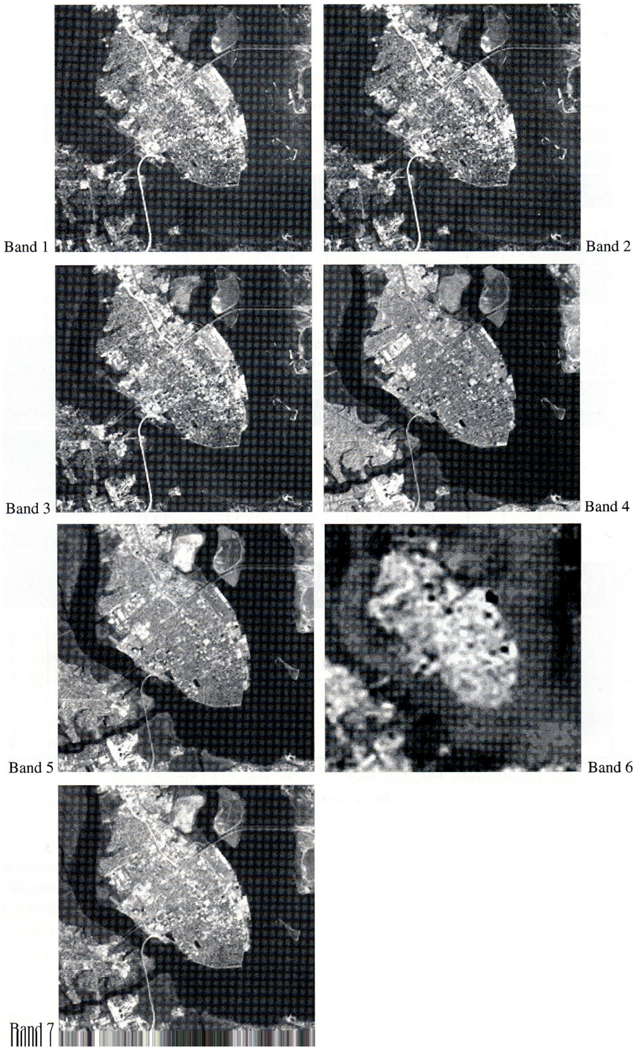
Jensen 2000

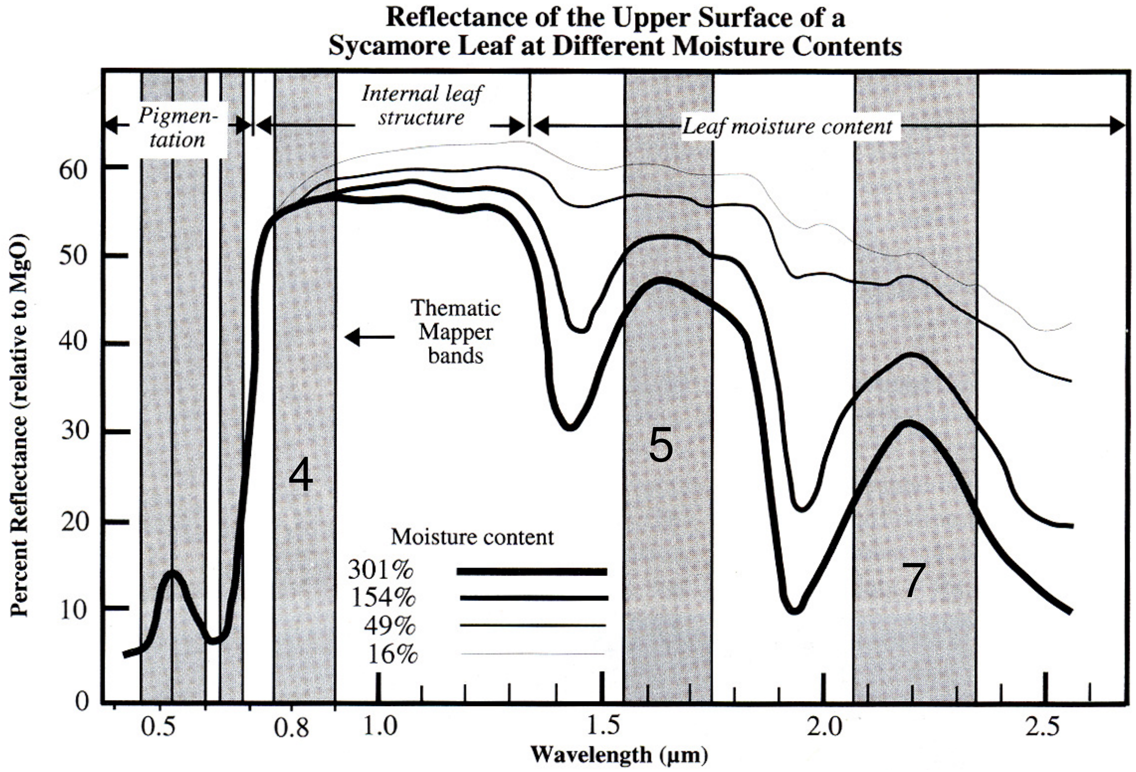
Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

Landsat Thematic Mapper Data of Charleston, SC





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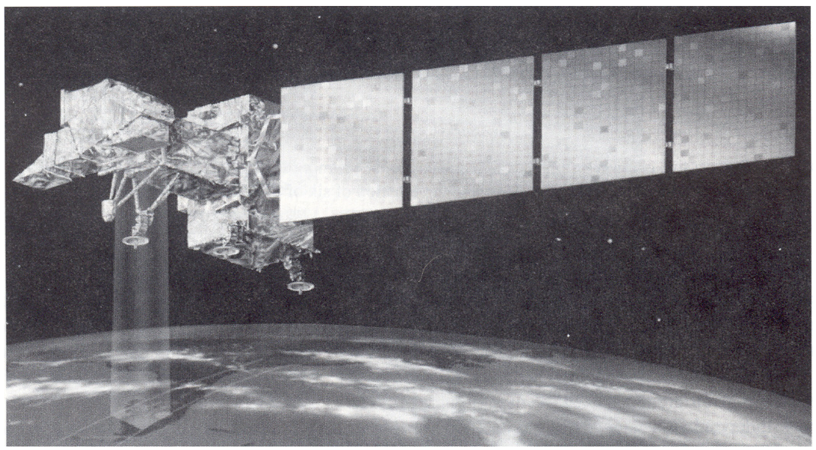
Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Earth Resource Technology Satellites (ERTS) and the Landsat Sensor Systems

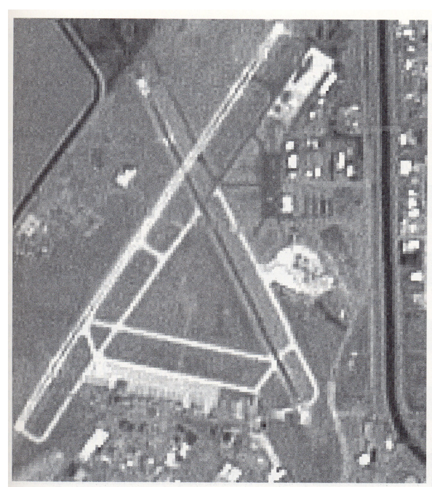
Landsat 7 ETM+



Sensor Technology	Scanning mirror spectrometer
Swath Width	185 km
Data Rate	250 images per day @ 31,450 km^2
Revisit	16 days
Orbit and Inclination	705 km, sun-synchronous Inclination = 98.2° Equatorial crossing 10:00 a.m. $\pm$15 min.
Launch	April 15, 1999; 6 year duration

Landsat 7 Enhanced Thematic Mapper Plus (ETM⁺)

Band	Spectral Resolution (µm)	Spatial Resolution (m) at Nadir
1	0.450–0.515	30 x 30
2	0.525–0.605	30 x 30
3	0.630–0.690	30 x 30
4	0.750–0.900	30 x 30
5	1.55–1.75	30 x 30
6	10.40–12.50	60 x 60
7	2.08–2.35	30 x 30
8 (pan)	0.52–0.90	15 x 15



The first Landsat 7 ETM+ panchromatic image obtained over Sioux Falls

Jensen 2000

Multispectral Remote Sensing systems

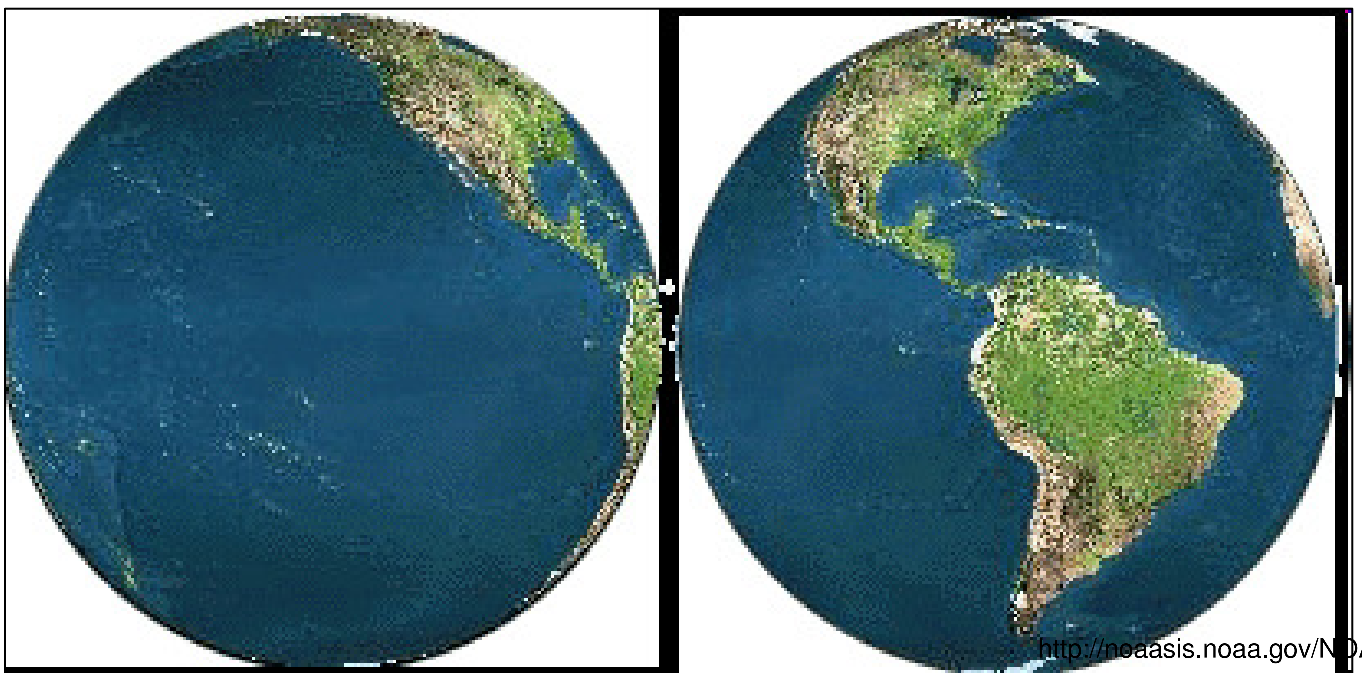
Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

National Atmospheric and Oceanic Administration (NOAA) Multispectral Scanner Sensors

NOAA operates two series of remote sensing satellites:
- the Geostationary Operational Environmental Satellites (GOES)
- the Polar-Orbiting Operational Environmental Satellites (POES).

Geostationary Operational Environmental Satellites (GOES)

GOES-15 (or GOES-West)



GOES-13 (or GOES-East)

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

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

National Atmospheric and Oceanic Administration (NOAA) Multispectral Scanner Sensors

Geostationary Operational Environmental Satellites (GOES)

GOES 15: **Launch Date**: March 04, 2010 Cape Canaveral Air Station, FL.

Orbital information: Type: Geosynchronous
Altitude: 35, 780 km

Sensors*:* ***Imager*** - *multichannel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere*.
Sounder - *provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution*

Imager

Band	Wavelength range (nm)	Spatial resolution (km)	Meteorological objective
1	530 – 750	1	Cloud cover and surface features during the day
2	3800 - 4000	4	Low cloud/fog and fire detection
3	5800 - 7300	4	Upper-level water vapor
4	10 200 – 11 200	4	Surface or cloud-top temperature
6	12 900 – 13 700	4	CO_2 band: Cloud detection

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

National Atmospheric and Oceanic Administration (NOAA) Multispectral Scanner Sensors

Polar-Orbiting Operational Environmental Satellites (POES)

NOAA-19: **Launch Date**: February 06, 2009 Vandenburg Air Force Base
Orbital information: Type: sun synchronous
Altitude: 870 km
Orbit period: 101-102 minutes
Revisit time: 1 day
Sensors*:* Advanced Very High Resolution Radiometer (AVHRR/3)
Swath width: 2700 km

AVHRR/3

Band	Wavelength range (nm)	Spatial resolution (km)	Meteorological objective
1	580 – 680	1.1	Dyatime cloud, snow, ice and vegetation mapping; used to compute NDVI.
2	725 – 1000	1.1	Land-water interface delineation; snow, ice, and vegetation mapping; used to compute NDVI.
3	1580 – 1640	1.1	Crop drought and plant vigour monitoring, discrimination between clouds, snow and ice.
4	3550 – 3930	1.1	Monitoring hot targets (volcanoes, forest fires), nighttime cloud mapping.
5	10 300 – 11 300	1.1	Day-and-night cloud and surface-temperature mapping.
6	11 500 – 12 500	1.1	Cloud and surface temperature, day and night cloud mapping; removal of atmospheric water vapor path radiance.

Multispectral Remote Sensing systems

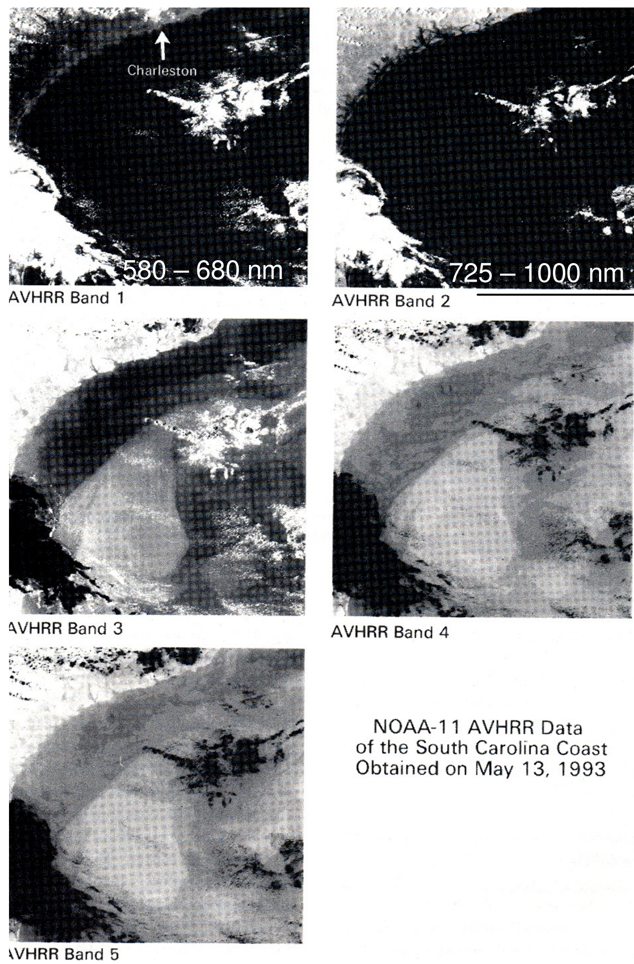
Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

National Atmospheric and Oceanic Administration (NOAA) Multispectral Scanner Sensors

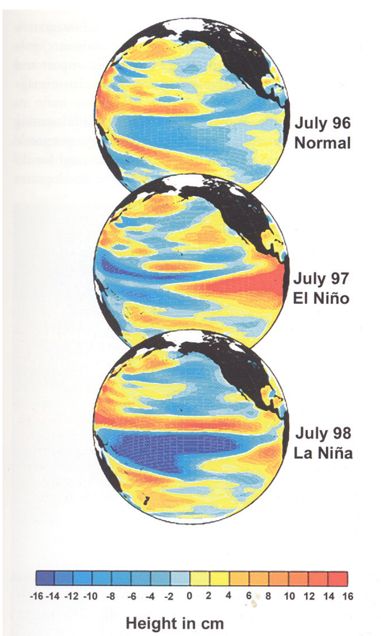
Polar-Orbiting Operational Environmental Satellites (POES)

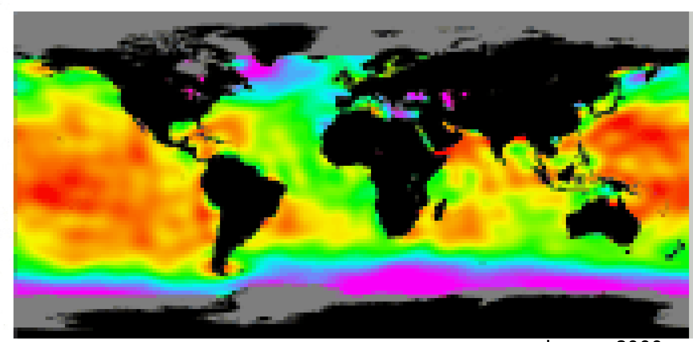
NOAA-19:

Landsat TM band 3
630 – 690 nm



Landsat TM band 4
760 – 900 nm





Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Aircraft Multispectral Scanners

Daedalus

<u>TMS (Thematic Mapper Simulator - ARC)</u>

Spatial Resolution: 25 meters (all bands) from 19.8 km

Swath width 714 pixels

IFOV: 2.5 mrad

Flight Altitude (m)	Pixel size (m)
1 000	2.5
2 000	5.0
4 000	10.0
16 000	40.0
50 000	125.0

NASA/ARC ER-2 aircraft

Band	Wavelength range (nm)
1	420 - 450
2 (TM1)	450 -520
3 (TM2)	520 - 600
4	600 - 620
5 (TM3)	630 - 690
6	690 - 750
7 (TM4)	760 – 900
8	910 – 1050
9 (TM5)	1550 – 1750
10 (TM7)	2080 – 2350
11 (TM6) High Gain	8500 - 14000
12 (TM6) Low Gain	8500 - 14000

Multispectral Remote Sensing systems

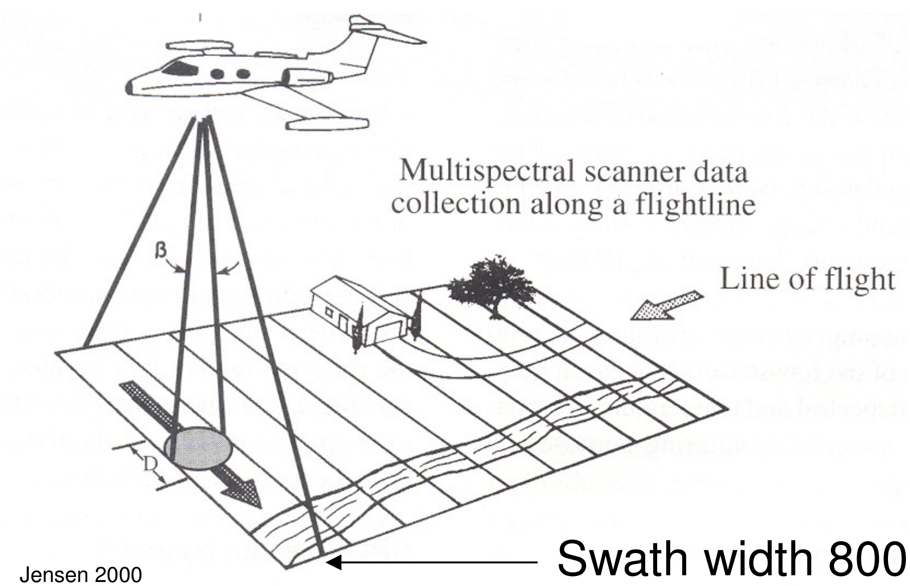
Multispectral Imaging Using Discrete Detectors and Scanning Mirrors

Aircraft Multispectral Scanners

ATLAS

Spatial Resolution: 2.5 - 25 meters depending upon altitude-above-ground-level

IFOV: 2.0 mrad



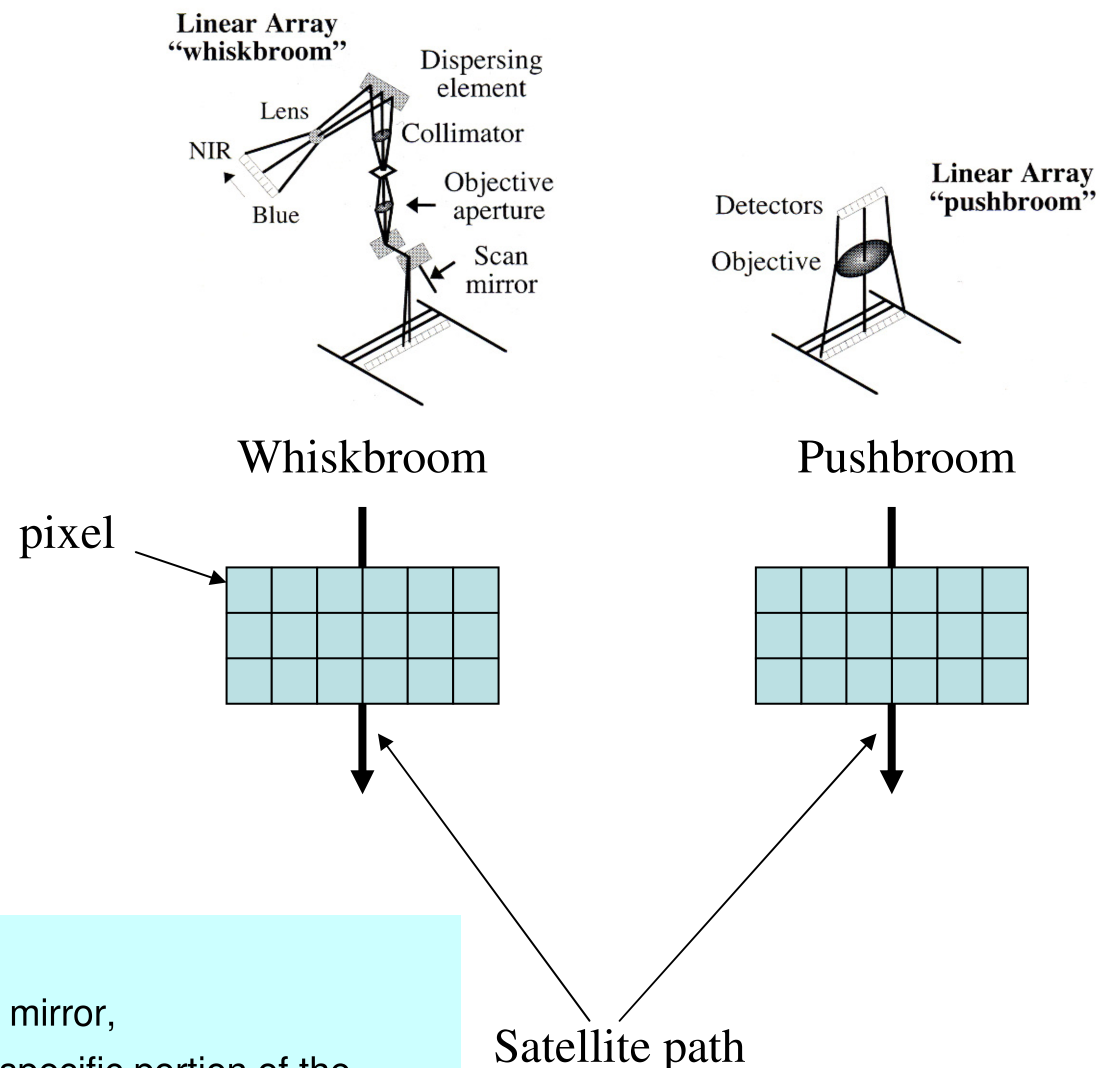
Swath width 800 pixels

Jensen 2000

Band	Wavelength range (nm)
1 (TM1)	450 - 520
2 (TM2)	520 - 600
3	600 - 630
4 (TM3)	630 - 690
5	690 - 750
6 (TM4)	760 – 900
7 (TM5)	1550 – 1750
8 (TM7)	2080 – 2350
9	removed
10	8200 - 8600
11	8600 - 9000
12	9000 - 9400
13	9600 - 10200
14	10200 - 11200
15	11200 - 12200

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays



Pushbroom:

I) there is no moving mirror,

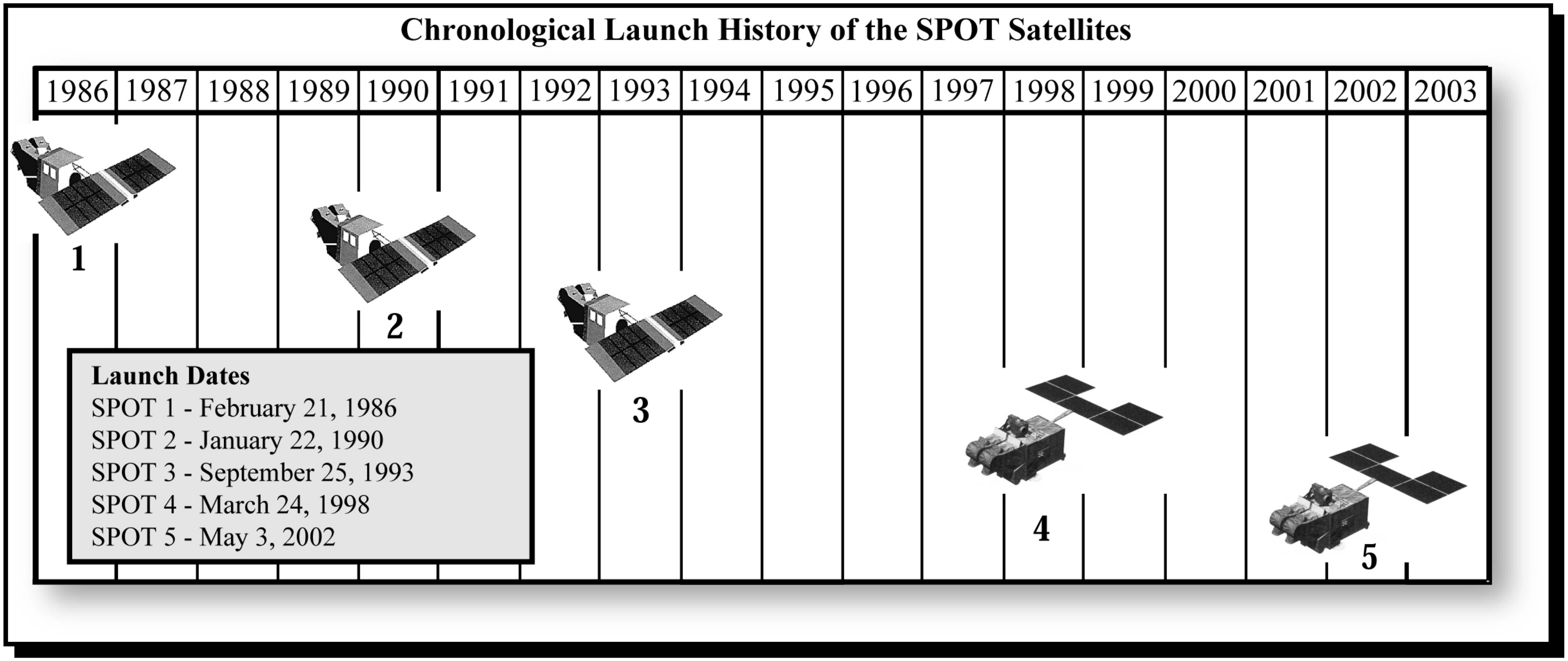
2) dwell longer on a specific portion of the terrain.

Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems



SPOT 6 and SPOT 7 – 2012 and 2013 respectively

Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems

SPOT-5 Satellite HRVIR Sensor Characteristics

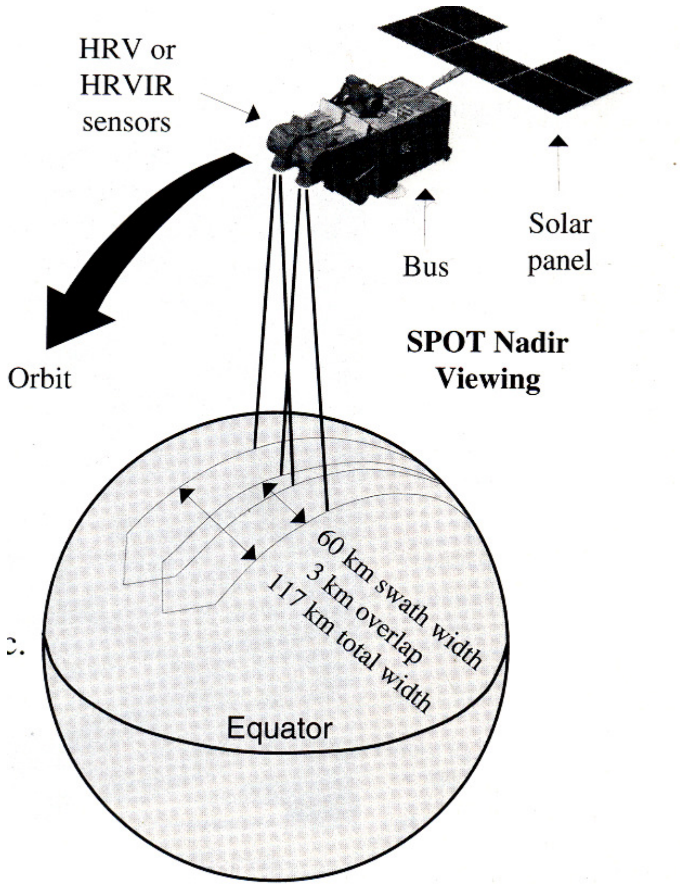
Launch Date	May 3, 2002
Orbital Altitude	822 kilometers
Speed	7.4 km/second (26,640 Km/hour)
Equator Crossing Time	10:30 AM (descending node)
Orbit Time	101.4 minutes
Revisit Time	2-3 days, depending on latitude
Swath Width	60 km x 60 km to 80 km at nadir
Resolution	Panchromatic: 5m (nadir) MS: 10m (nadir) SWI: 20m (nadir)
Image Bands	Pan: 480-710 nm Green: 500-590 nm Red: 610-680 nm Near IR: 780-890 nm Shortwave IR: 1,580-1,750 nm

Multispectral Remote Sensing systems

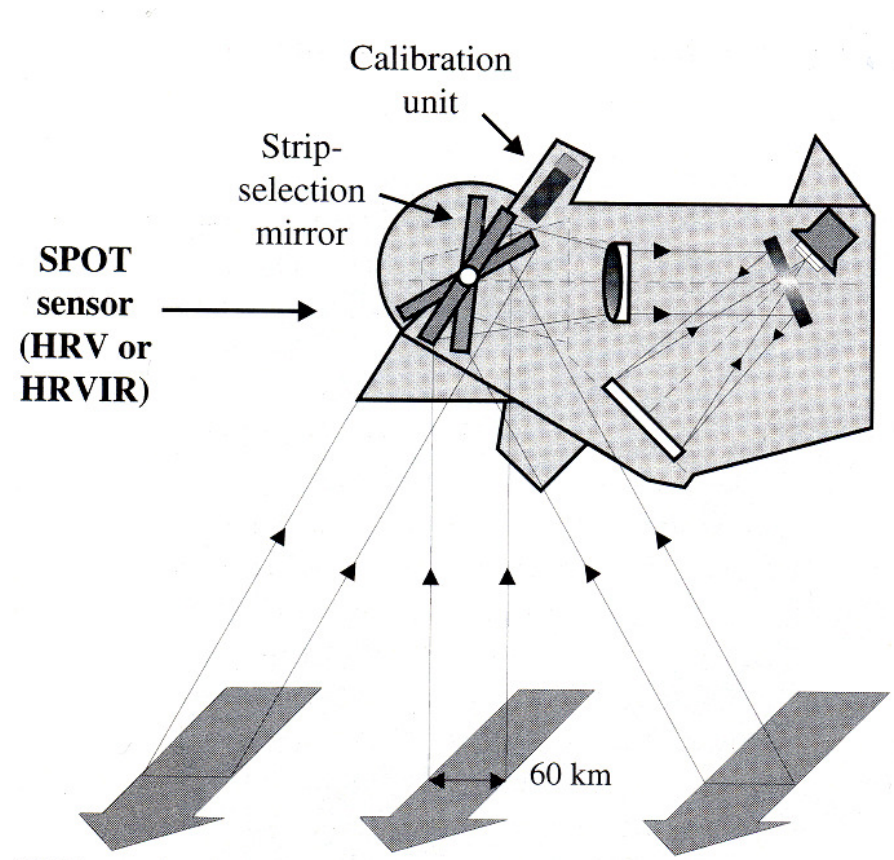
Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems

nadir viewing



off-nadir viewing



Two high-resolution visible (HRV) sensors – SPOT 1, 2, & 3

Two high-resolution visible infrared (HRVIR) sensors SPOT 4 & 5

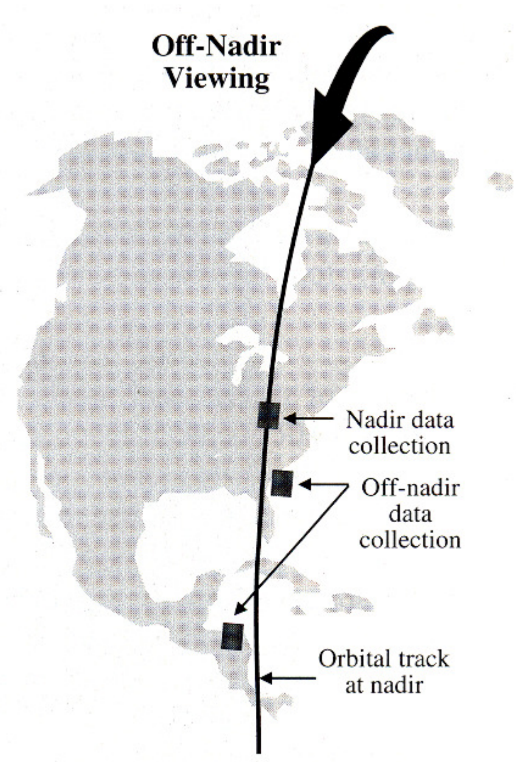
Jensen 2000

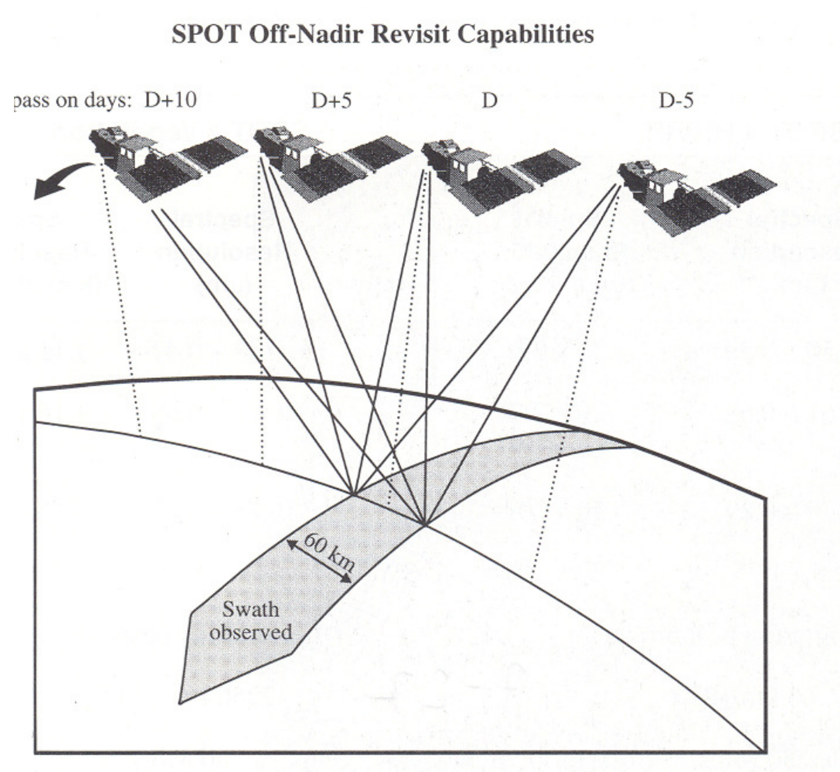
Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems

At nadir viewing the revisit frequency is 26 days.
At off-nadir viewing revisit time is one to four (or occasionally five) days.



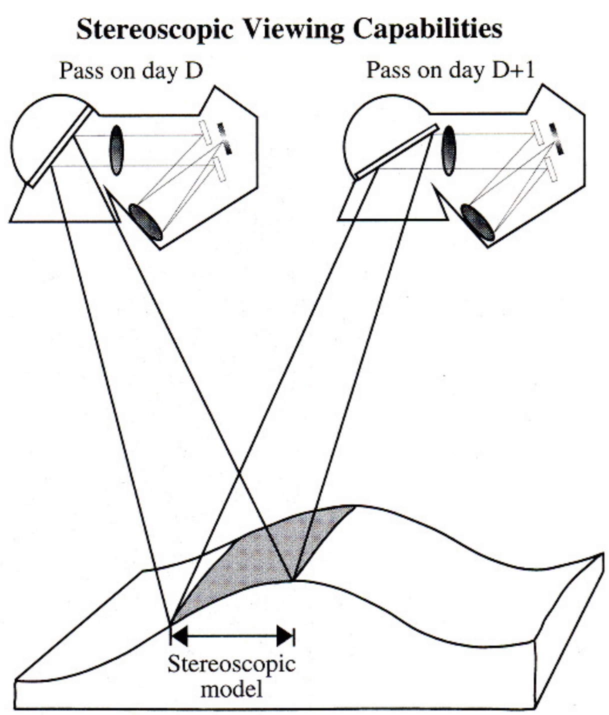


Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems



Maps with accuracy:
- planimetric of 12 m with 90 % confidence
- elevation for a DEM of 30 m with 90 % confidence

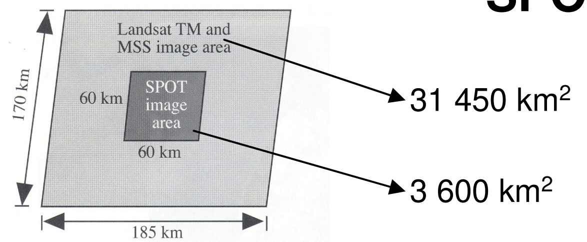
The ratio between the observation base (distance between the two satellite positions) and the height (satellite altitude) is approximately 0.75 at the equator and 0.50 at a latitude of 45°.

Jensen 2000

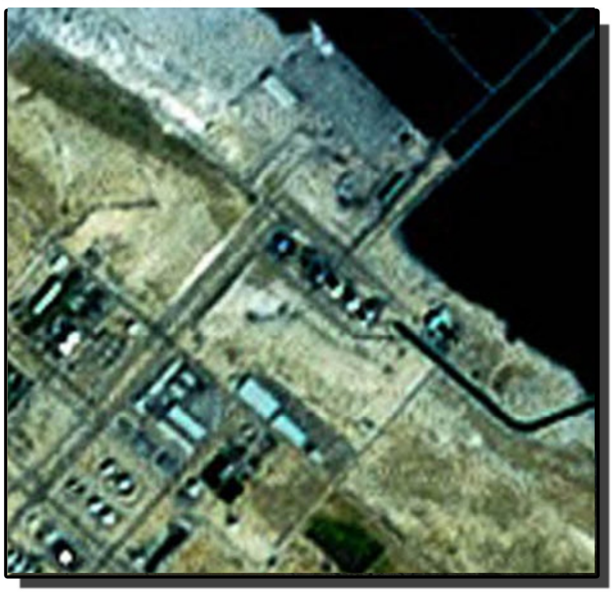
Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

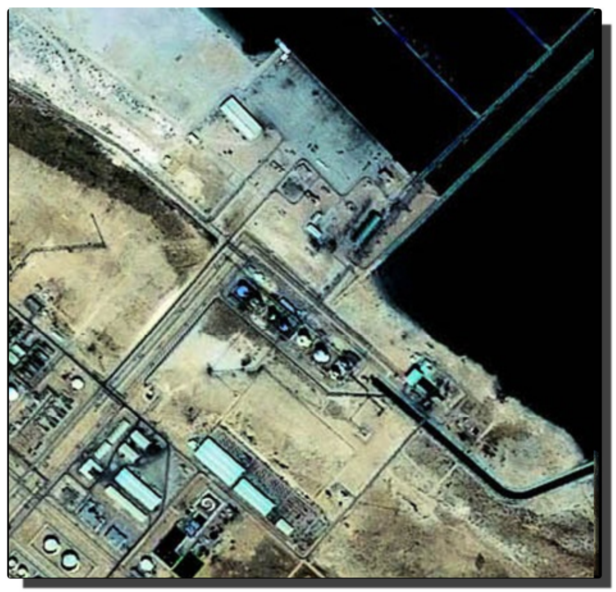
SPOT Sensor Systems



Landsat TM7 30m & Spot5 5m Resolution Merge Samples



Original Landsat TM7 Processing
MS 30m Fused with Pan 15m
Final Image Resolution 15m



Landsat TM7 & Spot5 Processing
LSTM7 MS 30m Fused with Spot5 Pan 5m
Final Image Resolution 5m

Landsat TM7 & Spot5 Processing
LSTM7 MS 30m Pan Sharpened with Spot5 Pan 5m
Final Image Resolution 5m

http://www.satimagingcorp.com

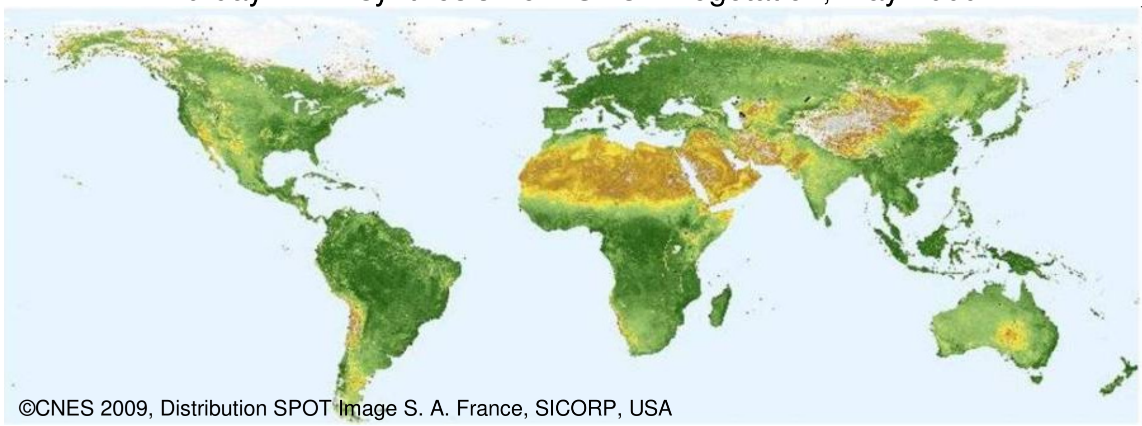
Multispectral Remote Sensing systems

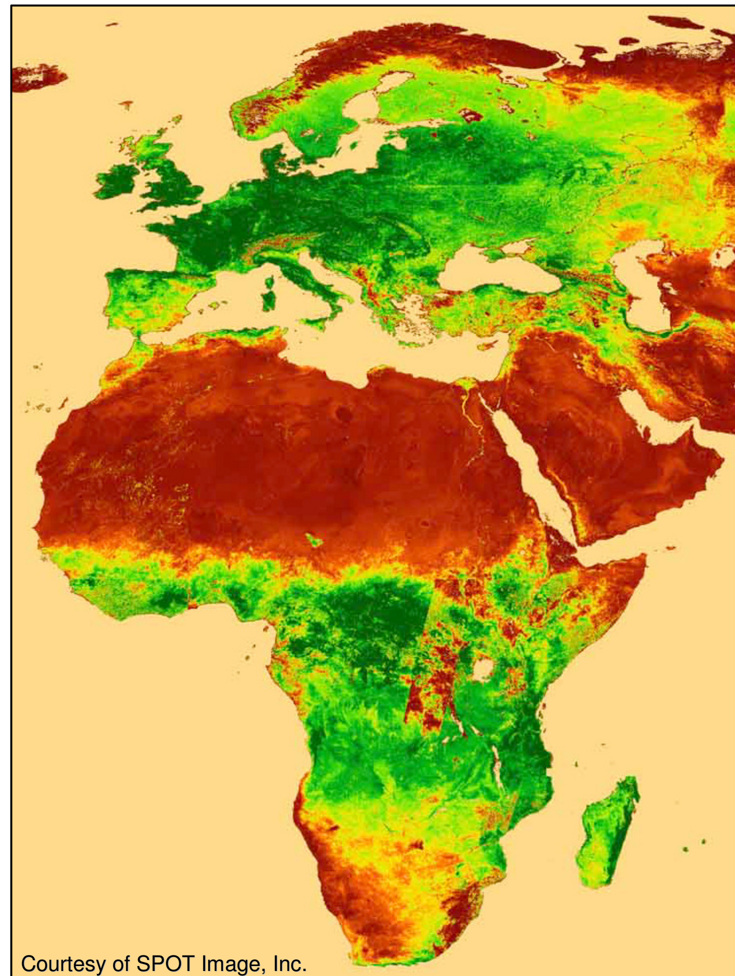
Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems

First Global 10-day Synthesis Image Produced Using the SPOT Vegetation Sensor

10-day NDVI synthesis from SPOT Vegetation, May 2009





SPOT Vegetation sensor

Product: Global composite NDVI images with 1 and 10 day syntheses

NDVI = (band3 – band2)/(band3 + band2)

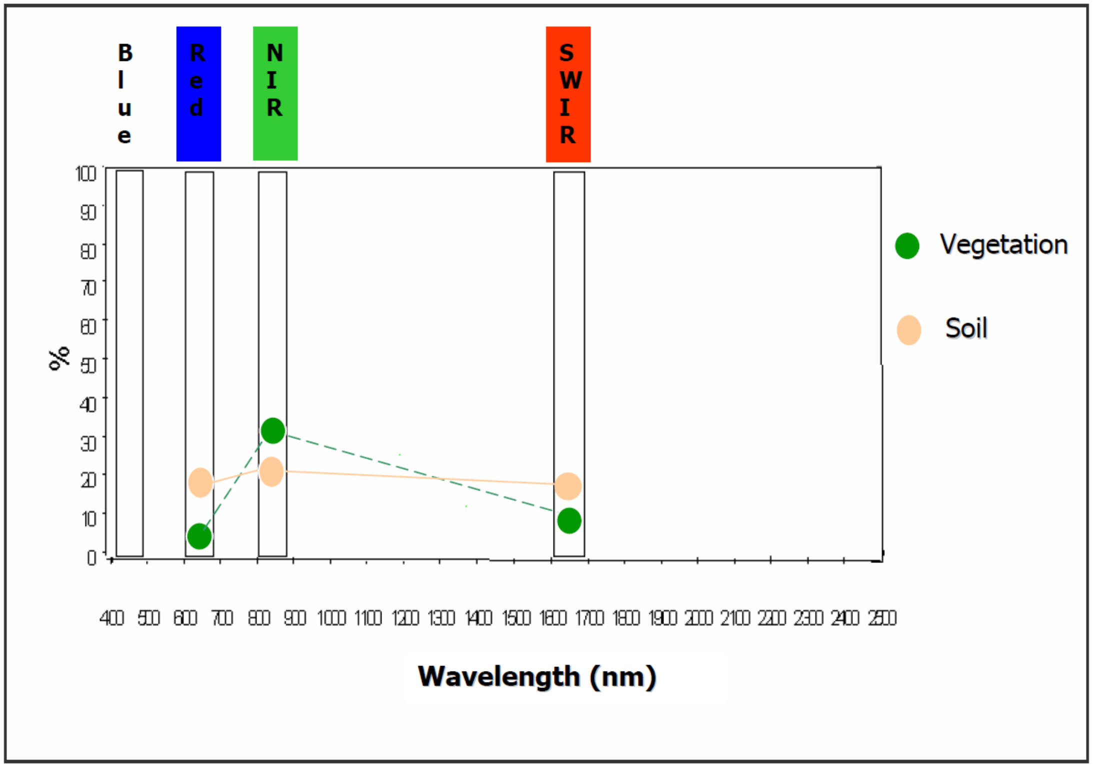
Band	Resolution	Wavelength µm	Description
0	1.15km	0.43-0.47	Blue
2	1.15km	0.61-0.68	Red
3	1.15km	0.78-0.89	Near Infrared
SWIR	1.15km	1.58-1.75	Short wave infrared

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

SPOT Sensor Systems

NDVI = (band3 – band2)/(band3 + band2)



Location of the four SPOT-VEGETATION sensor bands, vegetation and bare soils properties.

Vegetation NDVI = 0.40 – 0.80

Soil NDVI = 0.20 – 0.40

Locust
(Schistocerca gregaria)

Multispectral Remote Sensing systems

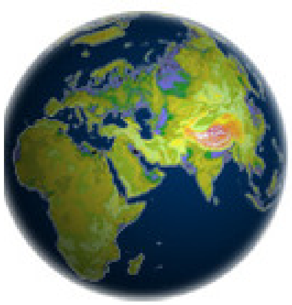
Multispectral Imaging Using Linear Arrays

Earth Observing System – Satelite *Terra* Instruments

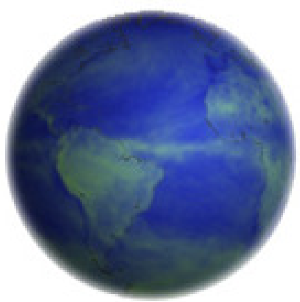
Sensors onboard Terra satellite (since 1999):

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
CERES - Clouds and the Earth's Radiant Energy System
MISR - Multi-angle Imaging Spectroradiometer
MODIS - Moderate-resolution Imaging Spectroradiometer
MOPITT - Measurement of Pollution in the Troposphere

Examples of each instrument's capabilities

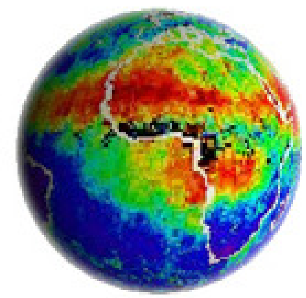


ASTER - land composition

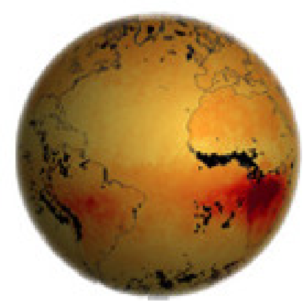


CERES – reflected energy

MODIS – vegetation, snow and ice



MISR – aerosols



MOPITT – carbon monixide

http://terra.nasa.gov/

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

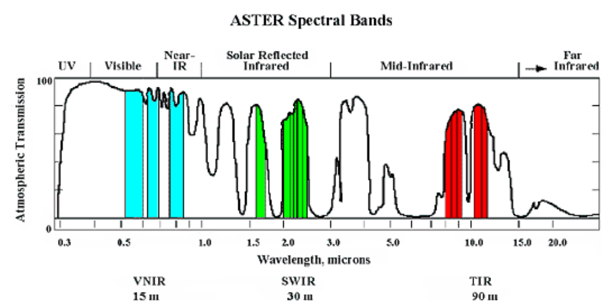
TERRA satellite

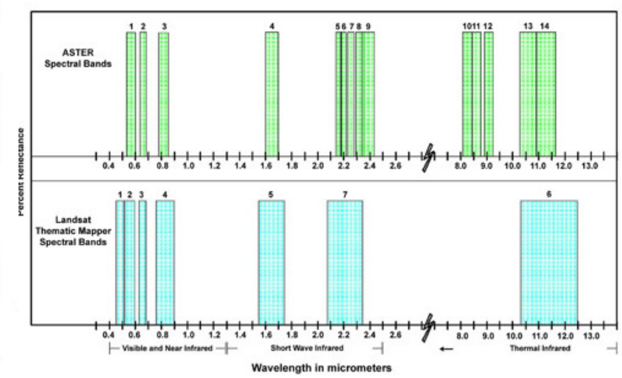
ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

Band	VNIR Spectral Resolution (μm)	Band	SWIR Spectral Resolution (μm)	Band	TIR Spectral Resolution (μm)
1 (nadir)	0.52 – 0.60	4	1.600 – 1.700	10	8.125 – 8.475
2 (nadir)	0.63 – 0.69	5	2.145 – 2.185	11	8.475 – 8.825
3 (nadir)	0.76 – 0.86	6	2.185 – 2.225	12	8.925 – 9.275
3 (backward)	0.76 – 0.86	7	2.235 – 2.285	13	10.25 – 10.95
		8	2.295 – 2.365	14	10.95 – 11.65
		9	2.360 – 2.430		
Technology (detector)	pushbroom Si		pushbroom PtSi:Si		whiskbroom Hg:Cd:Te
Spatial Resolution (m)	15 x 15		30 x 30		90 x 90
Swath Width	60 km		60 km		60 km
Quantization	8 bits		8 bits		8 bits

Jensen 2000





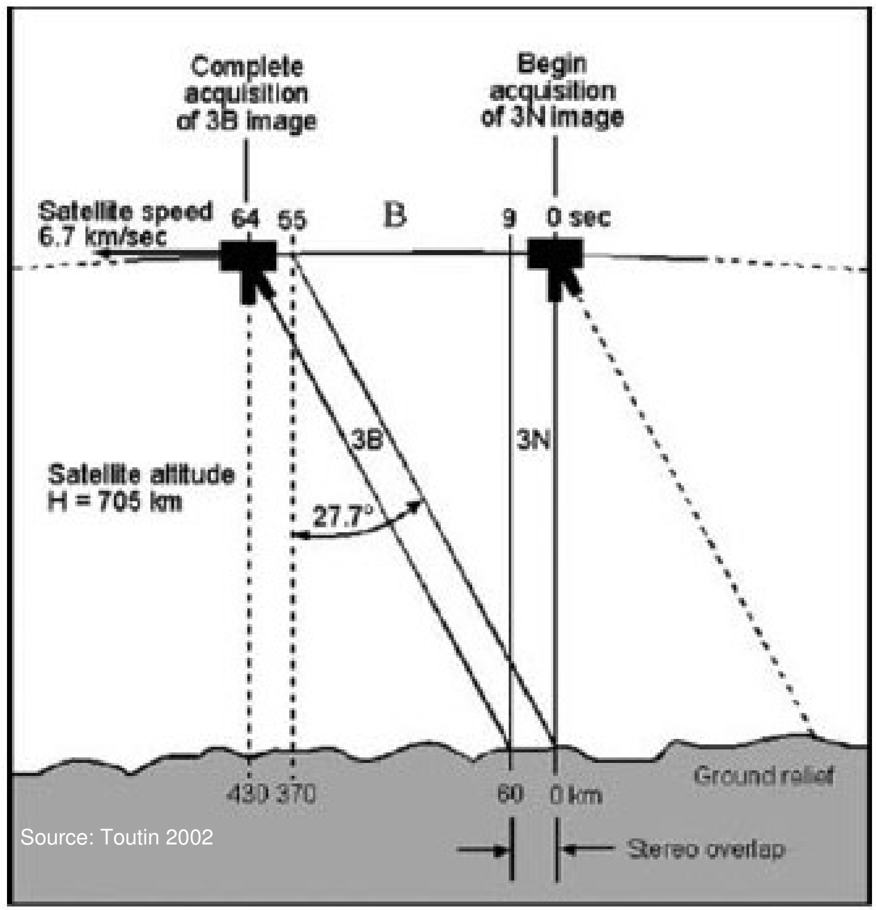
Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

TERRA satellite

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

Alongtrack mode of data acquisition



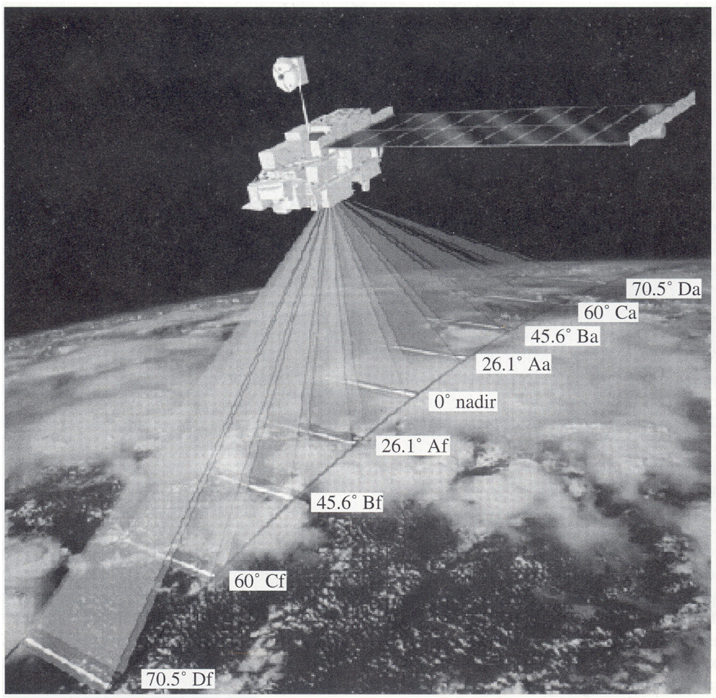
ASTER stereo configuration

[de Oliveira 2009]

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

TERRA satellite
MISR - Multi-angle Imaging Spectroradiometer



Sensors	Df	Cf	Bf	Af	An	Aa	Ba	Ca	Da
View angle	70.5°	60°	45.6°	26.1°	0°	26.1°	45.6°	60°	70.5°
425 – 467 nm	275 m x 1.1 km	275 m x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	275 x 275 m	1.1 x 1.1 km	1.1 x 1.1 km	275 m x 1.1 km	275 m x 1.1 km
543 – 571 nm	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	275 x 275 m	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km
660 – 682 nm	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m	275 x 275 m
846 – 886 nm	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	275 x 275 m	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km	1.1 x 1.1 km

275 x 275 m   1.1 x 1.1 km   275 m x 1.1 km

Jensen 2000

9 look angles spread out in the forward and aft directions along the flightline

Spatial samples are acquired every 275 m. Over a period of 7 minutes, a 360 km wide swath of Earth comes into view at all nine angles.

Large viewing angles provide enhanced sensitivity to atmospheric aerosol effects and to cloud reflectance effects.

Modest angles are required for land-surface viewing.

Multispectral Remote Sensing systems

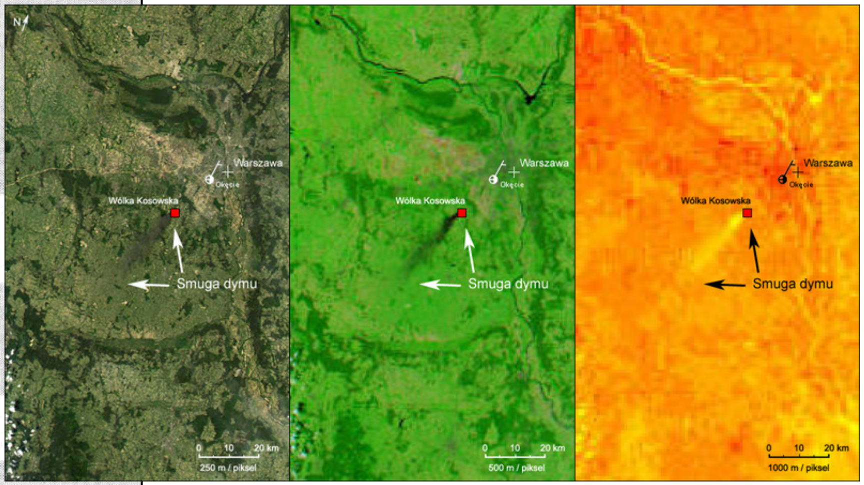
Multispectral Imaging Using Linear Arrays

TERRA satellite

MODIS - Moderate-resolution Imaging Spectroradiometer

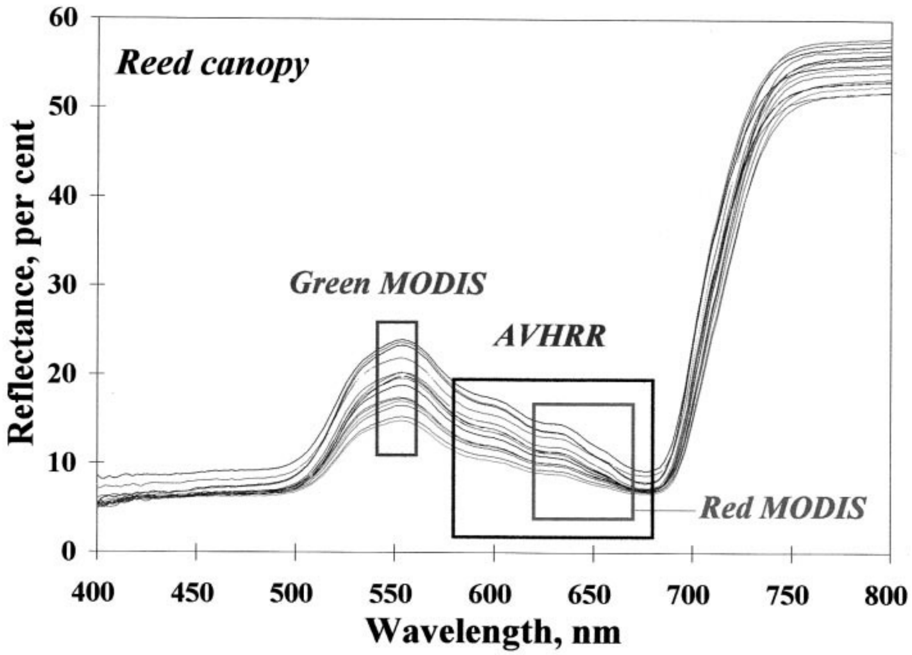
Band	Spectral Resolution (μm)	Spatial Resolution	Primary Use
1	0.620–0.670	250 x 250 m	Land-cover classification and chlorophyll absorption
2	0.841–0.876	250 x 250 m	
3	0.459–0.479	500 x 500 m	Land, cloud, and aerosol properties
4	0.545–0.565	500 x 500 m	
5	1.230–1.250	500 x 500 m	
6	1.628–1.652	500 x 500 m	
7	2.105–2.155	500 x 500 m	
8	0.405–0.420	1 x 1 km	Ocean color, phytoplankton, biogeochemistry
9	0.438–0.448	1 x 1 km	
10	0.483–0.493	1 x 1 km	
11	0.526–0.536	1 x 1 km	
12	0.546–0.556	1 x 1 km	
13	0.662–0.672	1 x 1 km	
14	0.673–0.683	1 x 1 km	
15	0.743–0.753	1 x 1 km	
16	0.862–0.877	1 x 1 km	
17	0.890–0.920	1 x 1 km	Atmospheric water vapor
18	0.931–0.941	1 x 1 km	
19	0.915–0.965	1 x 1 km	
20	3.600–3.840	1 x 1 km	Surface–cloud temperature
21	3.929–3.989	1 x 1 km	
22	3.929–3.989	1 x 1 km	
23	4.020–4.080	1 x 1 km	
24	4.433–4.498	1 x 1 km	Atmospheric temperature
25	4.482–4.549	1 x 1 km	
26	1.360–1.390	1 x 1 km	Cirrus clouds
27	6.535–6.895	1 x 1 km	Water vapor
28	7.175–7.475	1 x 1 km	
29	8.400–8.700	1 x 1 km	
30	9.580–9.880	1 x 1 km	Ozone
31	10.780–11.280	1 x 1 km	Surface–cloud temperature
32	11.770–12.270	1 x 1 km	
33	13.185–13.485	1 x 1 km	Cloud top altitude
34	13.485–13.785	1 x 1 km	
35	13.785–14.085	1 x 1 km	
36	14.085–14.385	1 x 1 km	

Jensen 2000

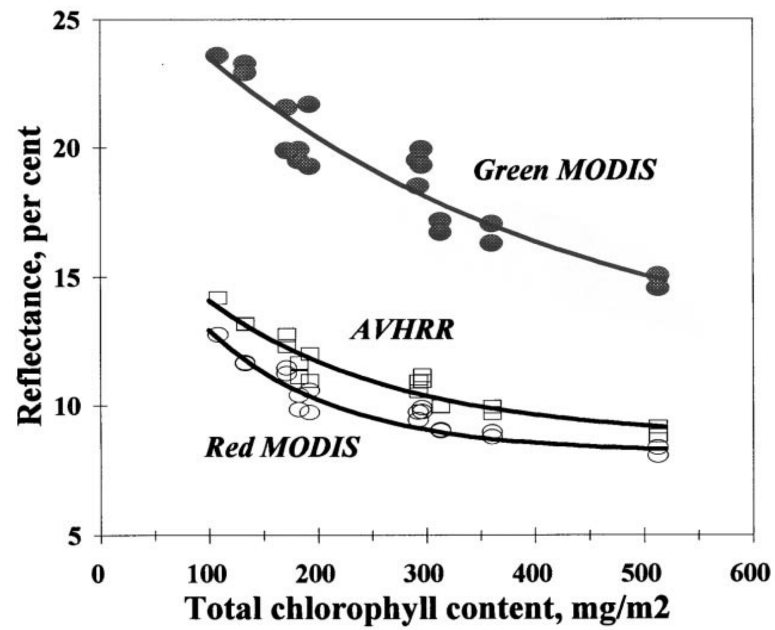


Multispectral images of Wólka Kosowska (10 mai 2011) acquired with sensor MODIS/Aqua

Multispectral Remote Sensing systems



a



b

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

Very High-Resolution Linear Array Remote Sensing Systems

	Space Imaging, Inc. IKONOS		ORBIMAGE, Inc. OrbView-3			EarthWatch, Inc. Quickbird		
Band	Spectral Resolution (μm)	Spatial Resolution (m) at Nadir	Band	Spectral Resolution (μm)	Spatial Resolution (m) at Nadir	Band	Spectral Resolution (μm)	Spatial Resolution (m) at Nadir
1	0.445 – 0.516	4 x 4	1	0.45 – 0.52	4 x 4	1	0.45 – 0.52	2.4 x 2.4
2	0.506 – 0.595	4 x 4	2	0.52 – 0.60	4 x 4	2	0.52 – 0.60	2.4 x 2.4
3	0.632 – 0.698	4 x 4	3	0.625 – 0.695	4 x 4	3	0.63 – 0.69	2.4 x 2.4
4	0.757 – 0.853	4 x 4	4	0.76 – 0.90	4 x 4	4	0.76 – 0.890	2.4 x 2.4
Pan	0.450 – 0.900	0.8 x 0.8	Pan	0.45 – 0.90	1 x 1	Pan	0.45 – 0.90	0.6 x 0.7
Sensor	Linear array pushbroom		Linear array pushbroom			Linear array pushbroom		
Swath	11 km		8 km			16.5 km		
Rate	25 Mb/s		50 Mb/s			50 Mb/s		
Revisit	< 3 days		< 3 days			1 to 5 days depending on latitude		
Orbit	681 km, Sun-synchronous Equatorial crossing 10 – 11 am		470 km, Sun-synchronous Equatorial crossing 10:30 a.m.			450 km, Sun-synchronous Equatorial crossing variable		
Launch	Apr 1999 (failed), Sep 1999		2000			2000		
Field of regard	up to 45 degrees off nadir		up to 50 degrees off nadir			up to 30 degrees off nadir		

Lockheed Martin Corp.
GeoEye

ORBIMAGE
GeoEye

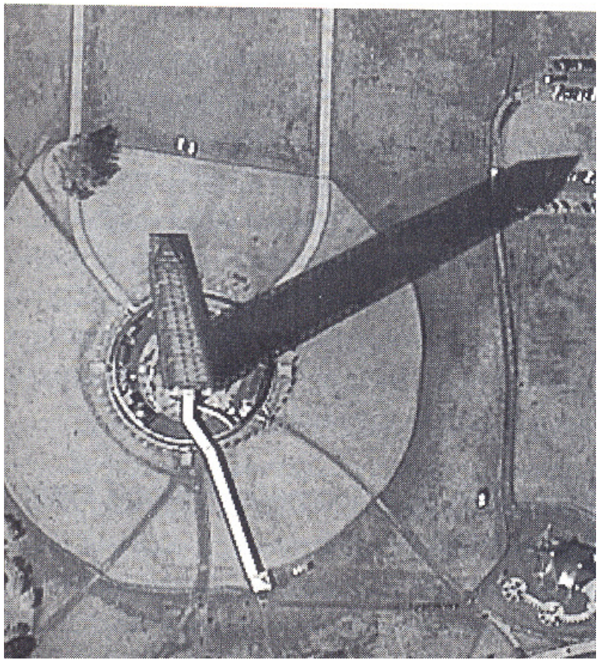
DigitalGlobe

Jensen 2000

Multispectral Remote Sensing systems

Multispectral Imaging Using Linear Arrays

Very High-Resolution Linear Array Remote Sensing Systems



Washington monument

Space Imaging, Inc., IKONOS 1 x 1 m panchromatic image of downtown Washington, DC

Jensen 2000

Hyperspectral Remote Sensing systems

NASA Earth Observing EO-1
HYPERION - hyperspectral imager

Imaging spectrometry - *t*he simultaneous acquisition of images in many relatively narrow, contiguous and/or non-contiguous spectral bands throughout the ultraviolet, visible and infrared portions of the spectrum.

Parameters	
Spectral range	400 – 2400 nm
Spatial resolution	30 m
Swath width	7.6 km
Spectral resolution	10 nm
Total number of bands	220

HYPERION - First accomplishments:

Acquire hyperspectral observations of the Earth with Landsat spatial resolution (30 m) and AVIRIS spectral resolution (10 nm) over the entire Landsat reflective range.

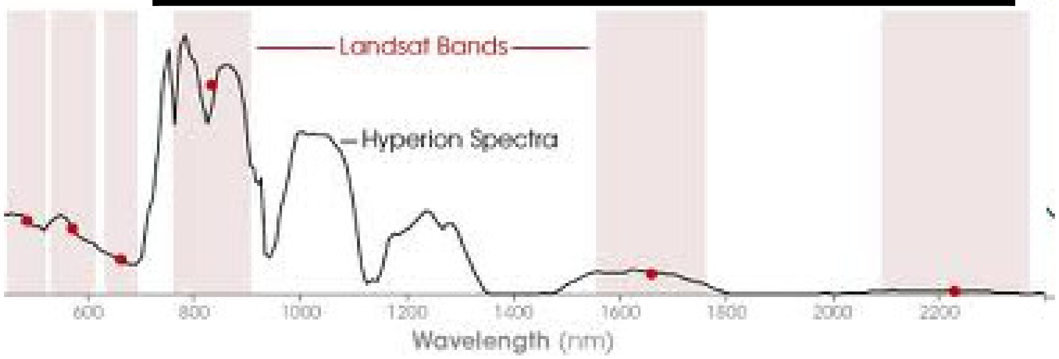
Accurately map and characterize temperature distributions of active lava flows and forest fire "hot spots" from space.

Track re-growth in partially logged Amazon forests and reliably estimate Amazon forest drought stress.

Demonstrate that spaceborne hyperspectral sensors can identify and map vegetation species (including invasive species), canopy nitrogen concentrations, and minerals.

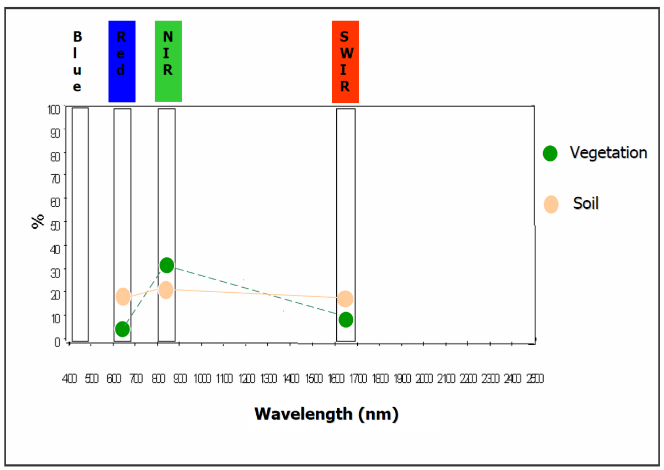
Map several fire fuel classes from space at very high accuracies, including senesced grass and soil.

Separate total carbon into living biomass, dead biomass, and soil background with high accuracy.

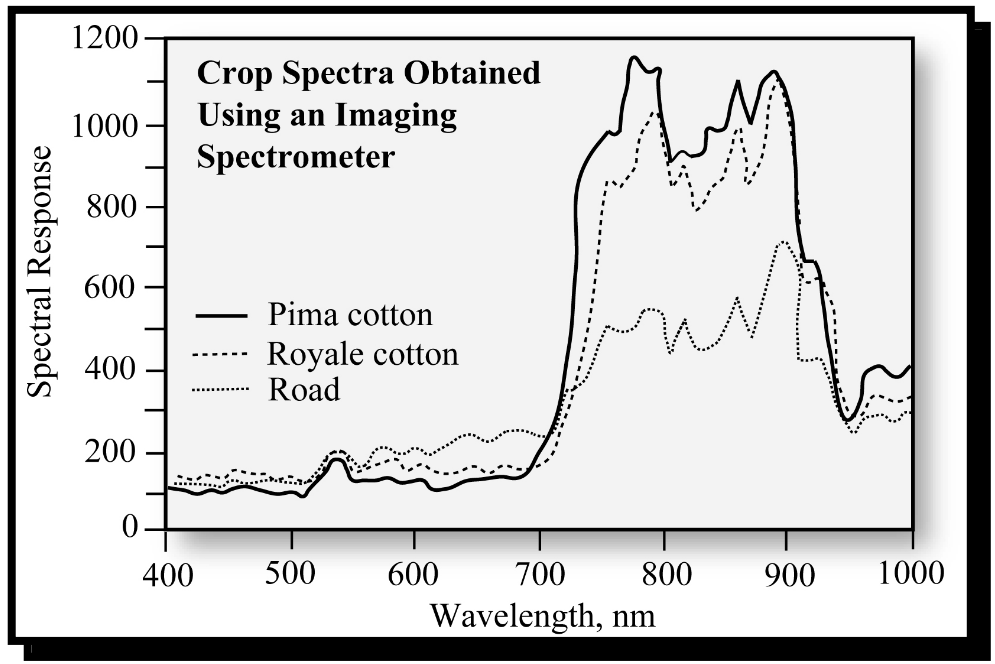


Imaging Spectrometry Using Linear and Area Arrays

Imaging spectrometry - *t*he simultaneous acquisition of images in many relatively narrow, contiguous and/or non-contiguous spectral bands throughout the ultraviolet, visible and infrared portions of the spectrum.



SPOT-VEGETATION sensor bands

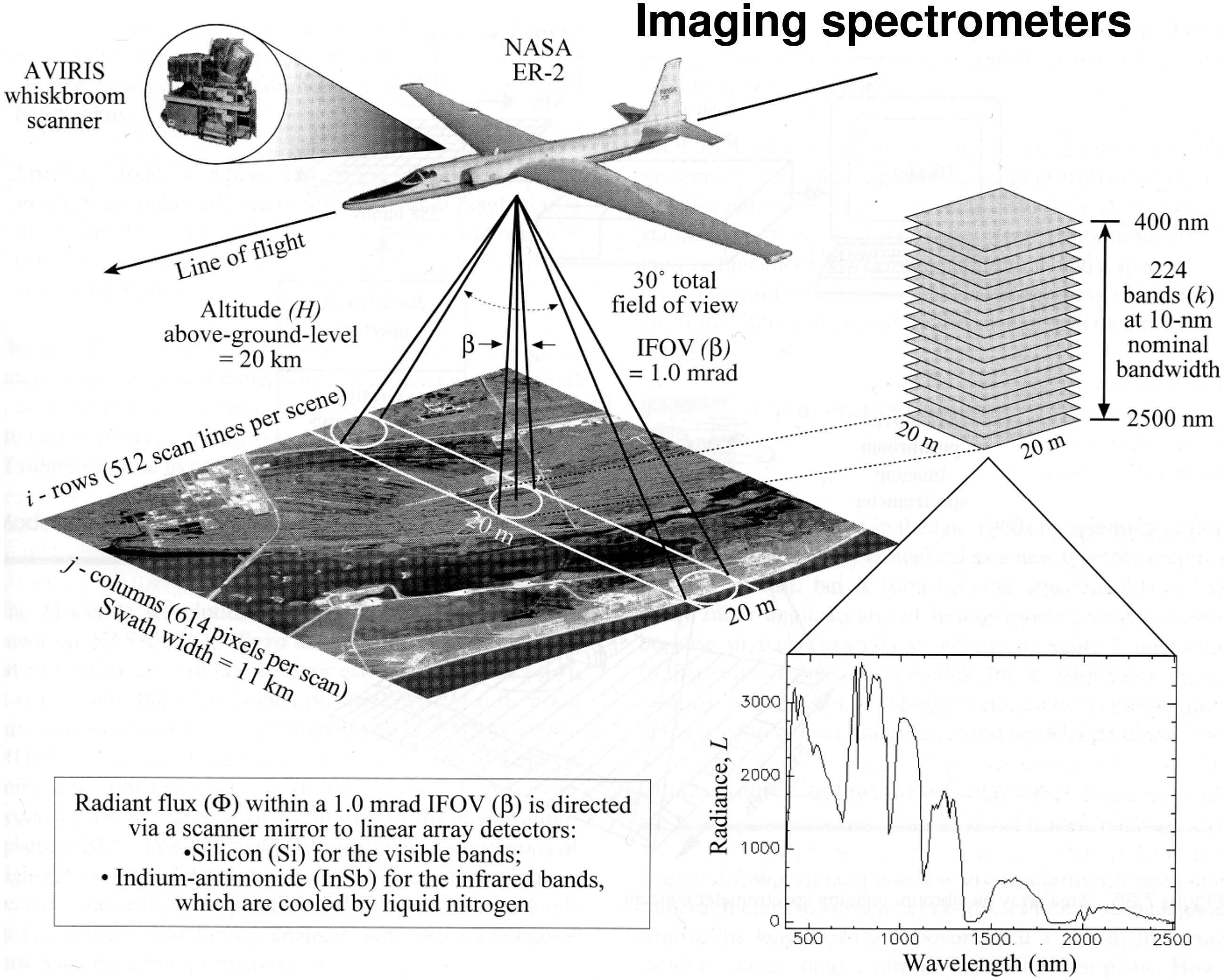


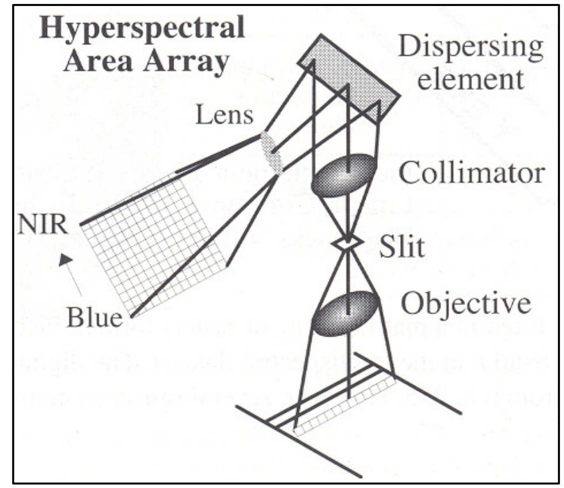
Imaging spectrometer crop spectra for three surfaces extracted from 2 x 2 m data obtained using a Hughes Wedge Imaging Spectrometer

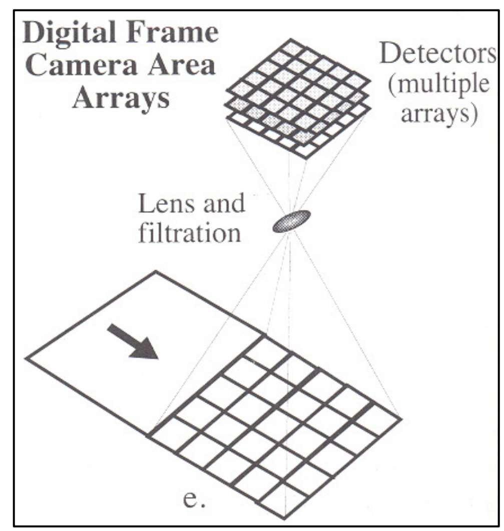
Jensen 2000

Imaging Spectrometry Using Linear and Area Arrays

Imaging spectrometers







Jensen 2000

Imaging Spectrometry Using Linear and Area Arrays

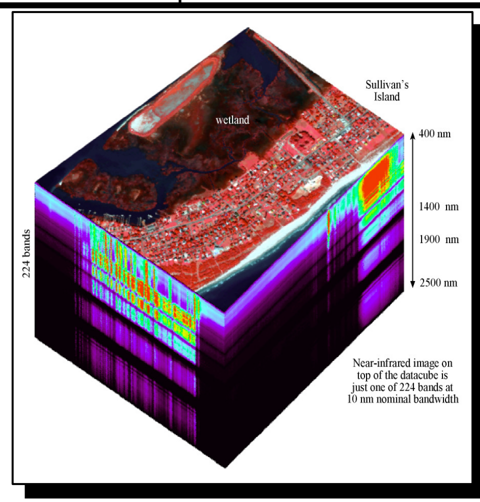
Imaging spectrometers

Airborne Visible Infrared Imaging Spectrometer (AVIRIS)

Compact Airborne Spectrographic Imager-2 (CASI-2)

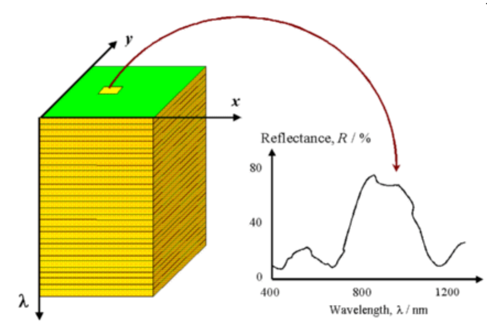
Sensor	Technology	Spectral resolution (nm)	Spectral interval (nm)	Data collection mode
AVIRIS	Whiskbroom linear array	400 – 2500	10	224 bands
CASI-2	Area array CCD (512 x 288)	400 – 1000	1.9	288 bands

NASA/ARC ER-2 aircraft



Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island

Hyperspectral data cube



Imaging Spectrometry Using Linear and Area Arrays

Airborne Systems

Advantages

- Flexible Timetable
- Resolution determined by altitude
- Large number of bands available

Disadvantages

- Cost
- Operational complexity

Digital Frame Cameras

Mechanical shutter opens, exposing the CCD sensor to light.

Light is converted to a charge in the CCD

The shutter closes, blocking the light.

The charge is transferred to the CCD output register and converted to a signal.

The signal is digitized and stored in computer memory

The stored image is processed and displayed on the camera's liquid crystal display (LCD), on a computer screen, or used to make hard-copy prints.

Satellite Photographic Systems

KVR-1000 camera

Spatial Resolution	2 m
Imaging Channels	1 channel
Spectral Range	580-720 nm (panchromatic)
Image size	18 x 72 cm
Covered area	40 x 160 км
Orbital Altitude	220 км
Average scale	1:220 000
Focus	1000 mm

Pyramids Gizeh
Courtesy of National Point of Contact

The main advantages of KVR-1000 images are:

•large covered square by one frame,
•high resolution of the images,
•big volume of the archive images.

Remote Sensing systems

Technology	Spatial Resolution	Spectral Resolution	Cost to Acquire
Space-based			
IKONOS	16 m^2	4 bands	\$27–62 km^2
Quickbird II	6.25 m^2	4 bands	\$30 km^2
LandSat	900 m^2	6 bands	\$0.0015 km^2
Hyperion	900 m^2	220 bands	NA
Aircraft			
Hyperspectral	9 m^2	74 bands	\$325 km^2
Color Aerial Photography	1 m^2	3 bands	\$175 km^2