Remote Sensing

Ch. 2 Sensors (Part 3 of 3)

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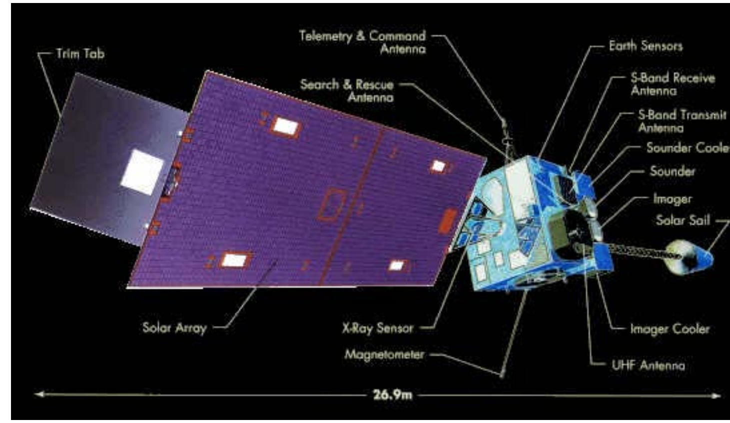
2.11 Weather Satellites/Sensors

- **Weather monitoring & forecasting** was one of **the first civilian applications** (as opposed to military) of satellite RS
- **In 1960**, the US, **TIROS-1** (Television and Infrared Observation Satellite - 1) : the first true weather satellite.
- **In 1966**, NASA, **ATS-1** (Applications Technology Satellite - 1) : geostationary orbit which provided hemispheric images of the Earth's surface and cloud cover every half hour. For the first time, the development and movement of weather systems could be routinely monitored.
- **Today**, several countries operate weather or meteorological satellites
    - have fairly **coarse spatial resolution** (when compared to systems for observing land) and provide **large areal coverage**.
    - quite **high temporal resolutions** 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.
    - **GOES, NOAA AVHRR, DMSP, GMS, Meteosat etc.**

2.11 Weather Satellites/Sensors

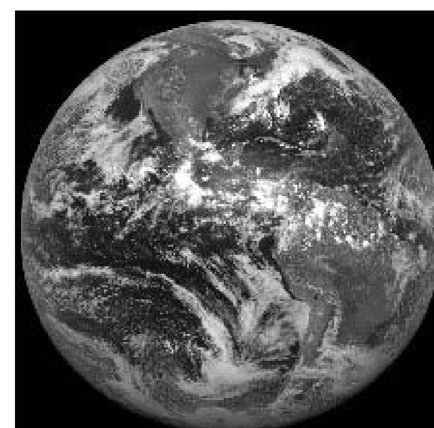


GOES (Geostationary Operational Environmental Satellite) System

• designed to provide the US National Weather Service with **frequent**, **small-scale imaging** of the Earth's surface and cloud cover, and used extensively by meteorologists for weather monitoring and forecasting for over 20 years.

• Two GOES satellites, placed in **geostationary** orbits **36,000 km** above the equator, each view approximately **one-third of the Earth**. **(1)** One is at **75°W** longitude and monitors North and South America and most of the Atlantic Ocean. **(2)** The other is 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 US, and the adjacent ocean areas where many severe storms originate and develop.

• **GOES Full Disk Visible Image** of North and South America displaying various cloud patterns (**mesoscale thunderstorms, "comma-shaped" cyclonic storms**).



2.11 Weather Satellites/Sensors

- **GOES-1 (1975) ~ GOES-7 (1992)** : viewing the Earth only a small percentage of the time (~5%).

- **GOES-8 (1994) ~** : 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.
  - have separate **imaging** and **sounding** instruments.

  - **Imager : 5 channels** sensing visible and IR reflected and emitted solar radiation. The infrared capability allows for day and night imaging. Sensor pointing and scan selection capability allows meteorologists to monitor specific weather trouble spots to assist in improved short-term forecasting. The imager data are **10-bit radiometric resolution**, and can be transmitted directly to local user terminals on the Earth's surface.

  - Sounder : 19 channel (18 thermal IR bands & 1 visible band).
  a spatial resolution of 8 km and **13-bit radiometric resolution**. used for **surface & cloud-top temperatures**, multi-level **moisture profiling** in the atmosphere, and **ozone distribution** analysis.

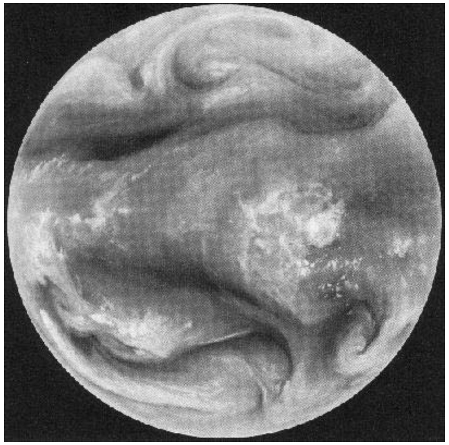
2.11 Weather Satellites/Sensors

GOES Imager Bands

Band	Wavelength Range (μm)	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 & volcanoes; night time determination of sea surface temperatures
3	6.47 - 7.02 (upper level water vapor)	4 km	estimating regions of mid-level moisture content and advection; 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 to water vapor)	4 km	identification of low-level moisture; determination of sea surface temperature; detection of airborne dust and volcanic ash

2.11 Weather Satellites/Sensors

- **Infradred Image** of Hurricane Fran approaching the southeastern US and the Bahamas in September 1996 (white is coldest & hightest elevation clouds).



* **Water Vapor Imagery :** It is possible to record **energy radiated by water vapor** in the **6.7 micrometer** range. Images are similar to the thermal infrared but with less well defined boundaries. By monitoring the **circulation patterns** throughout the day, it is possible to **estimate atmospheric wind speeds** and **directions** which allows for the **rapid updating of weather maps.**

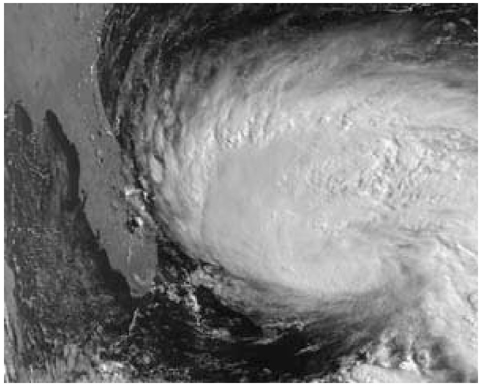
- **Natural Color Image** (same time/location as water vapor image); note that the water vapor image provides a much better representation of the **atmospheric circulation patterns**.

2.11 Weather Satellites/Sensors

NOAA AVHRR

- **sun-synchronous, near-polar orbits** (**830-870 km** above the Earth) and provide complementary information to the geostationary meteorological satellites (e.g. GOES).
- **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 crosses the equator in the early morning while the other crosses in the afternoon.

- The primary sensor **Advanced Very High Resolution Radiometer (AVHRR)** is used for both meteorology and small-scale Earth observation and reconnaissance, and detects radiation in the **visible**, **near** and **mid IR**, and **thermal IR** portions of the EM spectrum, over a **swath width of 3000 km**.



NOAA AVHRR Bands

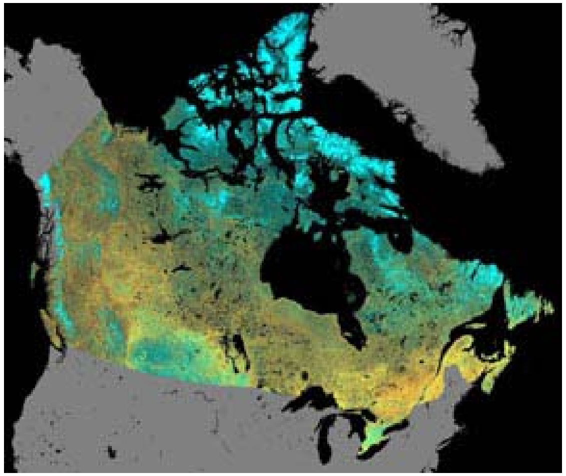
Band	Wavelength Range (μm)	Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 - 3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, & forest fire activity
4	10.3 - 11.3(thermal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

2.11 Weather Satellites/Sensors

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

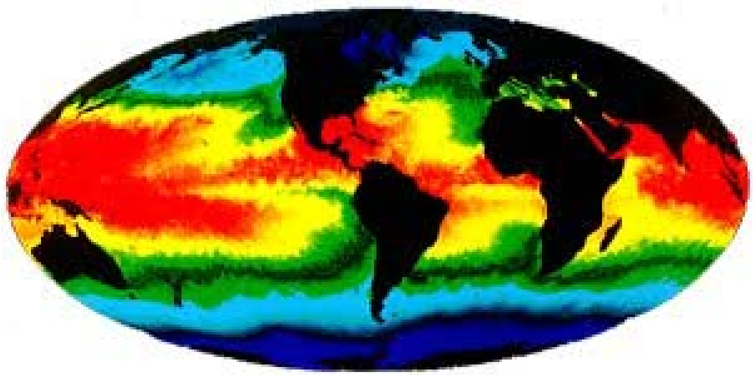
Format	Spatial Resolution	Transmission and Processing
APT (Automatic Picture Transmission)	4 km	low-resolution direct transmission and display
HRPT (High Resolution Picture Transmission)	1.1 km	full-resolution direct transmission and display
GAC(Global Area Coverage)	4 km	low-resolution coverage from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

AVHRR has much **coarser spatial resolution** than other typical land observations sensors, but is used extensively for **monitoring regional, small-scale phenomena**, including mapping of **sea surface temperature**, and natural **vegetation & crop conditions**. Mosaics covering large areas can be created from several AVHRR data sets allowing small scale analysis and mapping of broad vegetation cover.



2.11 Weather Satellites/Sensors

NOAA/TIROS Sea Surface Temperature: red represent higher sea surface temperature, blue lower sea surface temperature.



NOAA/TIROS Vegetation Cover: mosaic of false-color images for the northern hemisphere showing summer vegetation.

2.11 Weather Satellites/Sensors

Other Weather Satellites

DMSP (Defense Meteorological Satellite Program) series of satellites

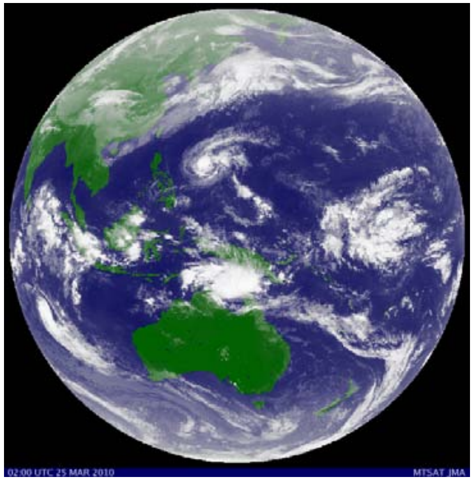
- used for weather monitoring.
- **near-polar orbiting** satellites whose Operational Linescan System **(OLS) sensor** provides **twice daily** coverage with a **swath width of 3000 km** at a **spatial resolution of 2.7 km.**
- **two broad bands**: a visible and near IR band (**0.4 to 1.1 µm**) and a thermal IR band (**10.0 to 13.4 µm**)
- An interesting feature of the sensor is its ability to acquire **visible band night time imagery** under very low illumination conditions. With this sensor, it is possible to collect striking images of the Earth showing (typically) the night time lights of large urban centers.

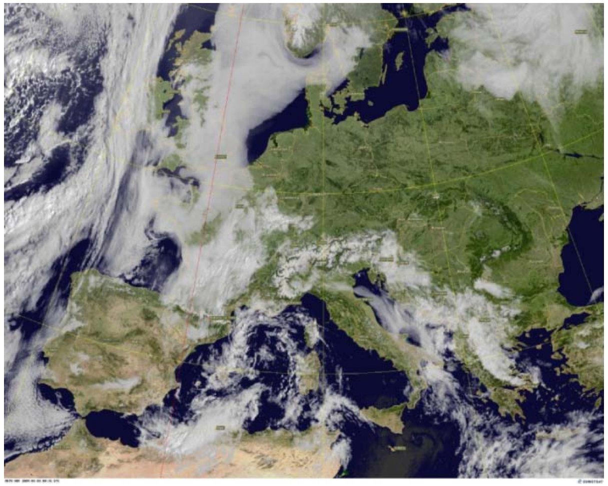
2.11 Weather Satellites/Sensors

Other Weather Satellites

GMS satellite series (by Japan) and **Meteosat** satellites (by the consortium of European communities)

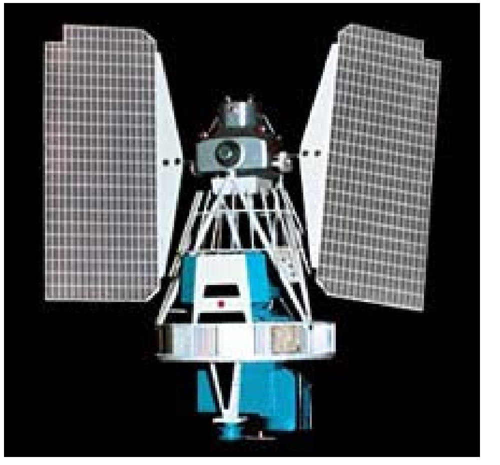
- Both are **geostationary** satellites situated above the equator over Japan and Europe, respectively.
- Both provide **half-hourly imaging** of the Earth similar to GOES.
- **GMS** has **2 bands**: 0.5 to 0.75 μm (1.25 km resolution), and
  10.5 to 12.5 μm (5 km resolution).
- **Meteosat** has **3 bands**: visible band (0.4 to 1.1 μm; 2.5 km resolution),
  mid-IR (5.7 to 7.1 μm; 5 km resolution), and
  thermal-IR (10.5 to 12.5 μm; 5 km resolution).





2.12 Land Observation Satellites/Sensors

Landsat



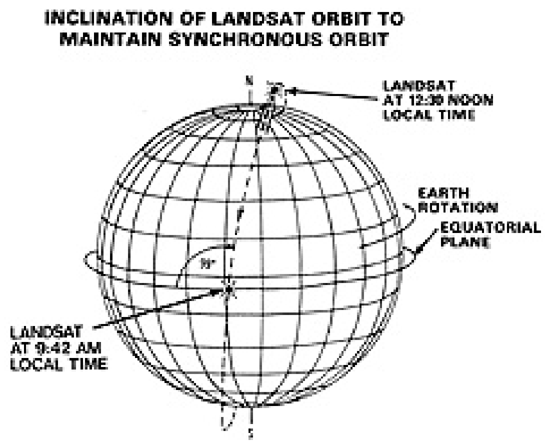
- The first satellite designed specifically to monitor the Earth's surface, **Landsat-1**, was launched by NASA in **1972**. Initially referred to as ERTS-1, (Earth Resources Technology Satellite), **Landsat** was designed as an experiment to test the feasibility of collecting **multi-spectral Earth observation data** from an unmanned satellite platform.

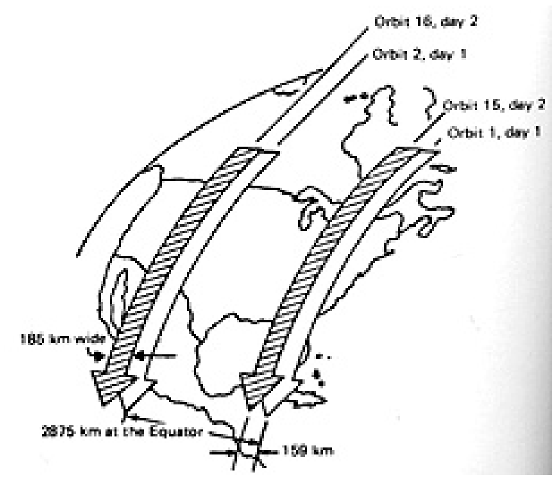
- In **1985**, the program became **commercialized**, providing data to civilian and applications users. The long lifespan of the program has provided **a voluminous archive of Earth resource data** facilitating long term monitoring and historical records and research.

- **Landsat's success** is due to several factors, including: **(1)** a combination of sensors with spectral bands tailored to Earth observation; **(2)** functional spatial resolution; and **(3)** good areal coverage (swath width and revisit period).

2.12 Land Observation Satellites/Sensors

- All Landsat satellites are placed in **near-polar**, **sun-synchronous** orbits, and at around **700 km** and have revisit periods of **16 days,** and have **equator crossing times in the morning** to optimize illumination conditions.



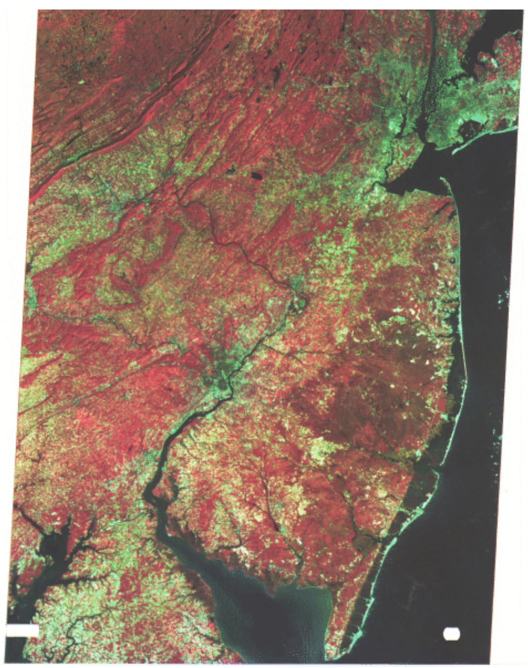


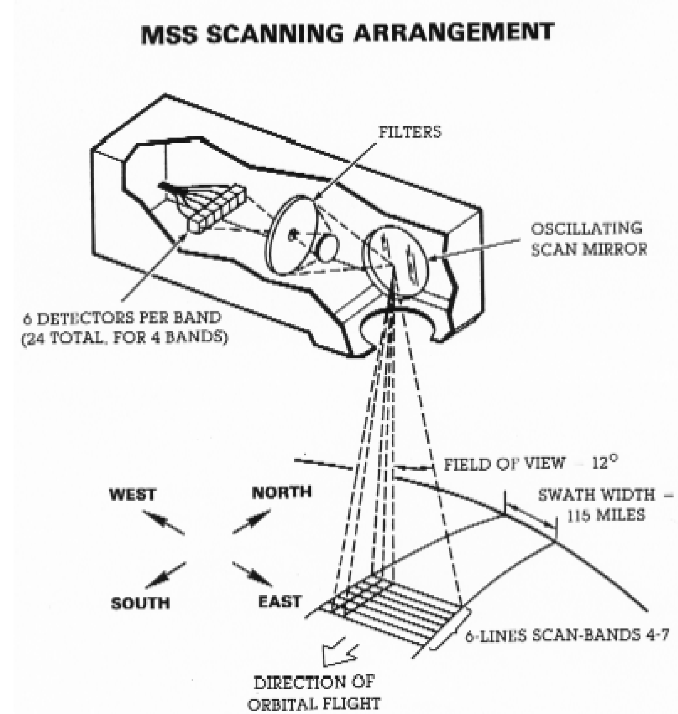
- Sensors on board the Landsat series of satellites,
  - the **Return Beam Vidicon (RBV)** camera systems
  - the **MultiSpectral Scanner (MSS)** systems
  - the **Thematic Mapper (TM)**.

- The most popular instrument in the early days of Landsat was the MultiSpectral Scanner (**MSS**) and later the Thematic Mapper (**TM**). Each of these sensors collected data over **a swath width of 185 km**, with a full scene being defined as 185 km x 185 km.

2.12 Land Observation Satellites/Sensors

- The **MSS** senses the EM radiation from the Earth's surface in **4 spectral bands**. Each band has a spatial resolution of approximately **60 x 80 meters** and a radiometric resolution of **6 bits**. Sensing is accomplished with **a line scanning device** using an oscillating mirror. **Six scan lines** are collected simultaneously with each west-to-east sweep of the scanning mirror.





MSS Bands 4 : Blue
MSS Bands 5 : Green
MSS Bands 7 : Red

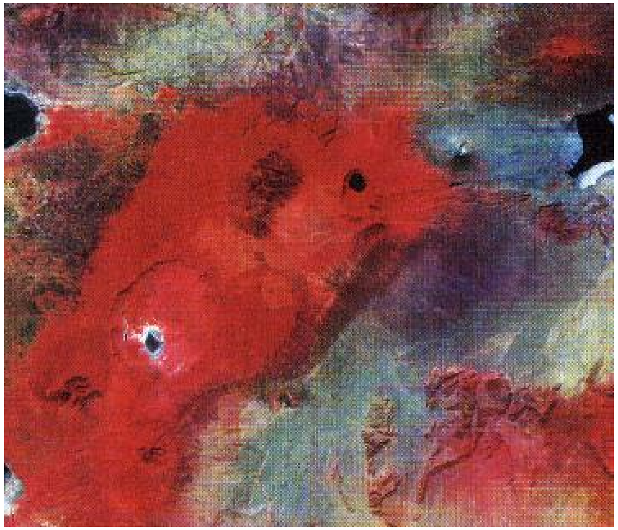
MSS Bands

Channel		Wavelength Range (µm)
Landsat 1,2,3 (79m resolution)	Landsat 4,5 (82m resolution)	
MSS 4	MSS 1	0.5 - 0.6 (green)
MSS 5	MSS 2	0.6 - 0.7 (red)
MSS 6	MSS 3	0.7 - 0.8 (near infrared)
MSS 7	MSS 4	0.8 - 1.1 (near infrared)

2.12 Land Observation Satellites/Sensors

- **Return Beam Vidicon (RBV):** This sensor is similar to a **video camera** and was used on **Landsat 1,2,3**. The RBV provided a **higher resolution (30 meter) panchromatic** (single band) image which hade the advantage of higher ground resolution than the MSS. With the advent of the 30 meter TM 7 band images, the RBV system was not used after Landsat 3.

- **Standard RGB Array**: **Landsat MSS bands 4, 5, and 7** are the equivalent energy levels used for **Color Infrared photographs**. By combining these three bands to produce a False Color Composite, it is possible to duplicate CIR photography. The intensities for each MSS band are represented as: **MSS band 4 = Blue, MSS band 5 = Green, MSS band 7 = Red**

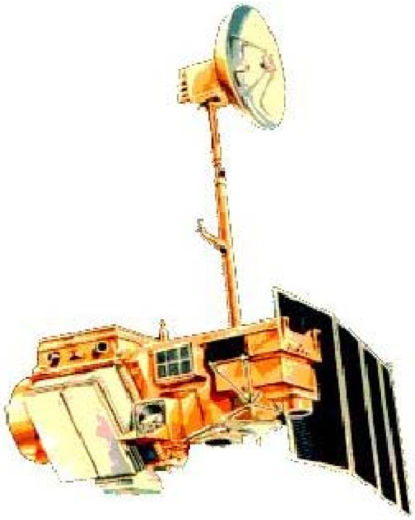


Rift Valley of Kenya & Tanzania - dry season

2.12 Land Observation Satellites/Sensors

• Routine collection of MSS data ceased in 1992, as the use of TM data, starting on **Landsat 4**, superseded the MSS.

• The **TM** sensor provides several **improvements over the MSS** sensor including:
(1**) higher spatial** (30m) and **radiometric** (8 bits) resolution;
(2) **finer spectral bands** (7 as opposed to 4 spectral bands);
(3) an **increase in the number of detectors** per band (16 for the non-thermal channels vs 6 for MSS).



Landsat 4

• **16 scan lines** are captured simultaneously for each non-thermal spectral band (four for thermal band), using an oscillating mirror which scans during both the forward (west-to-east) and reverse (east-to-west) sweeps of the scanning mirror. This difference from the MSS increases the **dwell time** and improves the geometric and radiometric integrity of the data.

• Spatial resolution of TM is **30 m** for all but the thermal infrared band (120 m). All channels are recorded over a range of 256 digital numbers (**8 bits**).

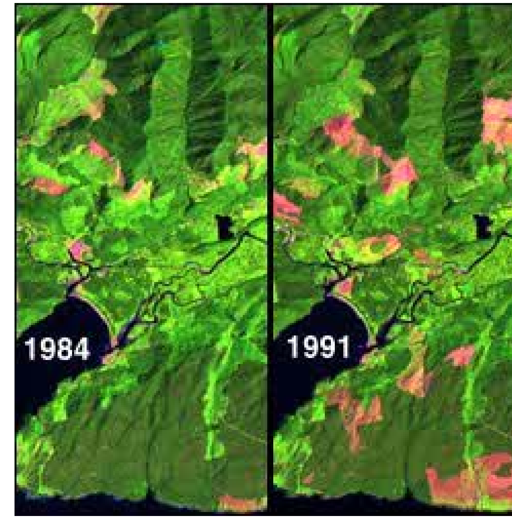
2.12 Land Observation Satellites/Sensors

TM Bands

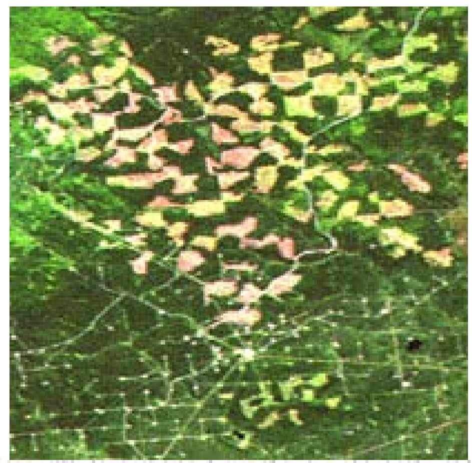
Channel	Wavelength Range (μm)	Application
TM 1	0.45 - 0.52 (blue)	soil/vegetation discrimination; coastal water mapping; deciduous/coniferous differentiation
TM 2	0.52 - 0.60 (green)	green reflectance by healthy vegetation mapping
TM 3	0.63 - 0.69 (red)	vegetated vs. non-vegetated and plant species discrimination (plant chlorophyll absorption)
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

2.12 Land Observation Satellites/Sensors

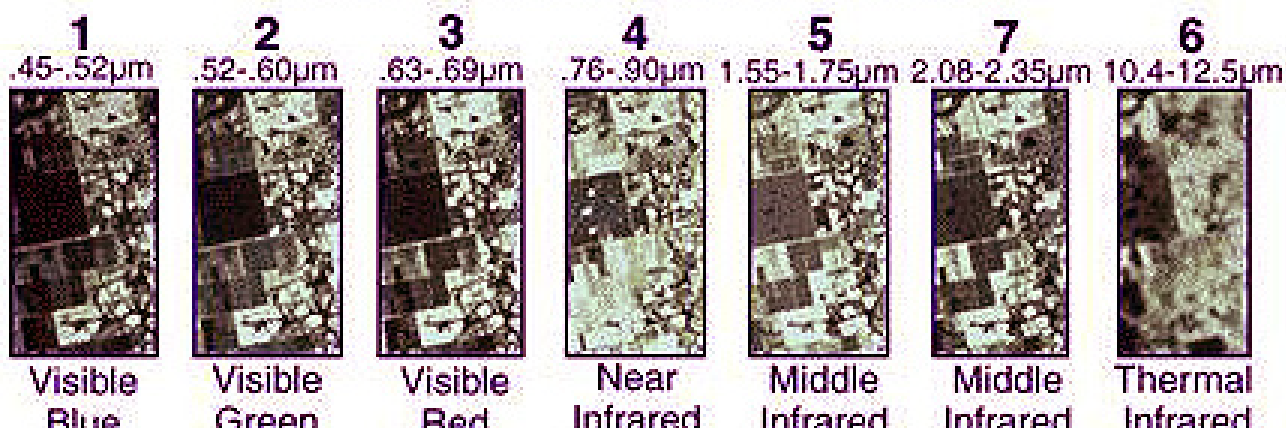
- Data from both the TM and MSS sensors are used for a wide variety of applications, including **resource management**, **mapping**, **environmental monitoring**, and **change detection** (e.g. monitoring forest clearcutting).



- The high spatial and spectral resolution of Landsat TM makes it possible to clearly delineate harvested areas (clearcuts) in a conifer forest in northern Alberta, Canada

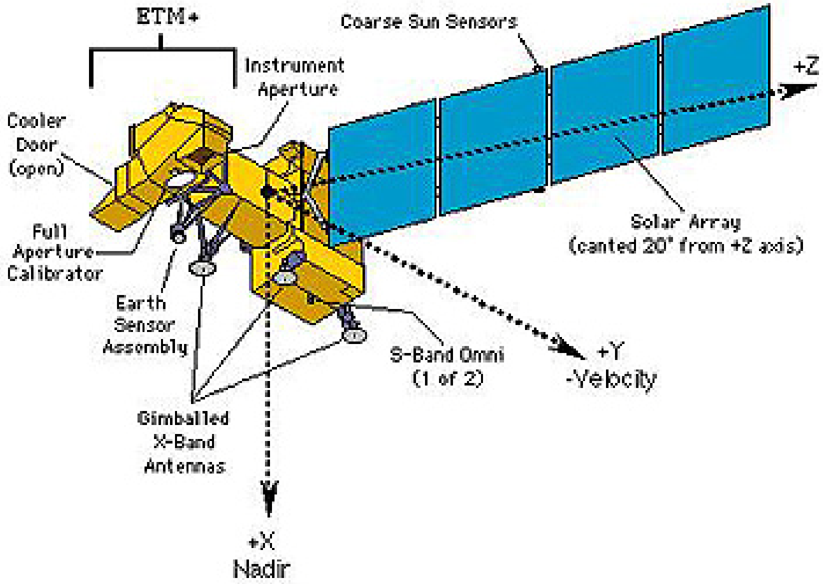


A scene in Florida



2.12 Land Observation Satellites/Sensors

- **Landsat 7** mounts only a single payload, the **Enhanced Thematic Mapper** (**ETM+**). The ETM+ includes not only the **7 TM bands** (the thermal band [6] has 60 m resolution), but also a **panchromatic band** that is capable of **15 m** resolution.



- Part of the Landsat 7 panchromatic image showing a portion of Sioux Falls, with individual buildings now resolvable.

2.12 Land Observation Satellites/Sensors

SPOT (Système Pour l'Observation de la Terre / Earth-observing Satellites)

- A series of Earth observation imaging satellites designed and launched by **France**, with support from Sweden and Belgium. **SPOT-1** was launched in **1986**, with successors following every three or four years.

- All satellites are in **sun-synchronous**, **near-polar** orbits at altitudes around **830 km** above the Earth, which results in orbit repetition every **26 days**. They have **equator crossing times around 10:30 AM** local solar time.

- SPOT was designed to be a commercial provider of Earth observation data, and was **the first satellite to use along-track (or pushbroom)** scanning technology.

2.12 Land Observation Satellites/Sensors

- The SPOT satellites each have **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 (PLA)** mode, or a **coarser spatial resolution** 3-channel **multispectral (MLA)** mode.

- Each along-track scanning HRV sensor consists of **4 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. The swath width for both modes is **60 km** at nadir.

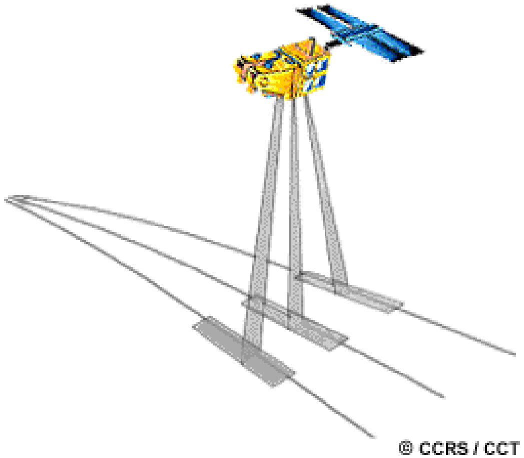
HRV Mode Spectral Ranges

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)

2.12 Land Observation Satellites/Sensors

- 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.**

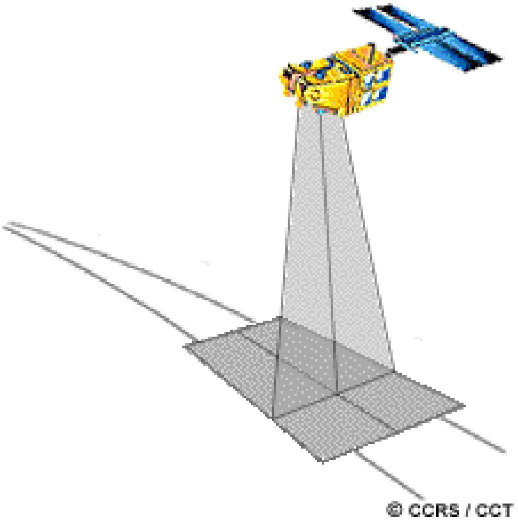
- This ability to point the sensors up to 27° from nadir, allows SPOT to view within a **950 km swath** and to revisit any location **several times per week**.



- As the sensors point away from nadir, the swath 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**.

- This oblique viewing capability increases the revisit frequency of **equatorial regions** to **3 days** (7 times during the 26 day orbital cycle). Areas at a **latitude of 45º** can be imaged more frequently (**11 times in 26 days**) due to the convergence or orbit paths towards the poles.

2.12 Land Observation Satellites/Sensors



- By pointing both HRV sensors to cover **adjacent ground swaths** at nadir, **a swath of 117 km** (3 km overlap between the two swaths) can be imaged. In this mode of operation, either panchromatic or multispectral data can be collected, but not both simultaneously.

- SPOT's benefits over other spaceborne optical sensors. (1) Its **fine spatial resolution** and (2) **pointable sensors** are the primary reasons for its popularity. (3) The 3-band multispectral data are well suited to displaying as false-color images and the panchromatic band can also be used to "sharpen" the spatial detail in the multispectral data.

- SPOT allows applications requiring fine spatial detail (such as **urban mapping**) to be addressed while retaining the cost and timeliness advantage of satellite data. Applications requiring frequent monitoring (agriculture, forestry) are well served by the SPOT sensors. The **stereoscopic imagery** from SPOT has played an important role in mapping applications and in the derivation of **Digital Elevation Models (DEMs)** from satellite data.

2.12 Land Observation Satellites/Sensors

IRS (Indian Remote Sensing)

IRS satellite series, combines features from both the Landsat MSS/TM sensors and the SPOT HRV sensor. The third satellite in the series, **IRS-1C**, launched in December, **1995** has three sensors:

(1) a single-channel panchromatic (**PAN**) **high resolution** camera
(2) a **medium resolution** 4-channel Linear Imaging Self-scanning Sensor (**LISS-III**)
(3) a **coarse resolution** 2-channel Wide Field Sensor (**WiFS**)

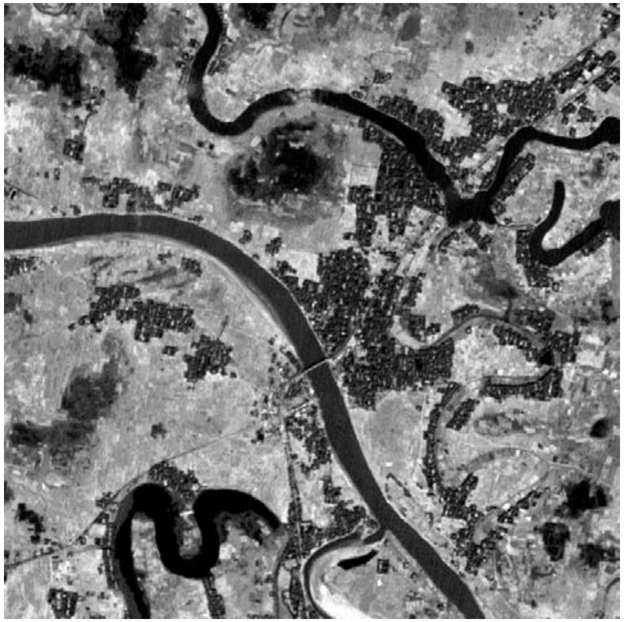
Sensor	Wavelength Range (μm)	Spatial Resolution	Swath Width	Revisit Period (at equator)
PAN	0.5 - 0.75	5.8 m	70 km	24 days
LISS-III				
Green	0.52 - 0.59	23 m	142 km	24 days
Red	0.62 - 0.68	23 m	142 km	24 days
Near IR	0.77 - 0.86	23 m	142 km	24 days
Shortwave IR	1.55 - 1.70	70 m	148 km	24 days
WiFS				
Red	0.62 - 0.68	188 m	774 km	5 days
Near IR	0.77 - 0.86	188 m	774 km	5 days

2.12 Land Observation Satellites/Sensors

- In addition to its high spatial resolution, the panchromatic sensor can be steered up to 26° across-track, enabling **stereoscopic imaging** and **increased revisit** capabilities (as few as five days), similar to SPOT. This high resolution data is useful for urban planning and mapping applications.

- The **4 LISS-III multispectral bands** are similar to Landsat's TM bands 1 to 4 and are excellent for **vegetation discrimination**, **land-cover mapping**, and **natural resource planning**.

- The **WiFS sensor** is similar to NOAA AVHRR bands and the spatial resolution and coverage is useful for **regional scale vegetation monitoring**.

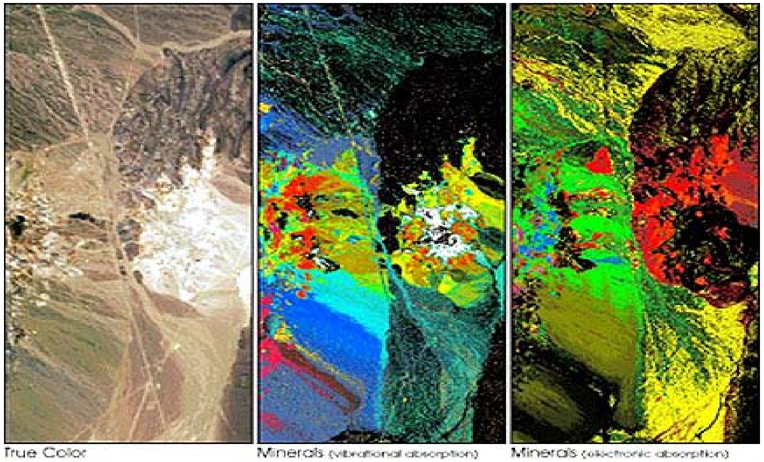


2.12 Land Observation Satellites/Sensors

hyperspectral satellites

Hyperspectral remote sensing allows a sensor to gather reflected radiation such that a special detector system consisting of CCD devices can record more than **200 spectral channels** simultaneously over the visible and IR wavelength ranges. With sampling at a **0.01 μm (10 nanometer) interval,** it is possible to plot the data as quasi-continuous narrow bands that approximate a **spectral signature** rather than histogram-like broader bands. With such detail, the **ability to detect and identify** individual materials or classes greatly **improves**. The **AVIRIS** (Airborne Visible/InfraRed Imaging Spectrometer), instrument developed at JPL, has **224 channel** over the ranges **from 0.38 to 2.5 μm.** Two hyperspectral satellites, **Hyperion** and **Proba**, now in orbit, demonstrate this capability.

The left image shows the area mapped as rendered in a **near natural color** version; the center image utilizes narrow bands that are at wavelengths in which certain **minerals** reflect energy; in the right image, modes are **electronic absorption**



2.12 Land Observation Satellites/Sensors

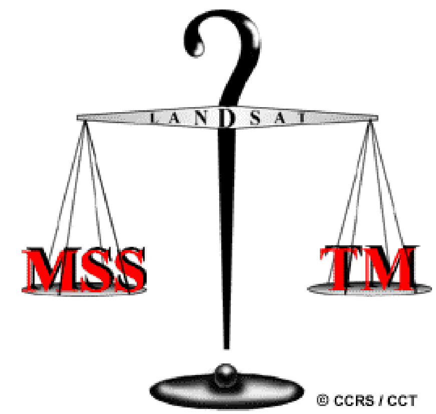
Did You Know?

- The Landsat title was used to distinguish the program from another satellite program in the planning stages, called Seasat, intended primarily for oceanographic applications. **The first Seasat** satellite was successfully launched in **1978**, but unfortunately was only operational for 99 days. Even though the satellite was short-lived and the Seasat program was discontinued, it collected some of **the first RADAR images** from space which helped heighten the interest in satellite RADAR remote sensing. Today, several RADAR satellites are operational or planned.

- originally the **MSS** sensor numbering scheme (bands 4, 5, 6, and 7) came from their numerical sequence after the 3 bands of the **RBV**(Return Beam Vidicon) sensors. However, due to technical malfunctions with the RBV sensor and the fact that it was dropped from the satellite sensor payload with the launch of **Landsat-4**, the **MSS** bands were **renumbered from 1 to 4**. For the TM sensor, if we look at the wavelength ranges for each of the bands, we see that **TM6** and **TM7 are out of order** in terms of increasing wavelength. This was because the TM7 channel was added as an afterthought late in the original system design process.

2.12 Land Observation Satellites/Sensors

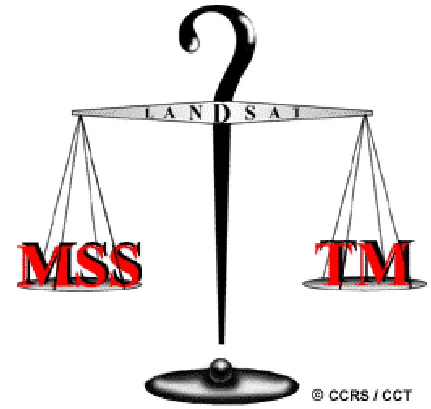
Quiz Explain why data from the Landsat TM sensor might be considered more useful than data from the original MSS sensor.



ANS

2.12 Land Observation Satellites/Sensors

Quiz Explain why data from the Landsat TM sensor might be considered more useful than data from the original MSS sensor.



ANS Although the areal coverage of a TM scene is virtually the same as a MSS scene, TM offers higher spatial, spectral, and radiometric resolution.

- The spatial resolution is **30 m** compared to **80 m**. Thus, the level of spatial detail detectable in TM data is better.
- TM has **more spectral channels** which are **narrower** and **better placed** in the spectrum for certain applications, particularly vegetation discrimination.
- In addition, the increase from 6 bits to **8 bits** for data recording represents a four-fold **increase in the radiometric resolution** of the data.

- However, this does not mean that TM data are "better" than MSS data. Indeed, MSS data are still used to this day and provide an excellent data source for many applications. If the desired information cannot be extracted from MSS data, then perhaps the higher spatial, spectral, and radiometric resolution of TM data may be more useful.

2.13 Marine Observation Satellites/Sensors

The Earth's oceans cover more than two-thirds of the Earth's surface and play an important role in the global climate system. They also contain an abundance of living organisms and natural resources which are susceptible to pollution and other man-induced hazards.

Nimbus

- The **Nimbus-7** satellite, launched in **1978**, carried the first sensor, the **Coastal Zone Color Scanner (CZCS)**, specifically intended for monitoring the Earth's oceans and water bodies. The primary objective of this sensor was to observe ocean color and temperature, particularly in coastal zones, with sufficient spatial and spectral resolution to detect pollutants in the upper levels of the ocean and to determine the nature of materials suspended in the water column.

- The Nimbus satellite was placed in a **sun-synchronous**, **near-polar** orbit at an altitude of **955 km**. Equator crossing times were **local noon** for ascending passes and local midnight for descending passes. The repeat cycle of the satellite allowed for global coverage every **six days**, or every 83 orbits. The CZCS sensor consisted of **6 spectral bands** in the visible, near-IR, and thermal portions of the spectrum each collecting data at a **spatial resolution** of **825 m** at nadir over a **1566 km swath width**.

2.13 Marine Observation Satellites/Sensors

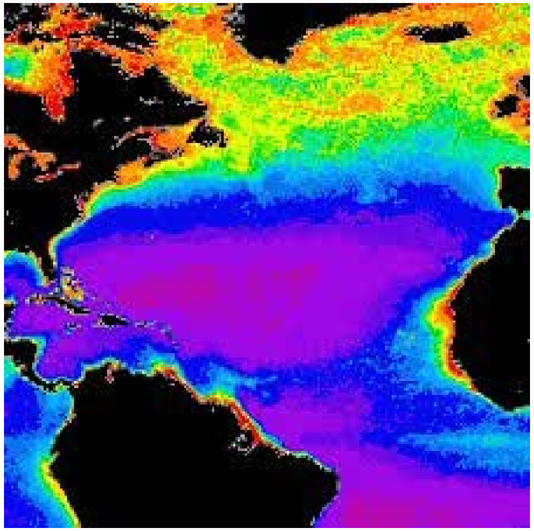
CZCS Spectral Bands

Channel	Wavelength Range (μm)	Primary Measured Parameter
1	0.43 - 0.45	Chlorophyll absorption
2	0.51 - 0.53	Chlorophyll absorption
3	0.54 - 0.56	Gelbstoffe (yellow substance)
4	0.66 - 0.68	Chlorophyll concentration
5	0.70 - 0.80	Surface vegetation
6	10.5 - 12.50	Surface temperature

- The first 4 bands of the CZCS sensor are very narrow and they were optimized to allow detailed discrimination of differences in water reflectance due to **phytoplankton concentrations** and **other suspended particulates** in the water.

- **Higher phytoplankton concentrations** are displayed in **green-yellow-red colors**; lower concentrations in **blue-magenta** color. Note **major discharge areas** in low latitudes such as the **Amazon River, South America** have high phytoplankton concentrations along the coast.

- In addition to detecting surface vegetation on the water, **band 5** was used to discriminate water from land prior to processing the other bands of information. The CZCS sensor ceased operation in 1986.



2.13 Marine Observation Satellites/Sensors

MOS

- The first Marine Observation Satellite (**MOS-1**) was launched by **Japan** in February, **1987** and was followed by its successor, MOS-1b, in February of 1990. These satellites carry three different sensors: a 4-channel Multispectral Electronic Self-Scanning Radiometer (**MESSR**), a 4-channel Visible and Thermal Infrared Radiometer (**VTIR**), and a 2-channel Microwave Scanning Radiometer (**MSR**), in the microwave portion of the spectrum.

- The MESSR bands are quite similar in spectral range to the Landsat MSS sensor and are thus useful for land applications in addition to observations of marine environments. The MOS systems orbit at altitudes around **900 km** and have revisit periods of **17 days**.

MOS Visible/Infrared Instruments

Sensor	Wavelength Ranges (μm)	Spatial Resolution	Swath Width
MESSR	0.51 - 0.59	50 m	100 km
	0.61 - 0.69	50 m	100 km
	0.72 - 0.80	50 m	100 km
	0.80 - 1.10	50 m	100 km
VTIR	0.50 - 0.70	900 m	1500 km
	6.0 - 7.0	2700 m	1500 km
	10.5 - 11.5	2700 m	1500 km
	11.5 - 12.5	2700 m	1500 km

2.13 Marine Observation Satellites/Sensors

SeaWiFS

- The **SeaWiFS** (Sea-viewing Wide-Field-of View Sensor) on board the **SeaStar** spacecraft is an advanced sensor designed for ocean monitoring.

- It consists of **8 spectral bands** of very narrow wavelength ranges tailored for very specific detection and monitoring of **various ocean phenomena** including: ocean primary production and phytoplankton processes, ocean influences on climate processes (heat storage and aerosol formation), and monitoring of the cycles of carbon, sulfur, and nitrogen.

- The orbit altitude is **705 km** with a local equatorial crossing time of **12 PM**. Two combinations of spatial resolution and swath width are available for each band:
 (1) a higher resolution mode of **1.1 km** (at nadir) over a swath of **2800 km**, and
 (2) a lower resolution mode of **4.5 km** (at nadir) over a swath of **1500 km**.

SeaWiFS Spectral Bands

Channel	Wavelength Ranges (μm)
1	0.402 - 0.422
2	0.433 - 0.453
3	0.480 - 0.500
4	0.500 - 0.520
5	0.545 - 0.565
6	0.660 - 0.680
7	0.745 - 0.785
8	0.845 - 0.885

2.14 Other Sensors

The three previous sections provide a representative overview of specific systems available for remote sensing in the **optical portions of the EM spectrum**. However, there are many **other types of less common sensors** which are used for RS purposes.

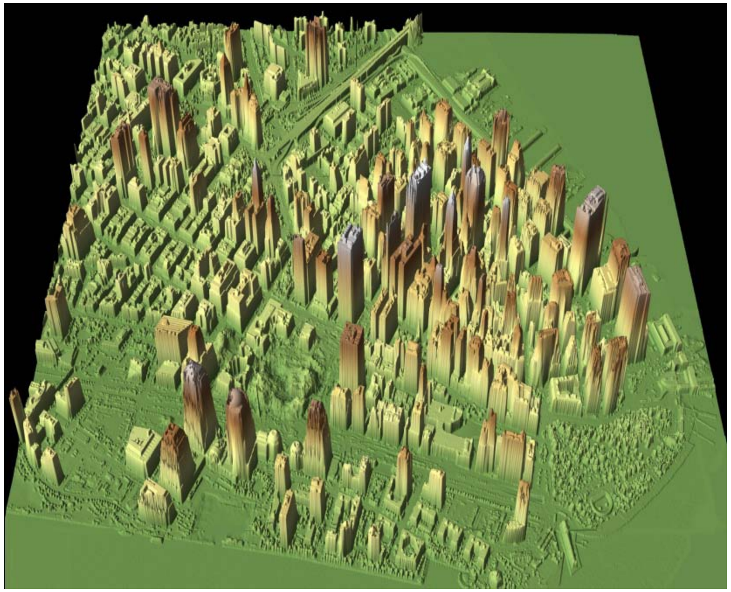
- **Video :** Although coarser in spatial resolution than traditional photography or digital imaging, video cameras provide a useful means of acquiring timely and inexpensive data and **vocally annotated imagery**. Applications with these requirements include **natural disaster management**, (fires, flooding), **crop and disease assessment**, **environmental hazard control**, and **police surveillance**. Cameras used for **video recording** measure radiation in the visible, near infrared, and sometimes mid-infrared portions of the EM spectrum.

- **FLIR (Forward Looking InfraRed) :** FLIR systems operate in a similar manner to **across-track thermal imaging sensors**, but provide an oblique rather than nadir perspective of the Earth´s surface. Typically positioned on aircraft or helicopters, and imaging the area ahead of the platform, FLIR systems provide relatively high spatial resolution imaging that can be used for **military applications**, **search and rescue operations**, **law enforcement**, and **forest fire monitoring**.

2.14 Other Sensors

- **Laser fluorosensor :** Some targets **fluoresce**, or **emit energy**, upon receiving incident energy. This is not a simple reflection, 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. This technology has been proven for **ocean applications**, such as **chlorophyll mapping**, and **pollutant detection**, particularly for naturally occurring and accidental oil slicks.

- **Lidar (LIght Detection And Ranging)** : An active imaging technology very **similar to 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.



2.14 Other Sensors

- **RADAR (RAdio Detection And Ranging)** : RADAR systems are **active sensors** which provide their own source of EM energy. Active radar sensors, whether airborne or spaceborne, **emit microwave radiation** in a series of pulses from an antenna, looking obliquely at the surface perpendicular to the direction of motion. When the energy reaches the target, some of the energy is reflected back towards the sensor. This **backscattered microwave radiation is detected, measured, and timed**. The time required for the energy to travel to the target and return back to the sensor **determines the distance or range to the target**.

By recording the range and magnitude of the energy reflected from all targets as the system passes by, a two-dimensional image of the surface can be produced. Because RADAR provides its own energy source, **images can be acquired day or night**. Also, microwave energy is able to **penetrate through clouds and most rain**, making it an all-weather sensor. Because of the unique characteristics and applications of microwave remote sensing, **Chapter 3** covers this topic **in detail**.

2.15 Data Reception, Transmission, and Processing

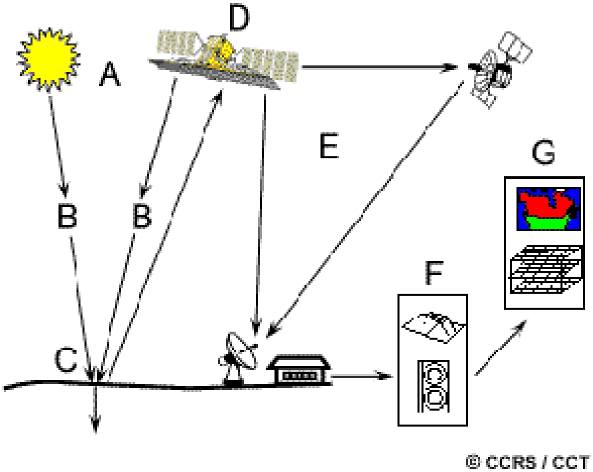
- Data acquired from satellite platforms need to be electronically transmitted to Earth, since the satellite continues to stay in orbit during its operational lifetime.

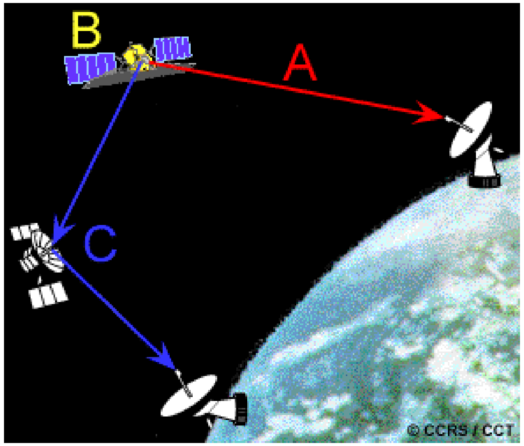
- There are three main options for **transmitting data** acquired by satellites to the surface.

(1) The data can be **directly transmitted to Earth** if a Ground Receiving Station (GRS) is in the line of sight of the satellite (A).

(2) The data can be recorded on board the satellite (B) for **transmission to a GRS at a later time**.

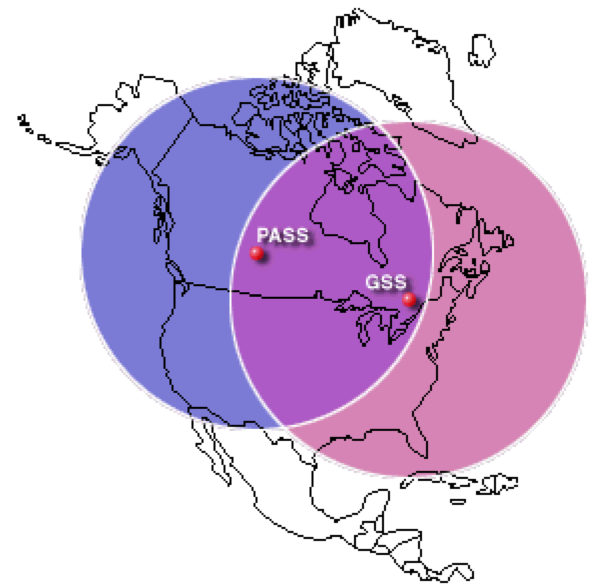
(3) Data can also be **relayed to the GRS** through the Tracking and Data Relay Satellite System (TDRSS) (C), which consists of a series of communications satellites in geosynchronous orbit. The data are transmitted from one satellite to another until they reach the appropriate GRS.





2.15 Data Reception, Transmission, and Processing

- In Canada, CCRS operates two **ground receiving stations** - one at Gatineau, Quebec (GSS) and another one at Prince Albert, Saskatchewan (PASS).
- The combined coverage circles for these Canadian ground stations enable the potential for reception of real-time or recorded data from satellites passing over almost any part of Canada's land mass, and much of the continental United States as well.
- The data are received at the GRS in a raw digital format. They may then, if required, be processed to correct systematic, geometric and atmospheric distortions to the imagery, and be translated into a standardized format. The data are written to some form of storage medium such as tape, disk or CD. The data are typically archived at most receiving and processing stations, and full libraries of data are managed by government agencies as well as commercial companies responsible for each sensor's archives.



2.15 Data Reception, Transmission, and Processing

- For many sensors it is possible to provide customers with **quick-turnaround** imagery when they need data as quickly as possible after it is collected.

- Near real-time processing systems are used to produce low resolution imagery in hard copy or soft copy (digital) format within hours of data acquisition. Such imagery can then be faxed or transmitted digitally to end users.

- One application of this type of fast data processing is to provide imagery to ships sailing in the Arctic, as it allows them to assess current ice conditions quickly in order to make navigation decisions about the easiest/safest routes through the ice. Real-time processing of imagery in airborne systems has been used, for example, to pass thermal infrared imagery to forest fire fighters right at the scene. Low resolution quick-look imagery is used to preview archived imagery prior to purchase. The spatial and radiometric quality of these types of data products is degraded, but they are useful for ensuring that the overall quality, coverage and cloud cover of the data is appropriate.