REMOTE SENSING SENSORS

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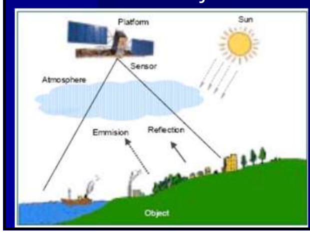
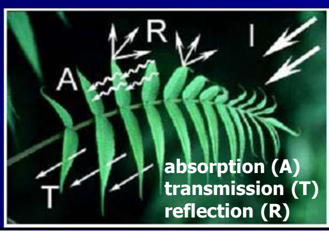
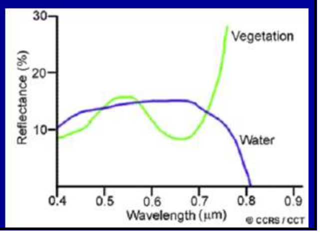
Remote Sensing

- Definition 1: Remote sensing is an art and science of obtaining information about an object or feature without physically coming in contact with that object or feature
- Definition 2: Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.
- The data collected can be of many forms: variations in acoustic wave distributions (e.g., sonar), variations in force distributions (e.g., gravity meter), variations in electromagnetic energy distributions (e.g., eye) etc.
- These remotely collected data through various sensors may be analyzed to obtain information about the objects or features. In this course we will deal with remote sensing through electromagnetic energy sensors only.
- By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, we can build up a spectral response for that object.



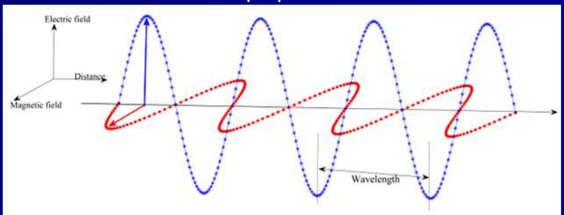




Electromagnetic Spectrum

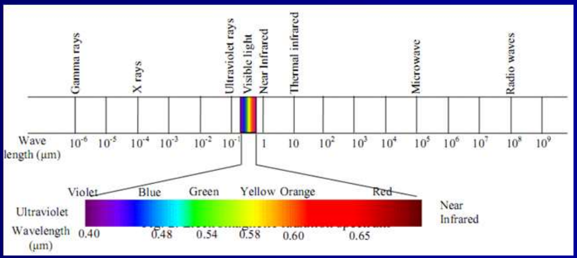
- Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields. It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy.
- Electro-magnetic energy (E) can be expressed either in terms of frequency (f) or wave length (λ) of radiation as

  $E = h\,c\,f$ or $h\,c / \lambda$
- where h is Planck's constant (6.626×10^{-34} Joules-sec), c is a constant that expresses the celerity or speed of light (3×10^{8} m/sec), f is frequency expressed in Hertz and λ is the wavelength expressed in micro meters ($1 \mu m = 10^{-6}$ m).
- Electromagnetic energy has both electric and magnetic components which oscillate perpendicular to each other and also perpendicular to the direction of energy propagation.



Electromagnetic Spectrum

- Distribution of the continuum of radiant energy can be plotted as a function of wavelength and is known as the electromagnetic radiation (EMR) spectrum.
- EMR spectrum is divided into regions or intervals of different wavelengths and such regions are denoted by different names. However, there is no strict dividing line between one spectral region and its adjacent one.



- The visible region (human eye is sensitive to this region) occupies a very small region in the range between 0.4 and 0.7 µm.
- The approximate range of color "blue" is 0.4–0.5 µm, "green" is 0.5-0.6 µm and "red" is 0.6-0.7 µm.
- Ultraviolet (UV) region adjoins the blue end of the visible region and infrared (IR) region adjoins the red end. The infrared (IR) region, spanning between 0.7 and 100 µm,

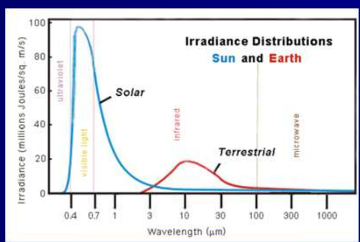
Electromagnetic Spectrum

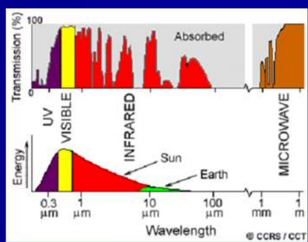
Spectrum of electromagnetic radiation

Region	Wavelength (μm)	Remarks
Gamma rays	$< 3\times10^{-5}$	Not available for remote sensing. Incoming radiation is absorbed by the atmosphere
X-ray	3×10^{-5} - 3×10^{-3}	Not available for remote sensing since it is absorbed by atmosphere
Ultraviolet (UV) rays	0.03 - 0.4	Wavelengths less than 0.3 are absorbed by the ozone layer in the upper atmosphere. Wavelengths between 0.3- 0.4 μm are transmitted and termed as "Photographic UV band".
Visible	0.4 - 0.7	Detectable with film and photodetectors.
Infrared (IR)	0.7 - 100	Atmospheric windows exist which allows maximum transmission. Portion between 0.7 and 0.9 μm is called photographic IR band, since it is detectable with film. Two principal atmospheric windows exist in the thermal IR region (3 - 5 μm and 8 - 14 μm).
Microwave	10^{3} - 10^{6}	Can penetrate rain, fog and clouds. Both active and passive remote sensing is possible. Radar uses wavelength in this range.
Radio	$> 10^{6}$	Have the longest wavelength. Used for remote sensing by some radars.

Electromagnetic Spectrum

- Primary source of energy that illuminates different features on the earth surface is the Sun but it is not the only one. the Earth and the terrestrial objects also are the sources of electromagnetic radiation. All matter at temperature above absolute zero (0°K or -273°C) emits electromagnetic radiations continuously.
- Although the Sun produces electromagnetic radiation in a wide range of wavelengths, the amount of energy it produces is not uniform across all wavelengths.





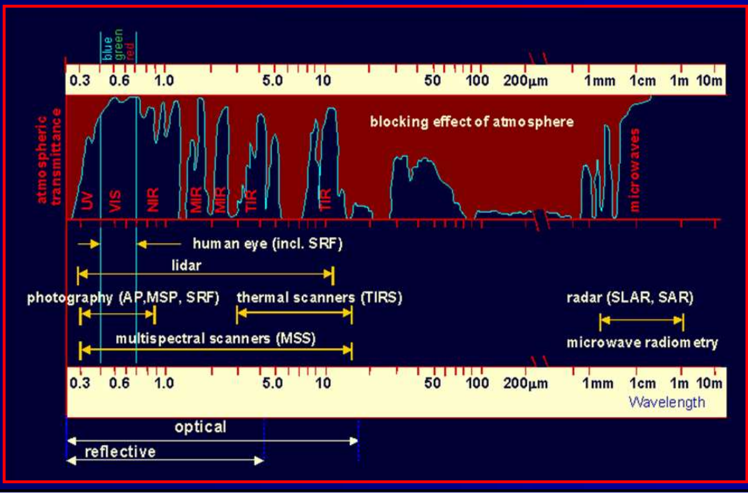
The solar irradiance (power of electromagnetic radiation per unit area incident on a surface) distribution of the Sun and Earth.

- Almost 99% of the solar energy is within the wavelength range of 0.28-4.96 μm. Within this range, 43% is radiated in the visible wavelength region between 0.4-0.7 μm. The maximum energy (E) is available at 0.48 μm wave length, which is in the visible green region.

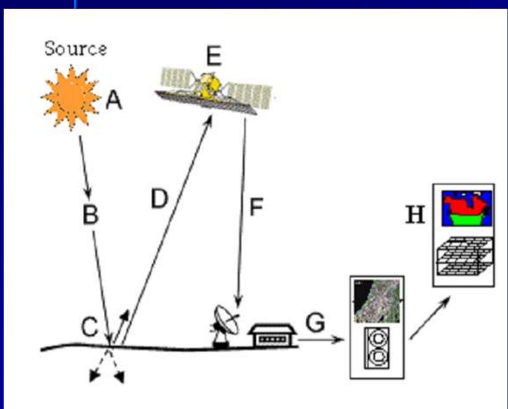
Electromagnetic Spectrum

Electromagnetic Spectrum is the continuum of radiant energy which travels with the speed of the light ranges from gamma rays with very short wavelengths (nanometers) to radio waves with very long wavelengths (kilometers).

As solar energy travels through atmosphere to reach the Earth, the atmosphere absorbs or backscatters a fraction of it and transmits only the remainder. Wavelength regions, through which most of the energy is transmitted through atmosphere are referred as atmospheric windows.



Main stages in Remote Sensing



A) Emission of electromagnetic radiation
- The Sun or an EMR source located on the platform

B) Transmission of energy from the source to the object
- Absorption and scattering of the EMR while transmission

C) Interaction of EMR with the object and subsequent reflection and emission

D) Transmission of energy from the object to the sensor

E) Recording of energy by the sensor
- Photographic or non-photographic sensors

F) Transmission of the recorded information to the ground station

G) Processing of the data into digital or harc copy image

H) Analysis of data

Characteristics of Remote Sensing Systems

- Energy Source
  - The energy sources for real systems are usually non-uniform over various wavelengths and also vary with time and space. This has major effect on the passive remote sensing systems. The spectral distribution of reflected sunlight varies both temporally and spatially. Earth surface materials also emit energy to varying degrees of efficiency. A real remote sensing system needs calibration for source characteristics.
- The Atmosphere
  - The atmosphere modifies the spectral distribution and strength of the energy received or emitted. The effect of atmospheric interaction varies with the wavelength associated, sensor used and the sensing application. Calibration is required to eliminate or compensate these atmospheric effects. To record reflected energy from object, remote sensing sensors are deployed (mounted) on platforms. Remote sensing platforms can be classified based on the elevation from the Earth's surface at which these platforms are placed.
- The Energy/Matter Interactions at the Earth's Surface
  - Remote sensing is based on the principle that each and every material reflects or emits energy in a unique, known way. However, spectral signatures may be similar for different material types. This makes differentiation difficult. Also, the knowledge of most of the energy/matter interactions for earth surface features is either at elementary level or even completely unknown.

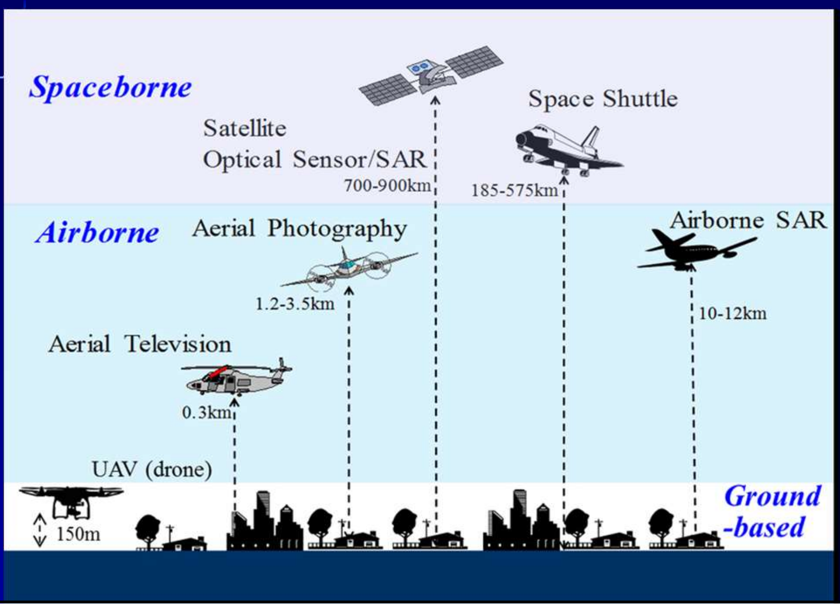
Characteristics of Remote Sensing Systems

- The Sensor
  - Real sensors have fixed limits of spectral sensitivity i.e., they are not sensitive to all wavelengths. Also, they have limited spatial resolution (efficiency in recording spatial details). Selection of a sensor requires a trade-off between spatial resolution and spectral sensitivity. For example, while photographic systems have very good spatial resolution and poor spectral sensitivity, non-photographic systems have poor spatial resolution.
- The Data Handling System
  - Human intervention is necessary for processing sensor data; even though machines are also included in data handling. This makes the idea of real time data handling almost impossible. The amount of data generated by the sensors far exceeds the data handling capacity.
- The Multiple Data Users
  - The success of any remote sensing mission lies on the user who ultimately transforms the data into information. This is possible only if the user understands the problem thoroughly and has a wide knowledge in the data generation. The user should know how to interpret the data generated and should know how best to use them.

Remote Sensing Platforms

- Remote Sensing sensors are deployed (mounted) on platforms to record reflected energy from object.
- Remote sensing platforms can be classified as follows based on the platform elevation from the Earth's surface;
  - Ground (land) platforms: up to 50 m
  - Airborne based platforms: up to 50 km
  - Space shuttles: 250-300 up to km
  - Space stations : 300-400 up to km
  - Satellites
    - Low level satellites: up to 500-2000 km
    - Middle level satellites: up to 10000 km
    - High level satellites: up to 36000 km
- The remote sensing platform affects the image resolution and image coverage on the ground.

Remote Sensing Platforms



Remote Sensing Platforms

- Ground based platforms

They are basically used for verification or calibration of the data collected from sensor mounted on airborne based platforms, space shuttles, space stations, and satellites. Ground based platform can move or fixed. The Spectral reflectance meters can be used by hand to identify the reflectance characteristics of individual leafs, plants or areas.

Remote Sensing Platforms

- Ground based platforms
- http://www.arm.gov/

Atmospheric Radiation Measurement (ARM)

The ARM Climate Research Facility, a DOE scientific user facility, provides the climate research community with strategically located in situ and remote sensing observatories designed to improve the understanding and representation, in climate and earth system models, of clouds and aerosols as well as their interactions and coupling with the Earth's surface.

Remote Sensing Platforms

- Ground based platforms
- http://aeronet.gsfc.nasa.gov/

The AERONET (AErosol RObotic NETwork) program

TThe AERONET (AErosol RObotic NETwork) program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists, and partners. AERONET collaboration provides globally distributed observations of spectral aerosol optical Depth (AOD), inversion products, and precipitable water in diverse aerosol regimes.

Remote Sensing Platforms

- Airborne based platforms
  - Balloon: up to 6 km
  - Zeppelin
  - Unmanned aerial vehicle
  - Helicopter
  - Low Altitude Aircraft: up to 9 km
  - High Altitude Aircraft: up to 21 km





Remote Sensing Platforms

- Space shuttles
  - The Space Shuttle was a partially reusable human spaceflight vehicle capable of reaching low Earth orbit, commissioned and operated by the U.S. National Aeronautics and Space Administration (NASA) from 1981 to 2011.
  - The official program name was Space Transportation System (STS)
  - Operational missions launched numerous satellites, interplanetary probes, and the Hubble Space Telescope (HST); conducted science experiments in orbit; and participated in construction and servicing of the International Space Station.
  - The Shuttle fleet's total mission time was 1322 days, 19 hours, 21 minutes and 23 seconds
  - Shuttle components included the Orbiter Vehicle (OV) with three clustered Rocketdyne RS-25 main engines, a pair of recoverable solid rocket boosters (SRBs), and the expendable external tank (ET) containing liquid hydrogen and liquid oxygen.
  - The Space Shuttle was launched vertically, like a conventional rocket, with the two SRBs operating in parallel with the OV's three main engines, which were fueled from the ET.

Remote Sensing Platforms

- Space shuttles

The Space Shuttle orbiter was the spaceplane component of the Space Shuttle, a partially reusable orbital spacecraft system that was part of the Space Shuttle program

- Columbia (1981 – 2003, Destroyed)
- Challenger (1983 – 1986, Destroyed)
- Discovery (1984-2010, Retired)
- Atlantis (1985-2011, Retired)
- Endeavour (1991-2011, Retired)

Remote Sensing Platforms

- Space stations
  - The space stations are research platforms, used to study the effects of long-term space flight on the human body as well as to provide platforms for greater number and length of scientific studies than available on other space vehicles.
  - The first space station was Salyut 1, which was launched by the Soviet Union on April 19, 1971.
  - The earlier Soviet stations were all designated "Salyut", but among these there were two distinct types: civilian and military. The military stations, Salyut 2, Salyut 3, and Salyut 5, were also known as Almaz stations.
  - The civilian stations Salyut 6 and Salyut 7 (1986) were built with two docking ports, which allowed a second crew to visit, bringing a new spacecraft with them

Soviet space station Mir (1986-2001)

Skylab 4

Remote Sensing Platforms

- Space stations
  - The Soviet space station Mir (1986-2001) had a modular design; a core unit was launched, and additional modules, generally with a specific role, were later added to that. This method allows for greater flexibility in operation, as well as removing the need for a single immensely powerful launch vehicle.
  - Skylab was a United States space station launched and operated by NASA, and occupied for about 24 weeks between May 1973 and February 1974 – the only space station the U.S. has operated exclusively

Mission	Emblem	Commander	Science Pilot	Pilot	Launch date	Landing date	Duration (days)
Skylab 1 *SL-1*		*unmanned launch of space station*			1973-05-14 17:30:00 UTC	1979-07-11 16:37:00 UTC	2248.96
Skylab 2 *SL-2 (SLM-1)*		Pete Conrad	Joseph Kerwin	Paul Weitz	1973-05-25 13:00:00 UTC	1973-06-22 13:49:48 UTC	28.03
Skylab 3 *SL-3 (SLM-2)*		Alan Bean	Owen Garriott	Jack Lousma	1973-07-28 11:10:50 UTC	1973-09-25 22:19:51 UTC	59.46
Skylab 4 *SL-4 (SLM-3)*		Gerald Carr	Edward Gibson	William Pogue	1973-11-16 14:01:23 UTC	1974-02-08 15:16:53 UTC	84.04
Skylab 5		Vance Brand	William B. Lenoir	Don Lind	(April 1974, Cancelled)		20 (notional)
Skylab Rescue		Vance Brand	Don Lind	(Survivors)	(On Standby)		

Remote Sensing Platforms

- Space stations
  - The International Space Station (ISS) is a space station, or a habitable artificial satellite, in low Earth orbit.
  - Its first component was launched into orbit in 1998, with the first long-term residents arriving in November 2000. It has been inhabited continuously since that date.
  - The last pressurised module was fitted in 2011, and an experimental inflatable space habitat was added in 2016. The station is expected to operate until 2030.
  - The ISS programme is a joint project between five participating space agencies: NASA (United States), Roscosmos (Russia), JAXA (Japan), ESA (Europe), and CSA (Canada).



Remote Sensing Platforms

- Space stations
  - The ownership and use of the space station is established by intergovernmental treaties and agreements. The station is divided into two sections, the Russian Orbital Segment (ROS) and the United States Orbital Segment (USOS), which is shared by many nations.
  - The ISS serves as a microgravity and space environment research laboratory in which crew members conduct experiments in biology, human biology, physics, astronomy, meteorology, and other fields.
  - The station is suited for the testing of spacecraft systems and equipment required for missions to the Moon and Mars.
  - The ISS maintains an orbit with an altitude of between 330 and 435 km. It circles the Earth in roughly 92 minutes and completes 15.5 orbits per day.

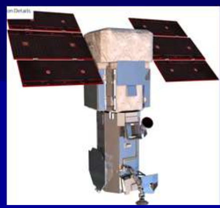


Remote Sensing Platforms

- Satellites

Satellite classification by mass criterions

- Large satellite: > 1000 kg (Hubble, Türksat 3A)
- Medium satellites: 500 kg - 1000 kg (THEOS)
- Mini satellites: 100 kg - 500kg (Göktürk -II)
- Micro satellites: 10 kg - 100 kg (UoSAT-1)
- Nano satellites: 1 kg — 10 kg (Delfi C3)
- Piko satellites: 0,1kg - 1kg (‹TÜpSAT1)
- Femto satellites: ağırlığı 0,1 kg'dan az



WorldView-3
On August 13, 2014, DigitalGlobe launched WorldView-3 into orbit
31 cm pankromatik
1.24 m multispektral

Satellite classification by application areas

- Military satellite
- Communication satellite
- meteorological satellite
- Navigation satellite
- Earth observation satellite
- Space exploration satellite

Satellite classification by orbit types

(On the basis of the distance from Earth)

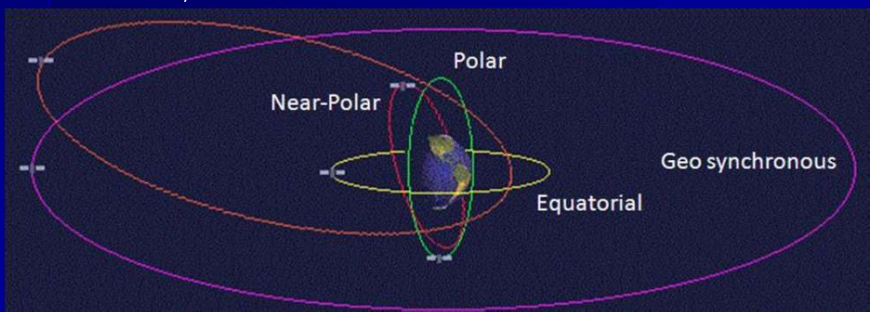
- Low Earth Orbit (LEO) satellite: 500-2000 km
- Medium Earth Orbit (MEO) satellite: 10000 km
- High Earth Orbit: (HEO) satellite: 36000 km

Remote Sensing Platforms

- Satellite orbits

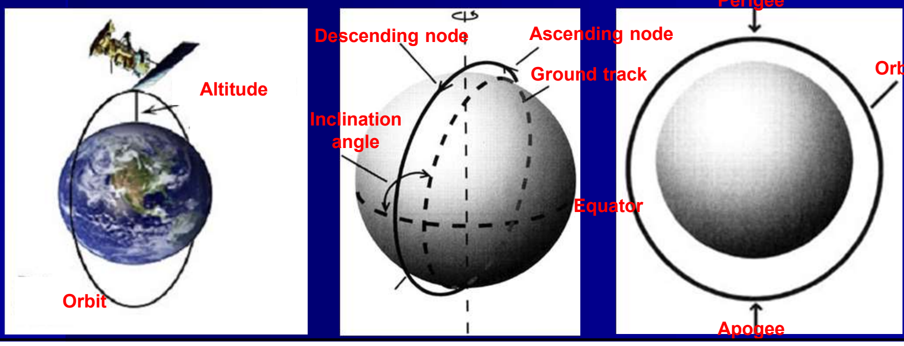
The path followed by a satellite in the space is called the orbit of the satellite. Orbits may be circular (or near circular) or elliptical in shape. The following orbits types are most common for remote sensing mission (https://www.youtube.com/watch?v=6dISKhVdX7g) https://www.youtube.com/watch?v=VM5nOaLU7XM

- Geostationary (Geo-synchronous) orbits
- Polar or near polar orbits
- Equatorial orbits
- Sun-synchronous orbits



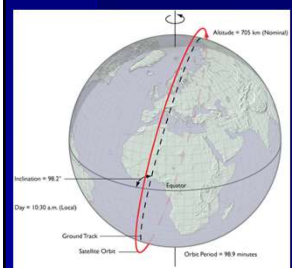
Remote Sensing Platforms

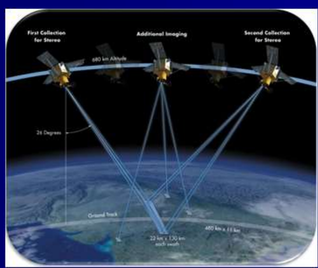
- Characteristics of satellite orbits
  - Orbital altitude is a distance (in km) from the satellite to the surface of the Earth
  - Orbital inclination angle is the angle (in degrees) between the orbital plane and the equatorial plane
  - Orbital period is the time (in minutes) required to complete one full orbit.
  - Apogee is the point in the orbit where the satellite is at maximum distance from the Earth.
  - Perigee is the point in the orbit where the satellite is nearest to the Earth.

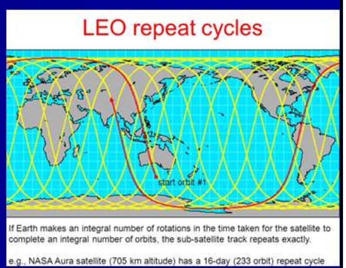


Remote Sensing Platforms

- Characteristics of satellite orbits
  - Repeat cycle is the time (in days) between two successive identical orbits.
  - The revisit time (ie, the time between two subsequent images of the same area) is determined by the repeat cycle together with the pointing capability of the sensor.
  - Pointing capability refers to the possibility of the sensor platform combination to look to the site of forward, or backward not only vertical down. Many modern satellites have such capability.
  - Orbital period is a time (in minutes or hour) taken by a satellite to compete one revolution in its orbit around the Earth. It varies from around 100 minutes for a near-polar earth observing satellite to 24 hours for a geo-stationary satellite.

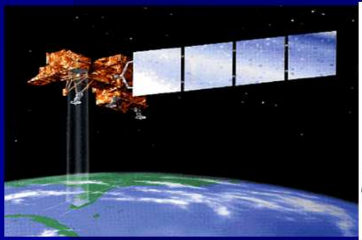


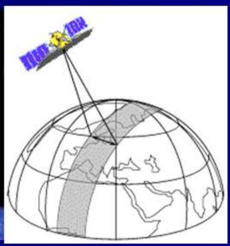


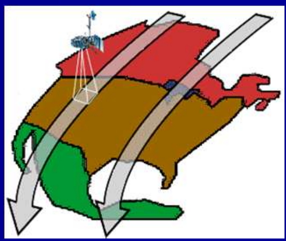


Remote Sensing Platforms

- Characteristics of satellite orbits
  - Swath: As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface by sensor is referred to as the swath.







Remote Sensing Platforms

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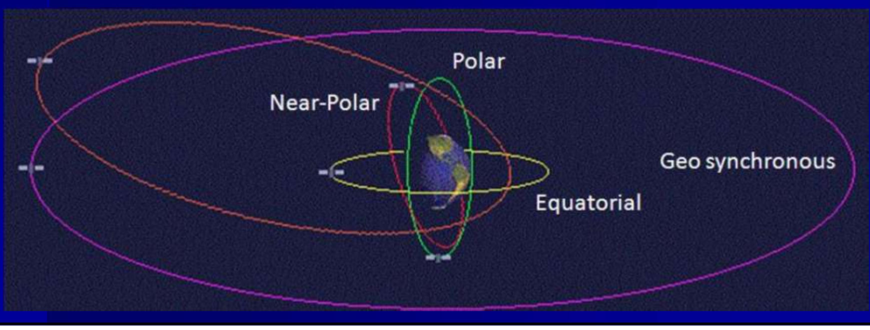
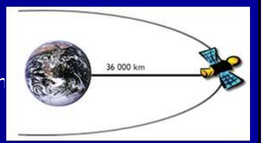
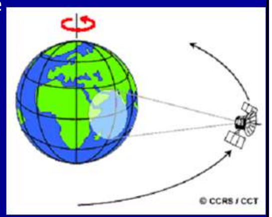


Remote Sensing Platforms

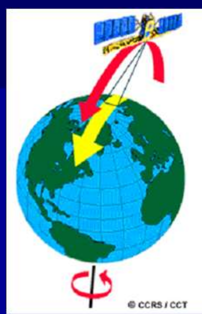
- Geostationary (Geo-synchronous) orbits
  - Although terms are often used interchangeably, technically a geosynchronous orbit matches the Earth's rotational period, but the definition does not require it to have zero orbital inclination to the equator.
  - Geosynchronous orbit (GSO)'s inclination and eccentricity may not necessarily be zero. In this case satellite may oscillate north and south during the course of a day.
  - Thus, a geostationary orbit is defined as a geosynchronous orbit at zero inclination.
  - Geostationary orbit (GEO) is an orbit which places the satellite above the same location at all times.
  - Geosynchronous orbit (GSO) period around the Earth is equal to one sidereal day, which is Earth's average rotational period of 23 hours, 56 minutes, 4.091 seconds. They must be placed at a very high altitude approximately 36,000 km in order to produce an orbital period equal to the period of Earth's rotation.
  - All geostationary orbits must be Geo-synchronous, but not all Geo-synchronous orbits are Geostationary.
  - Geostationary or geosynchronous orbits are located in the equatorial plane and used for communication and meteorological satellites. Example: INSAT, MeteoSAT, GOES, GMS etc.

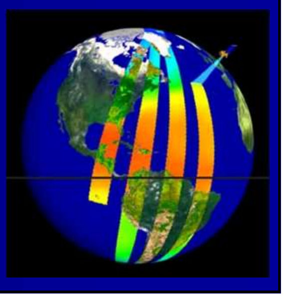




Remote Sensing Platforms

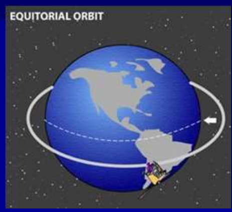
- Polar or near polar orbits
  - Polar orbit passes above or nearly above both North and South poles of the Earth on each revolution.
  - Therefore, it has an inclination of (or very close to) 90 degrees.
  - The near polar orbit is an orbit with an inclination angle between 80 degrees and 100 degrees.
  - Polar orbits or near polar orbits are usually medium or low orbits (approximately 700-800km) compared to the geo-synchronous orbits. Consequently the orbit period is less, which typically varies from 90-103 minutes.
  - The satellites in the polar orbits make more than one revolution around the earth in a single day and enables observation of the whole globe also near poles.
  - A polar orbiting satellite eventually sees every part of the Earth's surface, which is highly desirable for remote sensing applications.
  - Most of the remote sensing satellite platforms today are in near-polar orbits, which means that the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit. These are called ascending and descending passes, respectively.





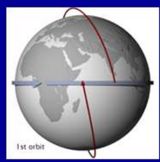
Remote Sensing Platforms

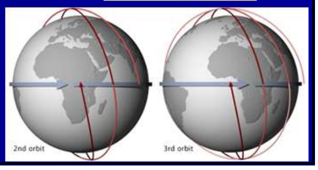
- Equatorial orbits
  - A satellite in equatorial orbit flies along the line of the Earth's equator.
  - To get into equatorial orbit, a satellite must be launched from a place on Earth close to the equator.
  - NASA often launches satellites aboard an Ariane rocket into equatorial orbit from French Guyana.
  - Equatorial orbits can be useful for satellites observing tropical weather patterns, as they can monitor cloud conditions around the globe.
  - Equatorial orbits are usually medium or low orbits.



- Sun-synchronous orbits

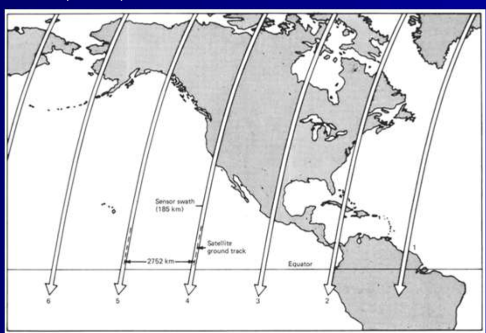
  https://www.youtube.com/watch?v=tOp1UYbmp0Y
  https://www.youtube.com/watch?v=nrtsd8Wxmw0
  - The sun-synchronous orbit is a special case of polar or near polar orbit.
  - Like a polar orbit, the satellite travels from the north to the south poles as the Earth turns below it.
  - In a sun-synchronous orbit, the satellite passes over the same part of the Earth at roughly the same local time (mid-morning around 10.30) each day.





Remote Sensing Platforms

- Sun-synchronous orbits
  - This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days.
  - These orbits are between 700 to 800 km altitudes.
  - These are used for satellites that need a constant amount of sunlight. A typical sun synchronous satellite completes 14 orbits a day, and each successive orbit is shifted over the Earth's surface
  - Example: Landsat, SPOT, IRS etc.



Spacing Between Adjacent Landsat 5 or 7 Orbit Tracks at the Equator

Remote Sensing Platforms

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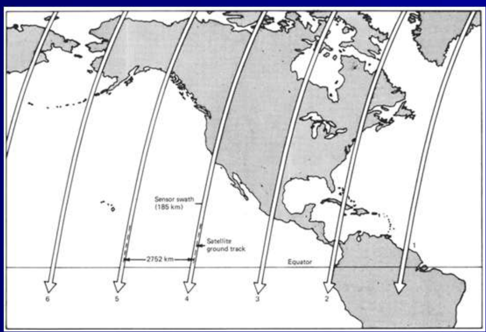
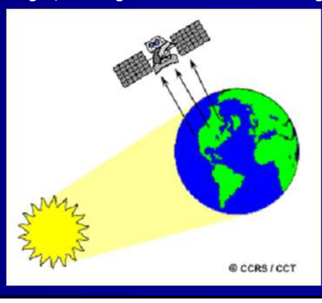


Spacing Between Adjacent Landsat 5 or 7 Orbit Tracks at the Equator

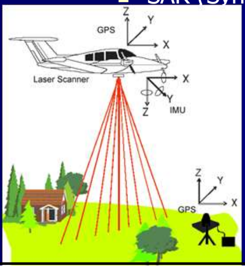
Remote Sensing Sensors

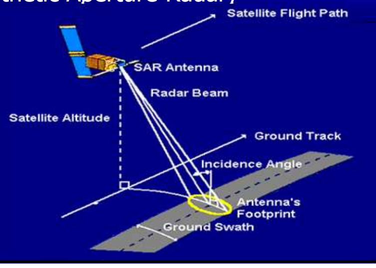
- Types of sensors based on energy source
  - Passive Sensors
    - Remote sensing systems which measure energy that is naturally available are called passive sensors.
    - Passive sensors can only be used to detect energy when the naturally occurring energy is available. The sun provides a very convenient source of energy for remote sensing.
    - The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then re-emitted, as it is for thermal infrared wavelengths. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.
      - Landsat
      - SPOT
      - Ikonos

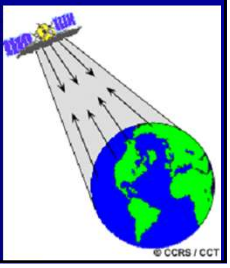


Remote Sensing Sensors

- Types of sensors based on energy source
  - Active Sensors
    - Active sensors provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.
    - Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season.
    - Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated.
      - LiDAR
      - SAR (Synthetic Aperture Radar)



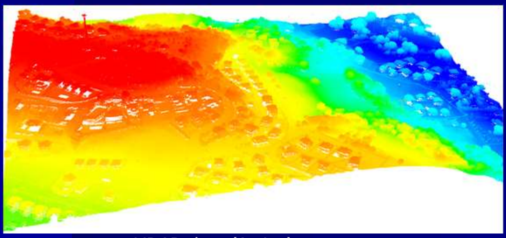




Remote Sensing Sensors

- Passive Sensors
  - Landsat
  - SPOT
  - Ikonos
- Active Sensors
  - LiDAR
  - SAR

Ikonos image (Passive)

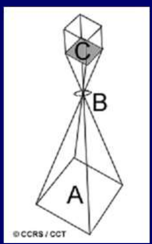


LiDAR data (Active)

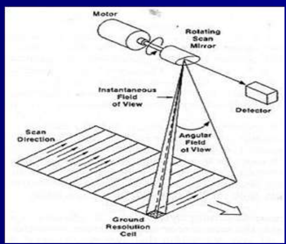
Terrasar-X image (Active)

Remote Sensing Sensors

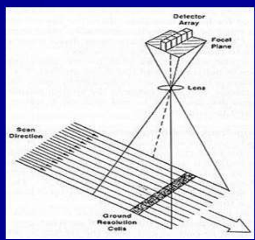
- Types of sensors based on generated product
  - No-imaging Sensors
    - Generates no images of the observed surface, used to collect precise spectral signature of objects.
  - Imaging Sensors
    - Scanning systems: Scans lines to generate image.
- Imaging Sensors
    - Framing systems (Frame cameras) : acquisition of a whole image at the same time.
    - Scanning systems (Multispectral Scanner): Scans lines to generate image.
      - Across-track (whiskbromm) scanners
      - Along-track (pushbroom) scanners



Frame cameras



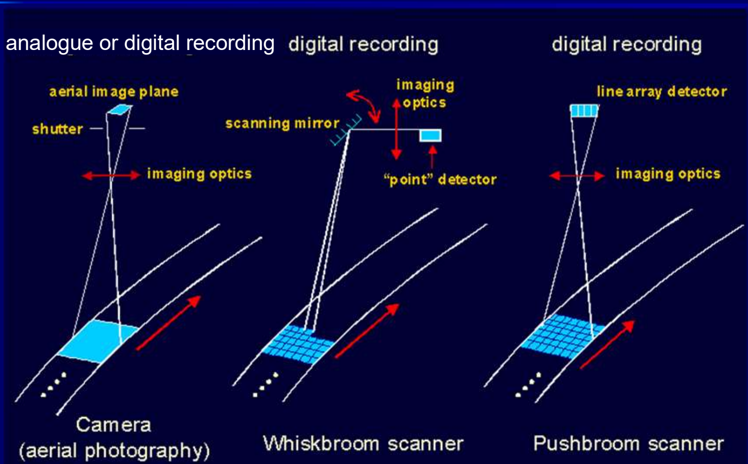
Across-track (whiskbromm) scanners



Along-track (pushbroom) scanners

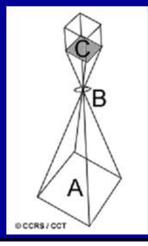
Remote Sensing Sensors

- Imaging Sensors



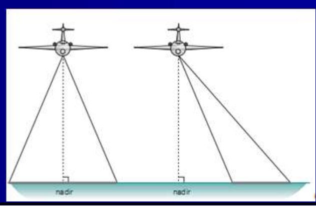
Remote Sensing Sensors

- Imaging Sensors
  - Framing systems (Cameras or Frame cameras)
    - Cameras (frame cameras) and their use for aerial photography are the simplest and oldest of sensors used for remote sensing of the Earth's surface.
    - Cameras are framing systems which acquire a near-instantaneous "snapshot" of an area (A), of the surface. Camera systems are passive optical sensors that use a lens (B) to form an image at the focal plane (C).
    - Photographic films are sensitive to light from 0.3 µm to 0.9 µm in wavelength covering the ultraviolet (UV), visible, and near-infrared (NIR). Panchromatic films are sensitive to the UV and the visible portions of the spectrum.
    - Colour and false colour (or colour infrared, CIR) photography involves the use of a three layer film with each layer sensitive to different ranges of light.
    - For a normal colour photograph, the layers are sensitive to blue, green, and red light.
    - In colour infrared (CIR) photography, the layers are sensitive to green, red, and the photographic portion of near-infrared radiation.



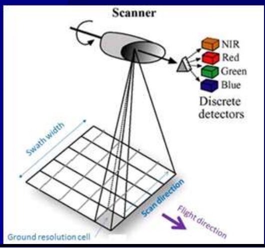
Remote Sensing Sensors

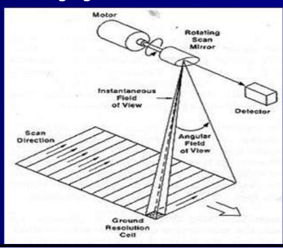
- Imaging Sensors
  - Framing systems (Cameras or Frame cameras)
    - Most aerial photographs are classified as either oblique or vertical, depending on the orientation of the camera relative to the ground during acquisition.
    - Digital cameras, which record electromagnetic radiation electronically. Instead of using film, digital cameras use a gridded array silicon coated CCDs (charge-coupled devices) that individually respond to electromagnetic radiation. Energy reaching the surface of the CCDs causes the generation of an electronic charge which is proportional in magnitude to the "brightness" of the ground area.
    - The Large Format Camera (LFC) was a photographic camera used in Space Shuttle by NASA in 1984 with a 305-mm focal lengthand a film format of 23 by 46 cm. A ground resolution of 10 m was achieved at altitudes of 200 to 250 km with standard photographic films.

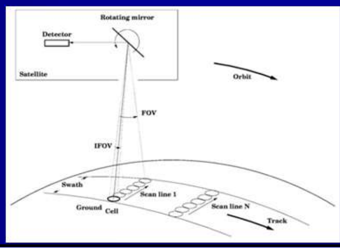


Remote Sensing Sensors

- Imaging Sensors
  - Across-track (whiskbromm) scanners
    - In Across-track scanner is also known as whisk-broom scanner, rotating or oscillating mirrors are used to scan the terrain in a series of lines, called scan lines, which are at right angles to the flight line.
    - As the aircraft or the platform moves forward, successive lines are scanned giving a series of contiguous narrow strips.
    - The incoming reflected or emitted radiation is separated into several thermal and non-thermal wavelength components using a dichroic grating and a prism. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS).
    - The first multispectral scanner (MSS) imaging sensor was across-track (whisk-broom) scanner. NOAA (National Oceanic and Atmospheric Administration) /AVHRR (Advanced Very High Resolution Radiometer) and Landsat/TM has cross-track (whisk-broom) scanner as imaging sensor.

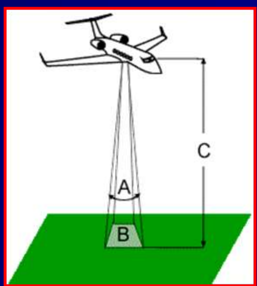


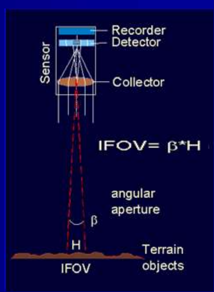




Remote Sensing Sensors

- Imaging Sensors
  - Across-track (whiskbromm) scanners
    - The IFOV is the angular cone of visibility of the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B).
    - The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C).
    - The detail discernible in an image is dependent on the spatial resolution of the sensor.
    - The spatial resolution is the size of the smallest possible feature that can be detected in satellite image and depends primarily on their Instantaneous Field of View (IFOV) of passive sensors.

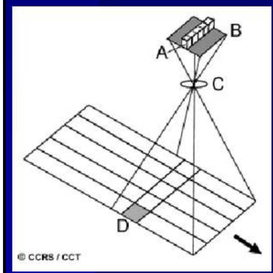


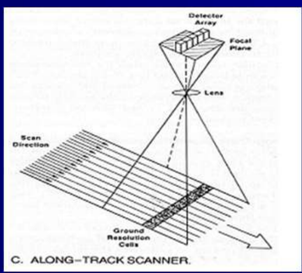


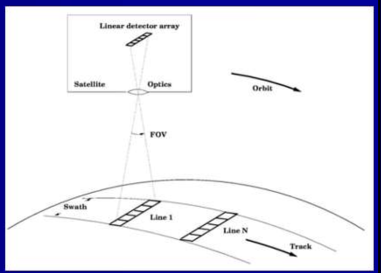
IFOV=B=A*C

Remote Sensing Sensors

- Imaging Sensors
  - Along-track (pushbroom) scanners
    - Along-track scanners also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction.
    - However, instead of a scanning mirror, they use a linear array of detectors (A) located at the focal plane of the image (B) formed by lens systems (C), which are "pushed" along in the flight track direction (i.e. along track).
    - These systems are also referred to as pushbroom scanners, as the motion of the detector array is analogous to the bristles of a broom being pushed along a floor.
    - Each individual detector measures the energy for a single ground resolution cell (D) and thus the size and IFOV of the detectors determines the spatial resolution of the system.

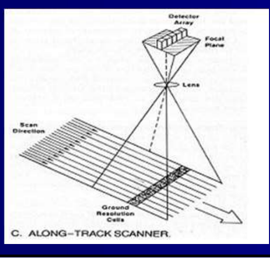


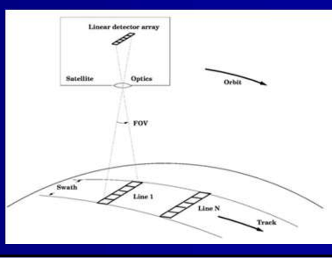




Remote Sensing Sensors

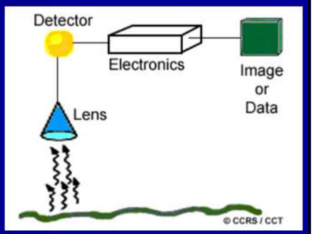
- Imaging Sensors
  - Along-track (pushbroom) scanners
    - A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.
    - This linear array typically consists of numerous charged coupled devices (CCDs). A single array may contain more than 10,000 individual detectors. Each detector element is dedicated to record the energy in a single column .
    - Also, for each spectral band, a separate linear array of detectors is used for multispectral scanner (MSS).
    - The first Along-track (pushbroom) scanner was SPOT-HRV.
    - Today, the high resolution satellite records image by using Along-track (pushbroom) scanners. IKONOS, OrbView 3 etc. has cross-track (whisk-broom) scanner as imaging sensor.

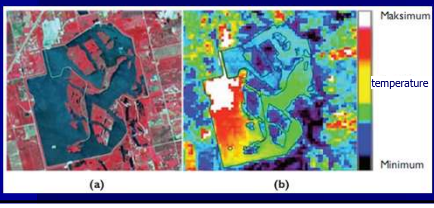


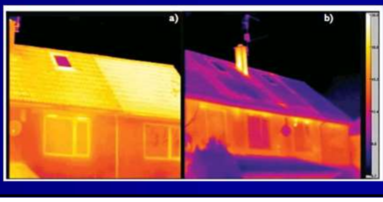


Remote Sensing Sensors

- Imaging Sensors
  - Thermal Imaging Sensor
    - Many multispectral (MSS) systems sense radiation in the thermal infrared as well as the visible and reflected infrared portions of the spectrum. However, remote sensing of energy emitted from the Earth's surface in the thermal infrared (3 μm to 15 μm) is different than the sensing of reflected energy.
    - Thermal imaging sensors use photo detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation.
    - The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions.



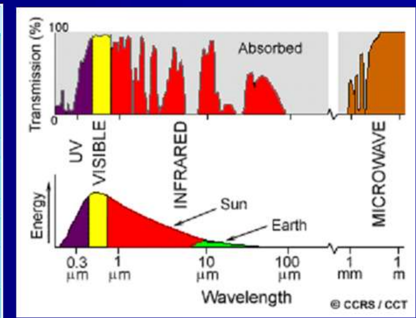


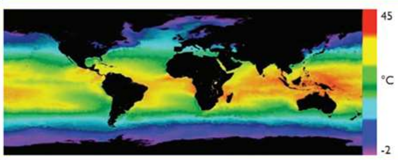


Remote Sensing Sensors

- Imaging Sensors
  - Thermal Imaging Sensor

Sensors	Waveleght (micron)	Spatial resolution
GOES	3.8-4 6.5-7 10.5-11.0 11.5-12.5	10 km
NOAA- AVHRR	3.5-4 10.3-11.3 11.5-12.5	1 km
Landsat-TM	10.4 - 12.5	120 m
ERS-1 ATSR	3.7 11 12	1 km
Landsat-ETM	10.4 - 12.5	60m
EOS -ASTER (Terra)	8-12 (5 bant)	90m
EOS- MODIS (Terra/Aqua)	daha çok 8-12 (16 bant)	1 km
TIMS (uçak)	8-12 (6 bant)	Uçuş yüksekliğine bağlı

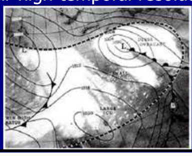




Yeryüzünün 2011 yılı Ocak ayında MODIS algılayıcısı ile ölçülen deniz yüzeyi sıcaklıkları. (© NASA)

Sensors for Weather Forecast

- The Meteorological Satellites or Weather Satellites
  - The weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth.
  - The meteorological or weather satellites was the first non-military satellites in Remote Sensing.
  - Metrological Satellites can be polar orbiting (NOAA 15, NOAA 18 series of polar orbiting meteorological satellites, Metop-A and Metop-B satellites operated by EUMETSAT, Meteor and RESURS series of Russian Satellites), covering the entire Earth asynchronously, or geostationary(GOES-12, 13, 15, 16, 17, Elektro-L No.1, Meteosat 6, 7, 8, 9, INSAT), hovering over the same spot on the equator
  - The first weather satellite to be considered a success was TIROS-1 (Television and Infrared Observation Satellite 1), launched by NASA on April 1, 1960.
  - ATS-1 (Applications Technology Satellite) was the first geostationary weather satellite launched by NASA on December 7, 1966.
  - The United States , launched the series of geostationary GOES (Geostationary Operational Enviromental Satellite) Metrological Satellites and NOAA (National Oceanic and Atmospheric Administration) Metrological Satellites between the 1975-1984.
  - The meteorological satellites enables the weather forecast, monitoring the atmosphere and climate of the Earth and with their high temporal resolution in contrast to the low spatial resolution.



Sensors for Weather Forecast

- The Meteorological Satellites or Weather Satellites

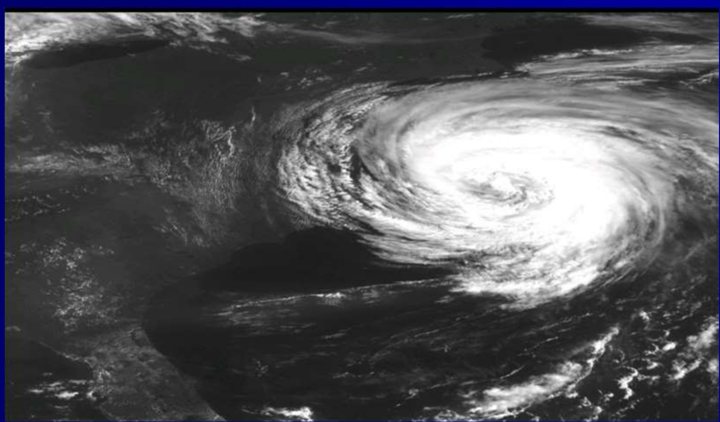


Image from the GOES-9 weather satellite of Hurricane Felix in August 1995

Sensors for Weather Forecast

- GEOS (Geostationary Operational Environmental Satellite)
  - The Geostationary Operational Environmental Satellite system (GOES), operated by the United States' National Oceanic and Atmospheric Administration (NOAA) supports weather forecasting, severe storm tracking, and meteorology research.
  - The GOES system uses geosynchronous satellites and operate in geostationary orbit 35,790 (approximately 36,000) kilometers.

Designation		Launch Date/Time (UTC)	Rocket	Launch Site	Longitude	First Image	Status	Retirement	Remarks
Launch	Operational								
SMS (Synchronous Meteorological Satellites), -derived satellites[edit] Manufactured by Ford Aerospace									
GOES-A	GOES-1	October 16, 1975, 22:40	Delta 2914	CCAFSLC-17A		October 25, 1975	Retired	March 7, 1985[12]	
GOES-B	GOES-2	June 16, 1977, 10:51	Delta 2914	CCAFSLC-17B	60°W		Retired	1993[13]	Reactivated as comsat in 1995,[13] finally deactivated in May 2001
GOES-C	GOES-3	June 16, 1978, 10:49	Delta 2914	CCAFSLC-17B			Retired	1993[14]	Reactivated as comsat in 1995,[14] decommissioned 29 June 2016

Sensors for Weather Forecast

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Designation		Launch Date/Time (UTC)	Rocket	Launch Site	Longitude	First Image	Status	Retirement	Remarks
Launch	Operational								
First generation[edit] Built on a Hughes Space and Communications HS-371 spacecraft bus									
GOES-D	GOES-4	September 9, 1980, 22:57	Delta 3914	CCAFSLC-17A	135°W		Retired	November 22, 1988[15]	
GOES-E	GOES-5	May 22, 1981, 22:29	Delta 3914	CCAFSLC-17A	75°W		Retired	July 18, 1990[16]	
GOES-F	GOES-6	April 28, 1983, 22:26	Delta 3914	CCAFSLC-17A	136°W[17]		Retired	January 21, 1989[17]	
GOES-G	N/A	May 3, 1986, 22:18	Delta 3914	CCAFSLC-17A	135°W (planned)	N/A	Failed	+71 seconds	Launch failure[18]
GOES-H	GOES-7	February 26, 1987, 23:05	Delta 3914	CCAFSLC-17A	75°W, 98°W, 112°W, 135°W, 95°W, 175°W		Retired	January 1996[19]	Reactivated as comsat for Peacesat from 1999-2012, moved to graveyard orbit April 12, 2012.[20]

Sensors for Weather Forecast

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Designation		Launch Date/Time (UTC)	Rocket	Launch Site	Longitude	First Image	Status	Retirement	Remarks
Launch	Operational								
Second generation[edit] Built on a Space Systems/Loral LS-1300 spacecraft bus									
GOES-I	GOES-8	April 13, 1994, 06:04	Atlas I	CCAFSLC-36B	75°W	May 9, 1994	Retired	May 4, 2004[21]	In graveyard orbit
GOES-J	GOES-9	May 23, 1995, 05:52	Atlas I	CCAFSLC-36B	135°W, 155°E	June 19, 1995	Retired	June 14, 2007[22]	In graveyard orbit
GOES-K	GOES-10	April 25, 1997, 05:49	Atlas I	CCAFSLC-36B	135°W, 65°W	May 13, 1997	Retired	1 December 2009[23]	In graveyard orbit
GOES-L	GOES-11	May 3, 2000, 07:07	Atlas IIA	CCAFSSLC-36A	135°W	May 17, 2000	Retired	16 December 2011[24]	Retired, Drifting west
GOES-M	GOES-12	July 23, 2001, 07:23	Atlas IIA	CCAFSSLC-36A	60°W	August 17, 2001	Retired	August 16, 2013	Operated at GOES-South covering South America, and retained as spare, following replacement at GOES-East by GOES-13. Now in a graveyard orbit.

Sensors for Weather Forecast

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  - The GOES system uses geosynchronous satellites and operate in geostationary orbit 35,790 (approximately 36,000) kilometers.

Designation		Launch Date/Time (UTC)	Rocket	Launch Site	Longitude	First Image	Status	Retirement	Remarks
Launch	Operational								
Third generation[edit] Built on a Boeing BSS-601 spacecraft bus									
GOES-N	GOES-13	May 24, 2006, 22:11	Delta IV-M+(4,2)	CCAFSSLC-37B	75°W	June 22, 2006	Standby		Replaced by GOES-16 at GOES-East on December 18, 2017. Instruments were shut off on January 2, 2018 and began a drift to a storage position at 60 degrees west longitude, where it may take over GOES-South duties.[25]
GOES-O	GOES-14	June 27, 2009, 22:51	Delta IV-M+(4,2)	CCAFSSLC-37B	105°W	27 July 2009	Standby		On-orbit spare, was used to cover GOES-East imagery and moved into position following GOES-13 malfunction in 2012,[26] also activated to cover GOES-13 outage in mid-2013
GOES-P	GOES-15	4 March 2010, 23:57	Delta IV-M+(4,2)	CCAFSSLC-37B	89.5°W, 135°W	7 April 2010	Active[27]		Still active, but since replaced operationally by GOES-17 as GOES-West

Sensors for Weather Forecast

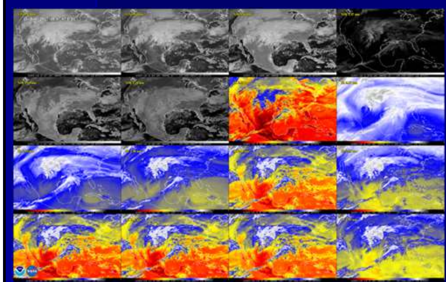
- GEOS (Geostationary Operational Environmental Satellite)
  - GOES-17 (formerly GOES-S) satellite was launched into space on 1 March 2018 in geosynchronous orbit at 35,700 km above Earth by an Atlas V (541) vehicle from Cape Canaveral Air Force Station, Florida.
  - GOES-17 has the same instruments and capabilities as GOES-16 (formerly GOES-East). These two satellites are expected to monitor most of the Western Hemisphere and detect natural phenomena and hazards in almost real time
  - GOES-16, 17 Instruments
    - Earth-facing
    - Sun imaging
    - Space environment measuring

Designation		Launch Date/Time (UTC)	Rocket	Launch Site	Longitude	First Image	Status	Retirement	Remarks
Launch	Operational								
Scheduled launches									
Fourth generation (GOES-R Series)[edit] Built on a Lockheed Martin A2100 spacecraft bus									
GOES-R	GOES-16	19 November 2016, 23:42[29]	Atlas V 541	CCAFSSLC-41	89.5°W	January 15, 2017	Active		Replaced GOES-13 at GOES-East on December 18, 2017.[25][30]
GOES-S	GOES-17	March 1, 2018[31]	Atlas V 541	CCAFSSLC-41	137°W		Active		GOES-West
GOES-T		2020[32]	EELV	CCAFS					
GOES-U		2024[32]	EELV	CCAFS					

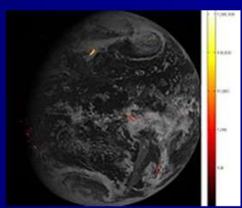
Sensors for Weather Forecast

- GEOS (Geostationary Operational Environmental Satellite)
  - **GOES-16, 17 Instruments**
    - **Earth-facing**
      - The Advanced Baseline Imager (ABI)
      - The Geostationary Lightning Mapper (GLM)
    - **Sun imaging**
      - Solar Ultraviolet Imager (SUVI)
      - Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)
    - **Space environment measuring**
      - Space Environment In-Situ Suite (SEISS)
      - Magnetometer (MAG)

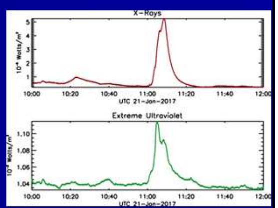
GOES-17



ABI – data from ABI's 16 spectral bands on 15 January 2017



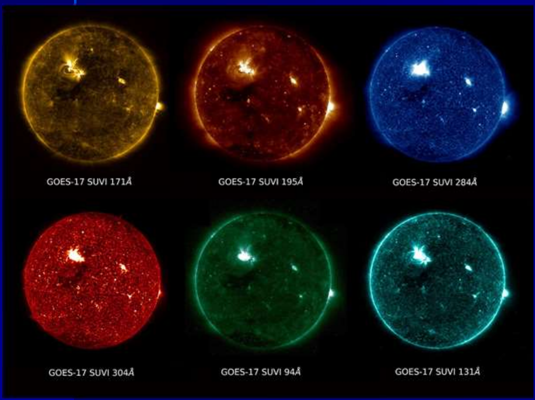
GLM – GLM data superimposed on ABI band 2 data on 14 February 2017



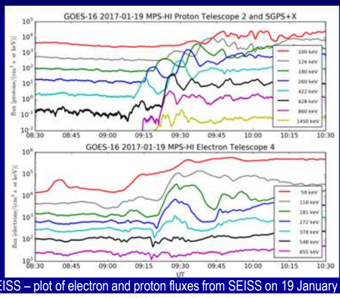
EXIS – plot of EXIS data showing a solar flare on 21 January 2017

Sensors for Weather Forecast

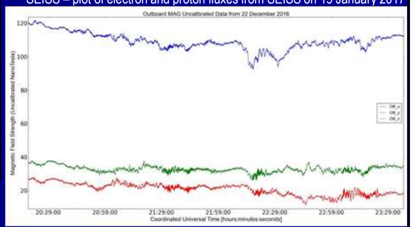
- GEOS (Geostationary Operational Environmental Satellite)
  - **GOES-16, 17 Instruments**



(SUVI) captures a solar flare on 28 May 2018



SEISS – plot of electron and proton fluxes from SEISS on 19 January 2017



MAG – plot of MAG data on 22 December 2016

Sensors for Weather Forecast

- GEOS (Geostationary Operational Environmental Satellite)
  - **GOES-16, 17 Instruments**

ABI spectral bands						
Band	λ (µm)	Central λ (µm)	Pixel spacing (km)	Nickname	Classification	Primary function
1	0.45–0.49	0.47	1	Blue	Visible	Aerosols
2	0.59–0.69	0.64	0.5	Red	Visible	Clouds
3	0.846–0.885	0.865	1	Veggie	Near-infrared	Vegetation
4	1.371–1.386	1.378	2	Cirrus	Near-infrared	Cirrus
5	1.58–1.64	1.61	1	Snow/Ice	Near-infrared	Snow/ice discrimination, cloud phase
6	2.225–2.275	2.25	2	Cloud Particle Size	Near-infrared	Cloud particle size, snow cloud phase
7	3.80–4.00	3.90	2	Shortwave Window	Infrared	Fog, stratus, fire, volcanism
8	5.77–6.6	6.9	2	Upper-level Tropospheric Water Vapor	Infrared	Various atmospheric features
9	6.75–7.15	6.95	2	Mid-level Tropospheric Water Vapor	Infrared	Water vapor features
10	7.24–7.44	7.34	2	Lower-level Tropospheric Water Vapor	Infrared	Water vapor features
11	8.3–8.7	8.5	2	Cloud-Top Phase	Infrared	Cloud-top phase
12	9.42–9.8	9.61	2	Ozone	Infrared	Total column ozone
13	10.1–10.6	10.35	2	Clean Infrared Longwave Window	Infrared	Clouds
14	10.8–11.6	11.2	2	Infrared Longwave Window	Infrared	Clouds
15	11.8–12.8	12.3	2	Dirty Infrared Longwave Window	Infrared	Clouds
16	13.0–13.6	13.3	2	CO2 Longwave Infrared	Infrared	Air temperature, clouds

ABI temporal resolution changes depending on the type of image

- Imaging of entire western hemisphere occurs every 5 to 15 minutes, while previously this was a scheduled event, with at most three photos per hour.
- Imaging of the continental United States once every 5 minutes, compared to one every 15 minutes in previous satellites
- One detailed image over some 1000 by 1000 km box every thirty seconds, a capability previous imagers did not have

ABI spatial resolution will be dependent on what band is being used

- band 2 is the highest resolution out of all channels, with a resolution of 500 m
- Channels 1, 3, and 5 will have a resolution of 1 km

GLM is used for measuring lightning (in-cloud and cloud-to-ground) activity

- GLM records a single channel in the NIR (777.4 nm) constantly, even during the day, to catch flashes from lightning.
- GLM has a 1372×1300 pixel CCD, with an 8-14 km spatial resolution (with the resolution decreasing near the edges of the FOV).
- The GLM has a frame rate of 2 milliseconds, meaning it considers the entire study area 500 times every second.

Sensors for Weather Forecast

- NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer)
  - NOAA has at least two polar-orbiting meteorological satellites in orbit at all times, with one satellite crossing the equator in the early morning and early evening and the other crossing the equator in the afternoon and late evening.
  - The primary sensor on board both satellites is the AVHRR instrument. The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature. The term surface can mean the surface of the Earth, the upper surfaces of clouds, or the surface of a body of water.
  - Morning-satellite data are most commonly used for land studies, while data from both satellites are used for atmosphere and ocean studies. Together they provide twice-daily global coverage, and ensure that data for any region of the earth are no more than six hours old.
  - The swath width, the width of the area on the Earth's surface that the satellite can "see", is 2,343 km from the 833 km nominal orbital altitude. The satellites orbit between 833 or 870 kilometers (+/− 19 kilometers above the surface of the Earth.
  - The first AVHRR was a 4-channel radiometer, first carried on TIROS-N (launched October 1978). This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7 (launched June 1981). The latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998.

Sensors for Weather Forecast

- NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer)
  - Measuring the same view, this array of diverse wavelengths, after processing, permits multi spectral analysis for more precisely defining hydrologic, oceanographic, and meteorological parameters.

AVHRR/3 Channel Characteristics			
Channel Number	Resolution at Nadir	Wavelength (um)	Typical Use
1	1.09 km	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09 km	0.725 - 1.00	Land-water boundaries
3A	1.09 km	1.58 - 1.64	Snow and ice detection
3B	1.09 km	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09 km	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09 km	11.50 - 12.50	Sea surface temperature

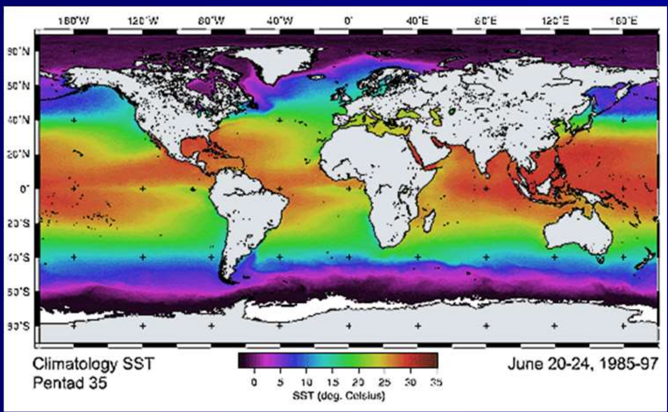
Sensors for Weather Forecast

- NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer)
  - NOAA Satellite Launch and Service Dates

Satellite name	Launch date	Service start	Service end
TIROS-N ['tairəus] [Television and Infrared Observation Satellite]	13 October 1978	19 October 1978	30 January 1980
NOAA-6	27 June 1979	27 June 1979	16 November 1986
NOAA-7	23 June 1981	24 August 1981	7 June 1986
NOAA-8	28 March 1983	3 May 1983	31 October 1985
NOAA-9	12 December 1984	25 February 1985	11 May 1994
NOAA-10	17 September 1986	17 November 1986	17 September 1991
NOAA-11	24 September 1988	8 November 1988	13 September 1994
NOAA-12	13 May 1991	14 May 1991	15 December 1994
NOAA-14	30 December 1994	30 December 1994	23 May 2007
NOAA-15	13 May 1998	13 May 1998	Present
NOAA-16	21 September 2000	21 September 2000	9 June 2014
NOAA-17	24 June 2002	24 June 2002	10 April 2013
NOAA-18	20 May 2005	30 August 2005	present
NOAA-19	6 February 2009	2 June 2009	present

Sensors for Weather Forecast

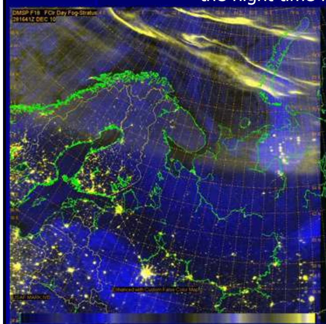
- NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer)
  - Global Sea Surface Temperature acquired from the different NOAA/ AVHRR satellite between 1985-1987



Global Sea Surface Temperature acquired from the NOAA/ AVHRR satellite

Sensors for Weather Forecast

- DMSP (Defense Meteorological Satellite Program)
  - The United States operates the DMSP (Defense Meteorological Satellite Program) series of satellites which are also used for weather monitoring. These are sun-synchronousnear-polar orbiting satellites at nominal altitude of 830 km 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.
  - It has two fairly broad wavelength bands: a visible and near infrared band (0.4 to 1.1 μm) and a thermal infrared 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 centres.



DMSP images of Auroral bands circling north of Scandinavia

Composite image of the Earth at night (created by DSMP images recorded 1994 -1995)

Sensors for Weather Forecast

- Other Weather Satellites
  - The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Meteosat
  - India, INSAT
  - Russia, Elektro–L
  - Japan, Himawari yada Geostationary Meteorological Satellite (GMS)

Himawari

Meteosat

INSAT

Elektro-L

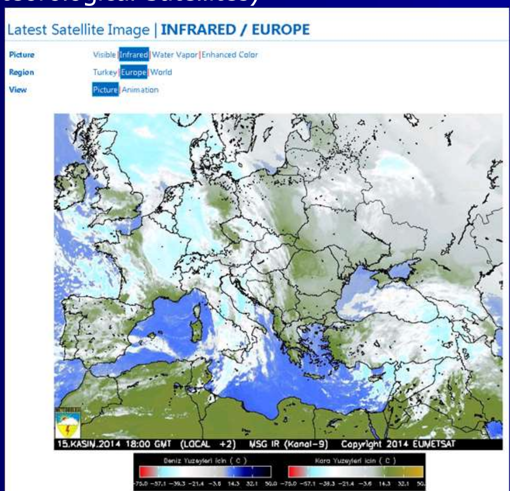
Sensors for Weather Forecast

- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
  - The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) is an intergovernmental organisation created through an international convention agreed by a current total of 30 European Member States
  - Meteosat-7,-8, 9 and 10, Metop-A, Metop-B and Jason-2 are the sensor operated by EUMETSAT

Member states (blue) and Cooperating states (green)

Sensors for Weather Forecast

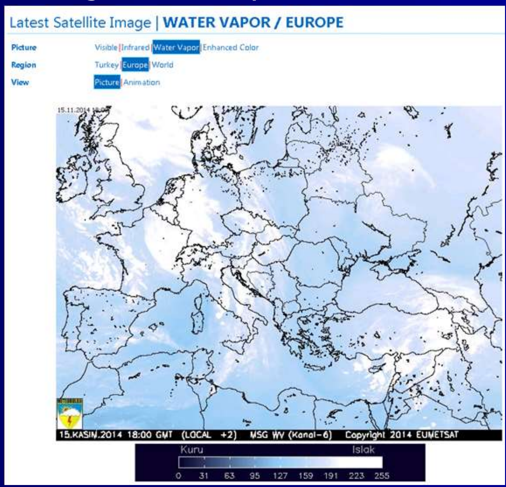
- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)



http://www.dmi.gov.tr/en-us/satellite.aspx?uB=eu&uT=e&uG=p

Sensors for Weather Forecast

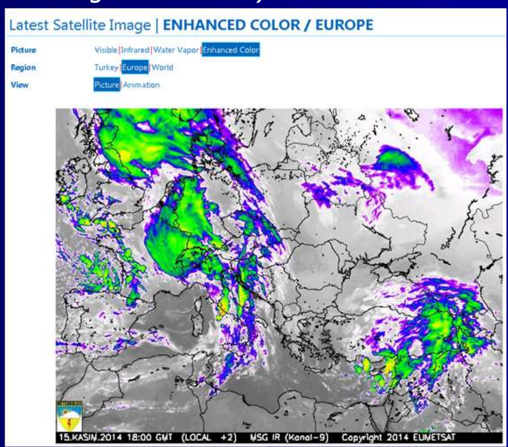
- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)



http://www.dmi.gov.tr/en-us/satellite.aspx?uB=eu&uT=e&uG=p

Sensors for Weather Forecast

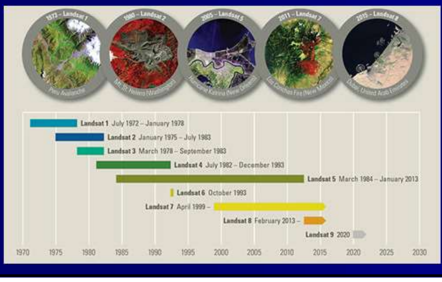
- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)



http://www.dmi.gov.tr/en-us/satellite.aspx?uB=eu&uT=e&uG=p

Sensors for Earth observation

- Landsat
  - The Department of the Interior, NASA, and the Department of Agriculture then embarked on an ambitious effort to develop and launch the first civilian Earth observation satellite on July 23, 1972, with the launch of the Earth Resources Technology Satellite (ERTS-1), which was later renamed Landsat 1.
  - The launches of Landsat 2, Landsat 3, and Landsat 4 followed in 1975, 1978, and 1982, respectively.
  - When Landsat 5 launched in 1984, continued to deliver high quality, global data of Earth's land surfaces for 28 years and 10 months. Landsat 6 failed to achieve orbit in 1993.
  - Landsat 7 successfully launched in 1999, Landsat 8 in 2013, and both satellites continue to acquire data. The Landsat 9 satellite is being developed toward a launch readiness date of December 2020.



  - The instruments on Landsat satellites have acquired millions of images is about 185 kilometers long and 185 kilometers wide.

https://www.youtube.com/watch?v=w4ZzqX5_W0o

  - The images, archived in the United States are a unique resource for global change research and applications in;
    - agriculture,
    - cartography,
    - geology,
    - forestry,
    - regional planning,
    - surveillance and education.

Sensors for Earth observation

- Landsat

Instrument	Picture	Launched	Terminated	Duration	Notes
Landsat 1		July 23, 1972	January 6, 1978	5 years, 6 months and 14 days	Originally named Earth Resources Technology Satellite 1. Landsat 1 carried two vital instruments; a camera built by the Radio Corporation of America (RCA) known as the Return Beam Vidicon (RVB). As well as a Multi spectral Scanner (MSS) built by the Hughes Aircraft Company.
Landsat 2		January 22, 1975	February 25, 1982	7 years, 1 month and 3 days	Nearly identical copy of Landsat 1. Payload consisting of a Return Beam Vidicon (RBV) and a Multi spectral Scanner (MSS). The specifications of these instruments were identical to Landsat 1.
Landsat 3		March 5, 1978	March 31, 1983	5 years and 26 days	Nearly identical copy of Landsat 1 and Landsat 2. Payload consisting of a Return Beam Vidicon (RBV) as well as a Multi spectral Scanner (MSS). Included with the MSS was a short-lived thermal band. MSS data was considered more scientifically applicable than the RBV which was rarely used for engineering evaluation purposes.
Landsat 4		July 16, 1982	December 14, 1993	11 years, 4 months and 28 days	Landsat 4 carried an updated Multi Spectral Scanner (MSS) used on previous Landsat missions, as well as a Thematic Mapper.
Landsat 5		March 1, 1984	June 5, 2013[10]	29 years, 3 months and 4 days	Nearly identical copy of Landsat 4. Longest Earth-observing satellite mission in history. Designed and built at the same time as Landsat 4, this satellite carried the same payload consisting of a Multi Spectral Scanner (MSS) as well as a Thematic Mapper.
Landsat 6		October 5, 1993	October 5, 1993	0 days	Failed to reach orbit. Landsat 6 was an upgraded version of its predecessors. Carrying the same Multi spectral Scanner (MSS) but also carrying an Enhanced Thematic Mapper, which added a 15m-resolution panchromatic band.
Landsat 7		April 15, 1999	Still active	19 years, 11 months and 12 days	Operating with scan line corrector disabled since May 2003.[11] The main component on Landsat 7 was the Enhanced Thematic Mapper Plus (ETM+). Still consisting of the 15m-resolution panchromatic band, but also includes a full aperture calibration. This allows for 5% absolute radiometric calibration.[12]
Landsat 8		February 11, 2013	Still active	6 years, 1 month and 16 days	Originally named Landsat Data Continuity Mission from launch until May 30, 2013, when NASA operations were turned over to USGS.[13] Landsat 8 has two sensors with its payload, the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS).[14]
Landsat 9		December 2020 (expected)			Landsat 9 will be a rebuild of its predecessor Landsat 8.[15]

Sensors for Earth observation

- Landsat
  - Landsat 1 through 5 carried the Landsat Multispectral Scanner (MSS).
  - Landsat 4 and 5 carried both the MSS and Thematic Mapper (TM) instruments.

Landsat 1-5 Multispectral Scanner (MSS)

Landsat 1-3 MSS	Landsat 4-5 MSS	Wavelength (micrometers)	Resolution (meters)
Band 4 - Green	Band 1 - Green	0.5 - 0.6	60*
Band 5 - Red	Band 2 - Red	0.6 - 0.7	60*
Band 6 - Near Infrared (NIR)	Band 3 - NIR	0.7 - 0.8	60*
Band 7 - NIR	Band 4 - NIR	0.8 - 1.1	60*

Landsat 4-5 Thematic Mapper (TM)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Blue	0.45 - 0.52	30
Band 2 - Green	0.52 - 0.60	30
Band 3 - Red	0.63 - 0.69	30
Band 4 - NIR	0.76 - 0.90	30
Band 5 - Shortwave Infrared (SWIR) 1	1.55 - 1.75	30
Band 6 - Thermal	10.40 - 12.50	120* (30)
Band 7 - SWIR 2	2.08 - 2.35	30

TM Bands

Channel	Wavelength Range (µm)	Application
TM 1	0.45 - 0.52 (blue)	soil/vegetation discrimination; bathymetry/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

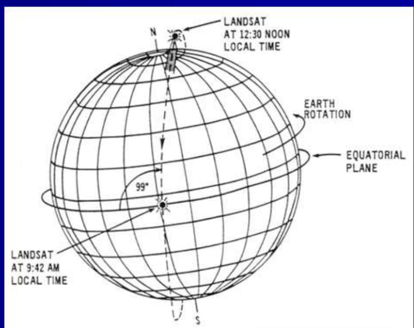
Sensors for Earth observation

- Landsat
  - Landsat 7 uses the Enhanced Thematic Mapper Plus (ETM+) scanner.
  - Landsat 8 uses two instruments, the Operational Land Imager (OLI) for optical bands and the Thermal Infrared Sensor (TIRS) for thermal bands.
  - Landsat missions use sun-synchronous, near polar orbits at different altitudes for each mission.

https://www.youtube.com/watch?v=xBhorGs8uy8

Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Blue	0.45 - 0.52	30
Band 2 - Green	0.52 - 0.60	30
Band 3 - Red	0.63 - 0.69	30
Band 4 - NIR	0.77 - 0.90	30
Band 5 - SWIR 1	1.55 - 1.75	30
Band 6 - Thermal	10.40 - 12.50	60* (30)
Band 7 - SWIR 2	2.09 - 2.35	30
Band 8 - Panchromatic	0.52 - 0.90	15



Sensors for Earth observation

- Landsat

Mission	Landsat-1		Landsat-2		Landsat-3		Landsat-4		Landsat-5		Landsat-6	Landsat-7	Landsat-8(LCDM)	
Mission period	1972-1978		1975-1982		1978-1983		1982-2001		1984-2012		1993, failed	April 1999 -	Feb 2013 -	
Orbit	Sun-synchronous, near-polar													
Altitude	917 km		917 km		917km		705 km		706 km			705km	705 km	
Inclination	99.2 deg		99.2 deg		99.2 deg		98.2 deg		98.2 deg			98.2deg	98.2 deg	
Eq. crossing (+/- 15min)	9:30am		9:30am		9:30am		9:45am		9:45am			10am	10 am	
Period (min)	103.34		103		103		99					98.9	98.9	
No. orbits /day	14		14		14		14		14			14	14	
Repeat cycle	18		18		18		16		16			16	16	
Swath width	185		185		185		185		185			185	185	
Sensors	RBV	MSS	RBV	MSS	RBV	MSS	MSS	TM	MSS	TM	ETM	ETM+	OLI	TIRS
Bands	1-3	4-7	1-3	4-7	1-4	4-8	1-4	1-7	1-4	1-7	1-8	1-8	1-9	1-2
Spatial resolution (m)	80	82	80	82	80	82 B8:240	79	30 B6:120	79	30 B6:120	B1-B5,B7: 30 B6: 120 B8: 15	B1-B5,B7: 30 B6: 60 B8: 15	30 B8:15	100
Radiometric resolution (Bits)	6	B1-B3:7 B4: 6	6	B1-B3:7 B4: 6	6	B1-B3:7 B4: 6	B1-B3:7 B4: 6	8	B1-B3:7 B4: 6	8	8	8	12	12

Sensors for Earth observation

- Landsat
  - LANDSAT 8 has two instruments Operational Land Imager (OLI) ve the Thermal InfraRed Sensor (TIRS)
  - Planned parameters for Landsat 8 standard products
  - Product type: Level 1T (terrain corrected),
  - Output format: GeoTIFF
  - Map projection: UTM (Polar Stereographic for Antarctica)
  - Datum: WGS 84
  - Orientation: North-up (map)
  - Resampling: Cubic convolution
  - Accuracy:
  - OLI: 12 meters circular error, 90-percent confidence
  - TIRS: 41 meters circular error, 90-percent confidence
  - Pixel size: 15 meters/30 meters/100 meters (panchromatic/multispectral/thermal)

https://www.youtube.com/watch?v=1b1q3LHb6-8
https://www.youtube.com/watch?v=A6WzAc1FTeA

Spectral Band	Wavelength	Resolution
Band 10 - Long Wavelength Infrared	10.30 - 11.30 µm	100 m
Band 11 - Long Wavelength Infrared	11.50 - 12.50 µm	100 m

Thermal InfraRed Sensor (TIRS) Specktral Band

Spectral Band	Wavelength	Resolution
Band 1 - Coastal / Aerosol	0.433 - 0.453 µm	30 m
Band 2 - Blue	0.450 - 0.515 µm	30 m
Band 3 - Green	0.525 - 0.600 µm	30 m
Band 4 - Red	0.630 - 0.680 µm	30 m
Band 5 - Near Infrared	0.845 - 0.885 µm	30 m
Band 6 - Short Wavelength Infrared	1.560 - 1.660 µm	30 m
Band 7 - Short Wavelength Infrared	2.100 - 2.300 µm	30 m
Band 8 - Panchromatic	0.500 - 0.680 µm	15 m
Band 9 - Cirrus	1.360 - 1.390 µm	30 m

Operational Land Imager (OLI) Specktral Band