# EAS 8803 FALL 2015

## Satellite Data Analysis (Satellite Remote Sensing)

**Instructor:** Prof. Irina N. Sokolik

Office 3104, phone 404-894-6180

isokolik@eas.gatech.edu

**Meeting Time:** Tuesday/Thursday: 4:35-5:55 PM L1118

## Introduction and Logistics

**Objectives:**

1. What this course is about.
2. How the course is organized:
   - Lectures
   - Computer Modeling Laboratories
   - Class Research Project
3. Reading.
4. Grading.
5. Course outline, lecture schedule, and reading assignments.

## 1. What this course is about

***General definition:***

**Remote sensing** is the collection of information about an object without coming into physical contact with it.

***Definition used in this course:***

**Remote sensing** is characterization of an object based on measurements of electromagnetic radiation.

- This course provides a foundation for understanding the physical principles of remote sensing of the atmosphere and oceans.

- The main goal of the course is to build a broad conceptual framework for physical understanding the methodology and various applications of remote sensing in studying the atmosphere and oceans.

NOTE: This course does NOT include remote sensing of land and vegetation, image processing, or instrumentation development.

- The course is designed as a collection of lectures and computer modeling laboratories.
- The lectures focus on the fundamentals of the interactions between electromagnetic radiation and atmospheric gases, aerosols and clouds, and ocean surfaces, covering the spectrum from the ultraviolet through the microwave.
- The labs provide hands-on experience in using remote sensing data for various applications in atmospheric and oceanic sciences. Topics to be covered include aerosol and cloud property retrievals, ozone and air pollution characterization, vertical temperature and humidity profile retrievals, sea ice characterization, and retrievals of ocean color and sea surface temperature, among others.

## 2. How this course is organized:

- **Lectures:**

Lectures are developed to provide the most critical material.

Lecture notes will be posted before the lectures (in PDF format) at the course website: **http://irina.eas.gatech.edu/EAS8803_Fall2015/**

**!!!!! Please review lecture materials before coming to the class.**

- **Computer Modeling Laboratories**

Will be posted at the course web and available on-line. Your written report will be required by the time of the following lab.

***Bring your own computer.!!!***

- **Exam:**

  Date of the exam will be posted later.

- **Class Research Project**

**Goal** is to perform an analysis and interpretation of remote sensing data in a well-defined problem.

Plan of a research project must be prepared by a student but discussed with and approved by me. Try to select a topic of your class project as close as possible to your research. Deadline for the title and abstract is the end of the second week of the course.

Research project must be prepared as a research paper and presented in the class. Presentations will be scheduled for the last week of the classes.

**General guidelines for preparing your class project:**

1) Define a topic of your project by selecting a specific atmospheric or oceanic parameter and remote sensing technique(s) used to retrieve this parameter.

*For instance, characterization of ozone from OMI observations.*

2) Identify and study at least 3-5 papers dealing with the selected topic.

3) Perform an original analysis of the remote sensing data in a well-defined problem.

*For instance, interannual variability of* $O_3$ *over the Northern America.*

4) Your paper (about 20 – 25 pages) should show

the importance of the atmospheric or oceanic parameter selected;

brief description of a remote sensor;

explanation of a retrieval algorithm;

results of your analysis;

validation of retrieved data against independent measurements and/or modeling;

brief summary (e.g., advantages and disadvantages of the retrieval technique, etc.)

## 3. Reading.

***Remote Sensing of the Lower Atmosphere: An Introduction.***

**Stephens G.** Oxford Univ. Press 1994.

***A First Course in Atmospheric Radiation.***

**Petty G.W.,** Sundog Publishing. Second Edition.

**Online tutorials:**

***Canada Centre for Remote Sensing (CCRS) remote sensing tutorial:***

http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309

***NASA remote sensing tutorial:***

http://fas.org/irp/imint/docs/rst/

***Univ. of Illinois tutorial: remote sensing for meteorology:***

http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/home.rxml

**Additional Text:**

***An introduction to atmospheric radiation.***

**Liou, K.N.,** Academic Press, Second Edition, Chapter 7, 2002.

***Satellite meteorology: An Introduction.***

**Kidder S.Q. and Vonder Haar T.H.,** Academic Press, 1995.

***Physical principles of remote sensing.***

**Rees W.G**., Cambridge Univ. Press, Second Edition, 2001.

**Introduction to the physics and techniques of remote sensing**.

**Elachi, C**. New York : Wiley, 1987

***Remote sensing: Principles and interpretation.***

**Sabins**, **F.F**., 1997.

**NOTE**: The various textbooks might have somewhat different terminology and use very different notations.

## 4. Grading.

| | |
|---|---|
| Exam | 20% |
| Computer modeling labs | 40% |
| Research project | 40% |

## ***Lecture 1.***

**Basics of remote sensing: Introductory survey**

1. Types of platforms used for remote sensing.

2. Passive and active remote sensing.

3. General characteristics: orbits, resolutions, types of satellite sensors, and viewing geometry.

***Reading***:

CCRS online tutorial. Chapter 2 - Satellites and Sensors

http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1262;

NASA online tutorial: History of Remote Sensing; Remote Sensing Systems

http://www.fas.org/irp/imint/docs/rst/Intro/Part2_7.html

**1. Types of platforms used for remote sensing:**

**ground-based, airborne and spaceborne.**

**Ground-based** platforms: ground, vehicles and/or towers => up to 50 m

***Examples:***

DOE ARM (Atmospheric radiation Program): http://www.arm.gov/

NASA AERONET (AErosol Robotic NETwork): http://aeronet.gsfc.nasa.gov/

**Airborne** platforms: airplanes, helicopters, high-altitude aircrafts, balloons => up to 50 km

***Examples:***

NCAR, NOAA, and NASA research aircrafts, http://www.eol.ucar.edu/raf/

**Spaceborne**: rockets, satellites, shuttle => from about 100 km to 36000 km

Space shuttle: 250-300 km

Space station: 300-400 km

**Low-level satellites: 700-1500 km**

High-level satellites: about 36000 km

***<u>Examples</u>:***

**NASA** current and planned Earth's observing satellite missions:

http://science.hq.nasa.gov/missions/earth.html

**NOAA weather satellites**: http://www.noaa.gov/satellites.html

## 2. Passive and active remote sensing.

**<u>Passive sensors</u>** measure natural radiation emitted by the target material or/and radiation energy from other sources reflected from the target.

Two main natural sources of radiation: Sun and Earth's thermal emission

***<u>Examples</u>:***

Passive microwave radiometer that detects naturally emitted microwave energy.

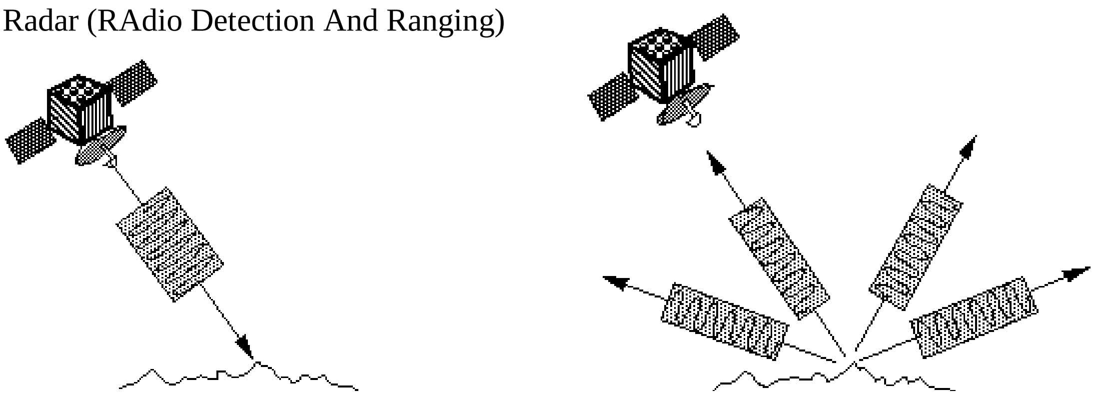
Radiometers that measure reflected (or backscattered) sun light from the atmosphere and ocean.

**<u>Active sensors</u>** transmit their own signal and measure the energy that is reflected (or scattered back) from the target material.

***<u>Examples:</u>***

Lidar (LIght Detection And Ranging)

Radar (RAdio Detection And Ranging)



*Radar transmits a pulse and measures reflected echo (backscatter)*

3. General characteristics: orbits, resolutions, types of satellite sensors, and viewing geometry.

➢ <u>**Satellites orbits: low-level and high-level**</u>

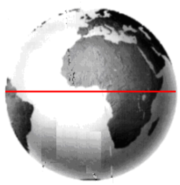
***Low-level (700-1500 km) Earth observation satellites (called LEO) fall into three broad groups:***

i). Equatorial orbiting satellites

ii). Polar orbiting satellite

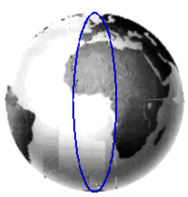
iii). Oblique orbiting (or near-polar) satellites

- LEO satellites are often on **sun-synchronous** orbits. **Sun-synchronous** means that the satellite remains fixed with respect to the Sun with the Earth rotating under the satellite (i.e., satellite passes over its target on the Earth at roughly the same local time).



Equatorial orbiting satellites, whose orbits are within the plane of the Equator

***<u>Example:</u>*** TRMM



Polar orbiting satellites, whose orbits are in the plane of the Earth's polar axis

- <u>Ascending pass</u> is when the satellite travels from south to north, and <u>descending</u> when the satellite travels from north to south.
- Oblique orbiting satellites can be launched eastwards into direct (called <u>prograde</u>) orbit (so called because the movement of such satellites is in the same direction as the rotation of the Earth), or westwards into <u>retrograde</u> orbit.
- The <u>inclination</u> of an orbit is specified in terms of the angle between its ascending track and the Equator.
- Prograde orbits <u>regress</u> while retrograde orbits <u>precess</u> with respect to the planes of their initial orbits because the Earth is not a perfect sphere and it causes a gyroscopic influence on satellites in oblique orbits.

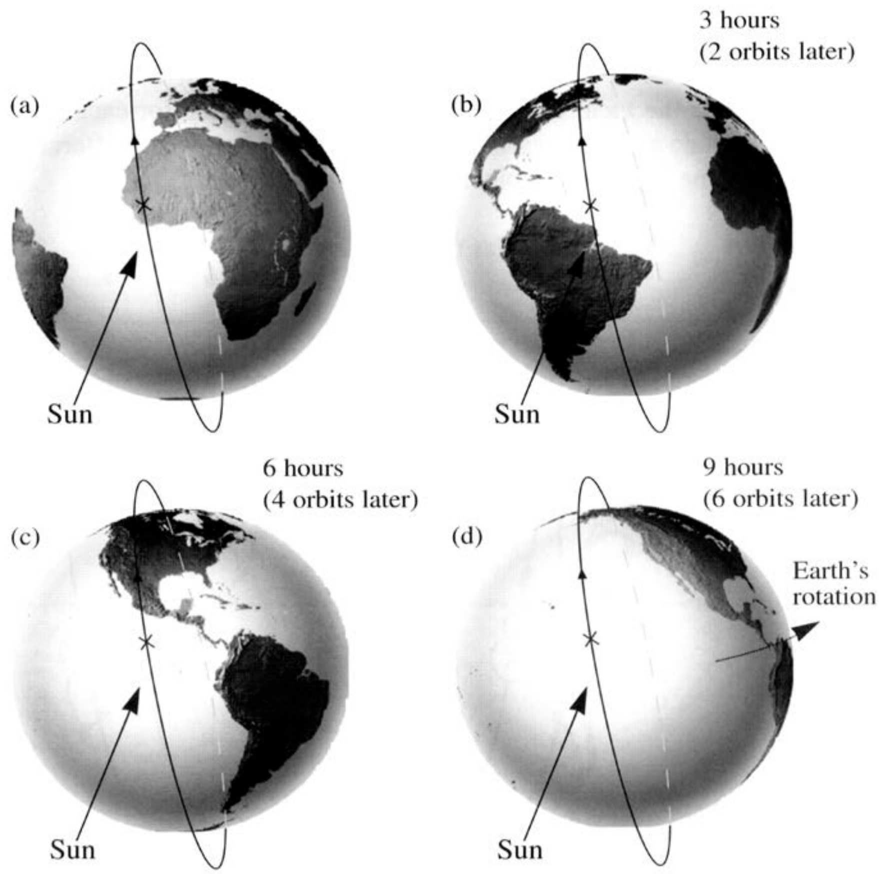



**Figure 1.1** Oblique orbiting (near-polar orbiting) satellites: Sun-synchronous orbits (each 3 hours)

**<u>High-level (about 36000 km) satellites</u>**:

**Geostationary** satellites (often called weather satellites) are "fixed" above a given point on the Earth surface because their circular orbits above the equator have rotation period equals to the earth's rotation period.

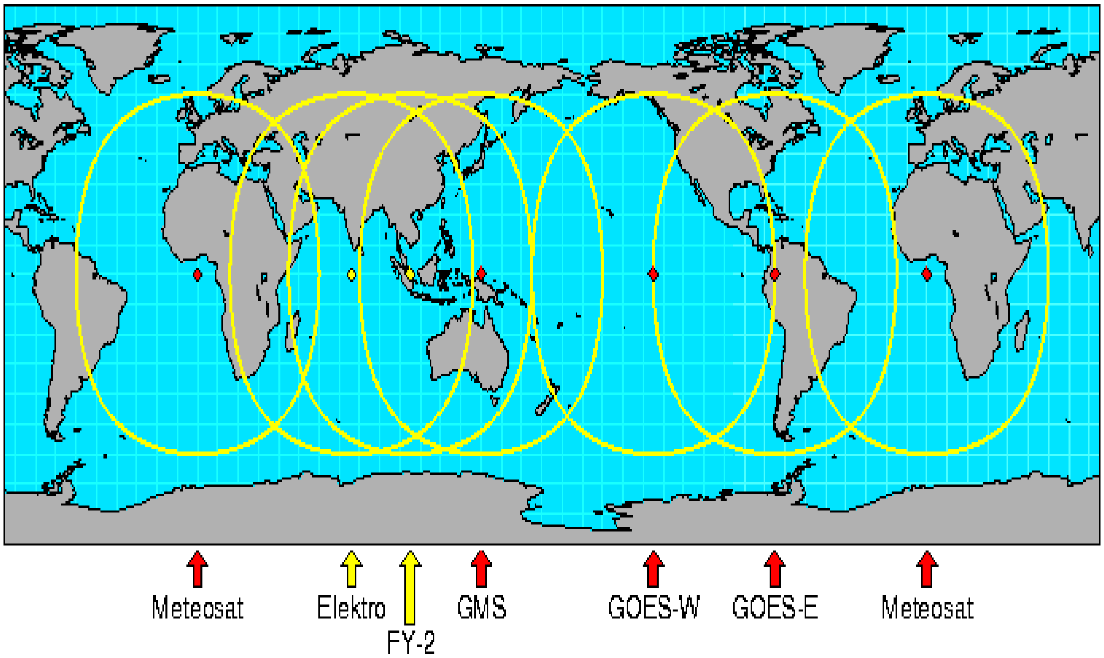



**Figure 1.2** Example of geostationary satellite coverage.

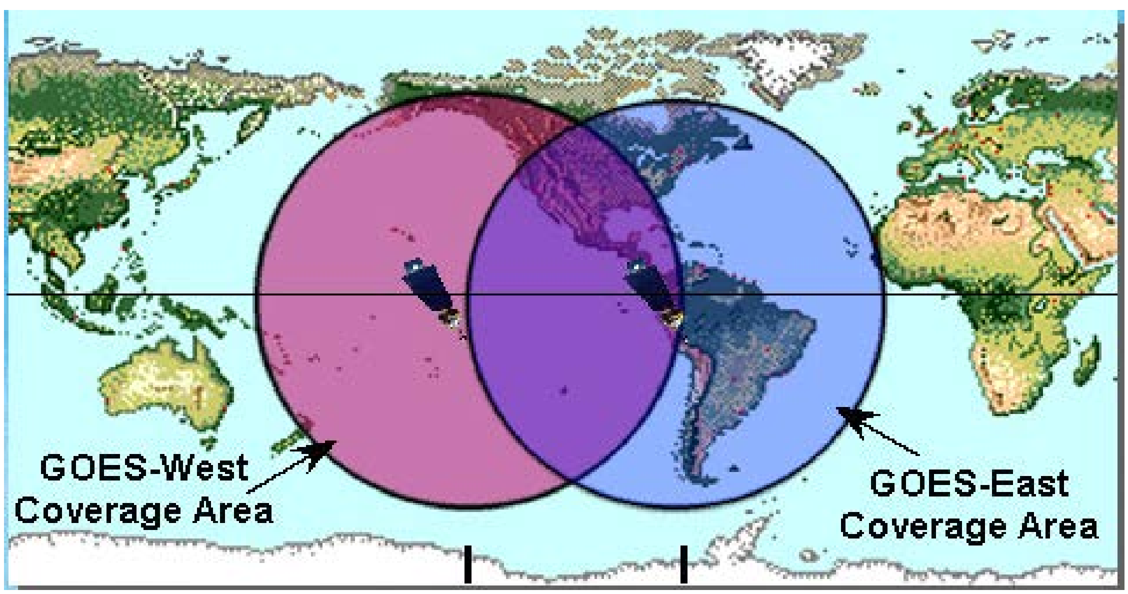
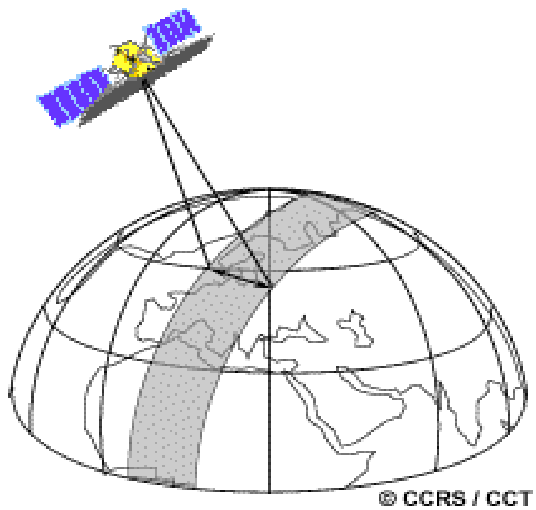



**Figure 1.3** U.S. geostationary satellites: GOES

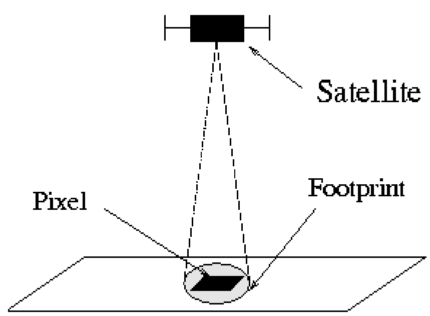
- ***Resolutions: spatial, spectral, radiometric, and temporal***

**Swath** is the width of the track covered by a sensing system on the surface of the Earth. In general, swaths for spaceborne sensors vary between tens and hundreds of kilometers wide.




**Spatial resolution** is often defined as the ability to distinguish between two closely spaced objects on an image. No single definition for spatial resolution exists.

- Spatial resolution depends on the field of view (FOV), altitude and viewing angle of a sensor.



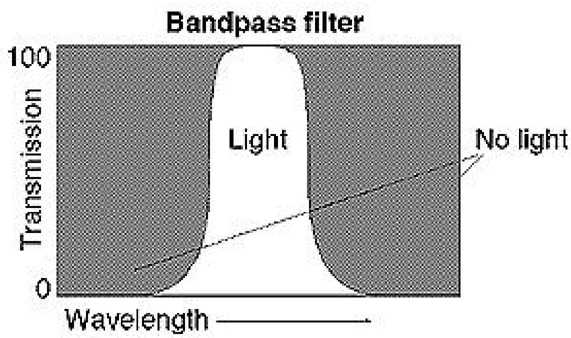

**NOTE**: small pixel => large spatial resolution

- The size of the pixel sets a lower limit on the spatial resolution.
- A measure of the size of the pixel is given by the instantaneous field of view

**Instantaneous Field of View** (IFOV) is the solid angle through which a detector is sensitive to radiation.

**Spectral** resolution refers to the dimension and number of wavelength regions (or bands) in the electromagnetic spectrum to which the sensor is sensitive.

- Based on the spectral resolution the sensors fall into the following broad groups: broad-band, narrow-band, spectral and hyperspectral sensors.




The narrower the bandwidth, the better the spectral resolution!

***Examples***:

Broad-band sensor: CERES (Clouds and the Earth's Radiant Energy System)

Three bands (channels): Solar region: 0.3 - 5.0 μm; IR window: 8 - 12 μm; and total: 0.3 to > 100 μm

Narrow-band sensor: MODIS (Moderate Resolution Imaging Spectroradiometer)

Table 1.1 MODIS spectral bands

| Primary Use | Band | Bandwidth[1] | Spectral Radiance[2] | Required SNR[3] |
|---|---|---|---|---|
| Land / Cloud / Aerosols Boundaries | 1 | 620 - 670 | 21.8 | 128 |
| | 2 | 841 - 876 | 24.7 | 201 |
| Land / Cloud / Aerosols Properties | 3 | 459 - 479 | 35.3 | 243 |
| | 4 | 545 - 565 | 29.0 | 228 |
| | 5 | 1230 - 1250 | 5.4 | 74 |
| | 6 | 1628 - 1652 | 7.3 | 275 |
| | 7 | 2105 - 2155 | 1.0 | 110 |
| Ocean Color Phytoplankton Biogeochemistry | 8 | 405 - 420 | 44.9 | 880 |
| | 9 | 438 - 448 | 41.9 | 838 |
| | 10 | 483 - 493 | 32.1 | 802 |

| | | | | |
|---|---|---|---|---|
| | 11 | 526 - 536 | 27.9 | 754 |
| | 12 | 546 - 556 | 21.0 | 750 |
| | 13 | 662 - 672 | 9.5 | 910 |
| | 14 | 673 - 683 | 8.7 | 1087 |
| | 15 | 743 - 753 | 10.2 | 586 |
| | 16 | 862 - 877 | 6.2 | 516 |
| **Atmospheric Water Vapor** | 17 | 890 - 920 | 10.0 | 167 |
| | 18 | 931 - 941 | 3.6 | 57 |
| | 19 | 915 - 965 | 15.0 | 250 |
| **Surface/Cloud Temperature** | 20 | 3.660 - 3.840 | 0.45 (300K) | 0.05 |
| | 21 | 3.929 - 3.989 | 2.38 (335K) | 2.00 |
| | 22 | 3.929 - 3.989 | 0.67 (300K) | 0.07 |
| | 23 | 4.020 - 4.080 | 0.79 (300K) | 0.07 |
| **Atmospheric Temperature** | 24 | 4.433 - 4.498 | 0.17 (250K) | 0.25 |
| | 25 | 4.482 - 4.549 | 0.59 (275K) | 0.25 |
| **Cirrus Clouds Water Vapor** | 26 | 1.360 - 1.390 | 6.00 | 150(SNR) |
| | 27 | 6.535 - 6.895 | 1.16 (240K) | 0.25 |
| | 28 | 7.175 - 7.475 | 2.18 (250K) | 0.25 |
| **Cloud Properties** | 29 | 8.400 - 8.700 | 9.58 (300K) | 0.05 |
| **Ozone** | 30 | 9.580 - 9.880 | 3.69 (250K) | 0.25 |
| **Surface/Cloud Temperature** | 31 | 10.780 - 11.280 | 9.55 (300K) | 0.05 |
| | 32 | 11.770 - 12.270 | 8.94 (300K) | 0.05 |
| **Cloud Top Altitude** | 33 | 13.185 - 13.485 | 4.52 (260K) | 0.25 |

| | | | | |
|---|---|---|---|---|
| | 34 | 13.485 - 13.785 | 3.76 (250K) | 0.25 |
| | 35 | 13.785 - 14.085 | 3.11 (240K) | 0.25 |
| | 36 | 14.085 - 14.385 | 2.08 (220K) | 0.35 |
| ** Footnotes:<br>[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm<br>[2] Spectral Radiance values are (W/m² -µm-sr)<br>[3] SNR = Signal-to-noise ratio<br>[4] NE(delta)T = Noise-equivalent temperature difference* | | | | |

**Radiometric** resolution is a measure of the sensitivity of a sensor to differences in the intensity of the radiation measured the sensor.

- The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

***Technical definition**:*

Radiometric resolution is a measure of how many grey levels are measured between pure black and pure white.

- The radiometric resolution is measured in bits: 1-bit system ($2^1$ = 2) measures only two radiation levels; 2-bit system measures ($2^2$=4) four levels, etc.

**Temporal** resolution is a measure of how often data are obtained for the same area (i.e., how often an area can be revisited).

- The temporal resolution varies from hours for some systems to about 20 days to others. High temporal resolution: daily or twice daily.

➢ Types of sensors.

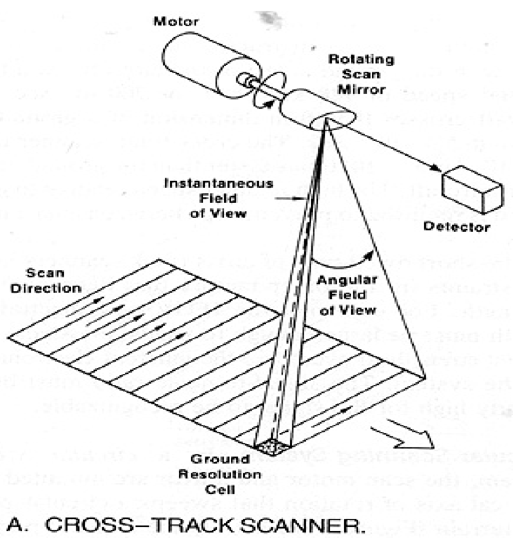
Classification based on energy source or generated product.

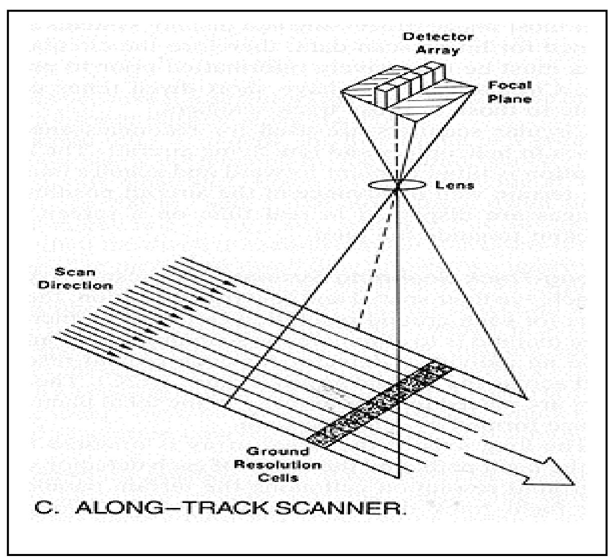
- Energy source: Passive (owns no energy source) or active (owns energy source in restricted spectral bands, like radar systems).

- Product:
  - No-imaging: Generates no images of the observed surface, used to collect precise spectral signature of objects.
  - Imaging: Generates images of the observed surface.
- Imaging systems are classified by:
  - Framing systems: acquisition of a whole image at the same time
  - Scanning systems: Scans lines to generate image

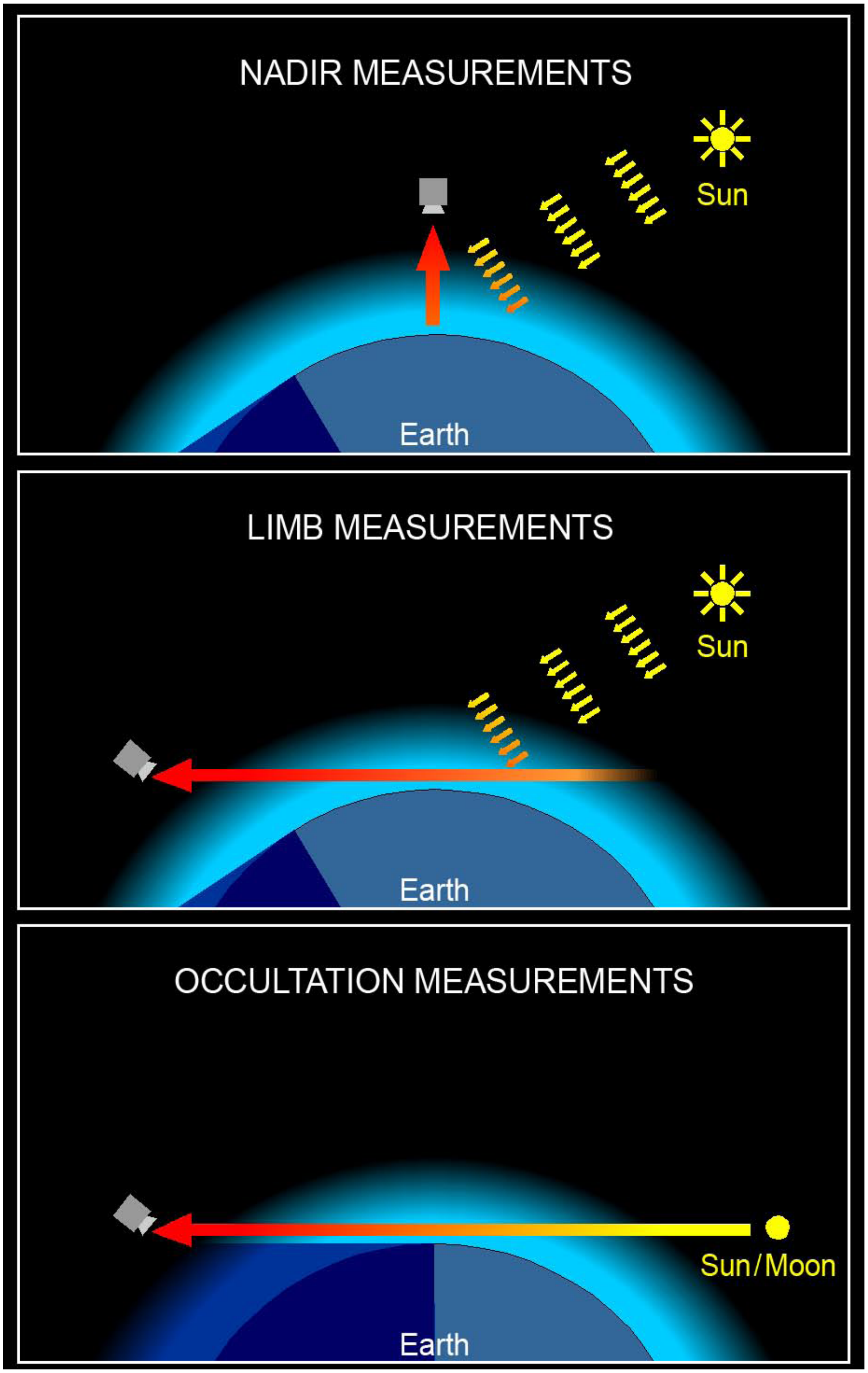
*Scanning systems*: cross-track scanners; spin scanners; along-track scanners side-scanning (or oblique scanners) (e.g., radar)

***Examples:***




**Viewing geometry:**


NADIR MEASUREMENTS
Sun
Earth
LIMB MEASUREMENTS
Sun
Earth
OCCULTATION MEASUREMENTS
Sun/Moon
Earth