Fundamentals of Remote Sensing

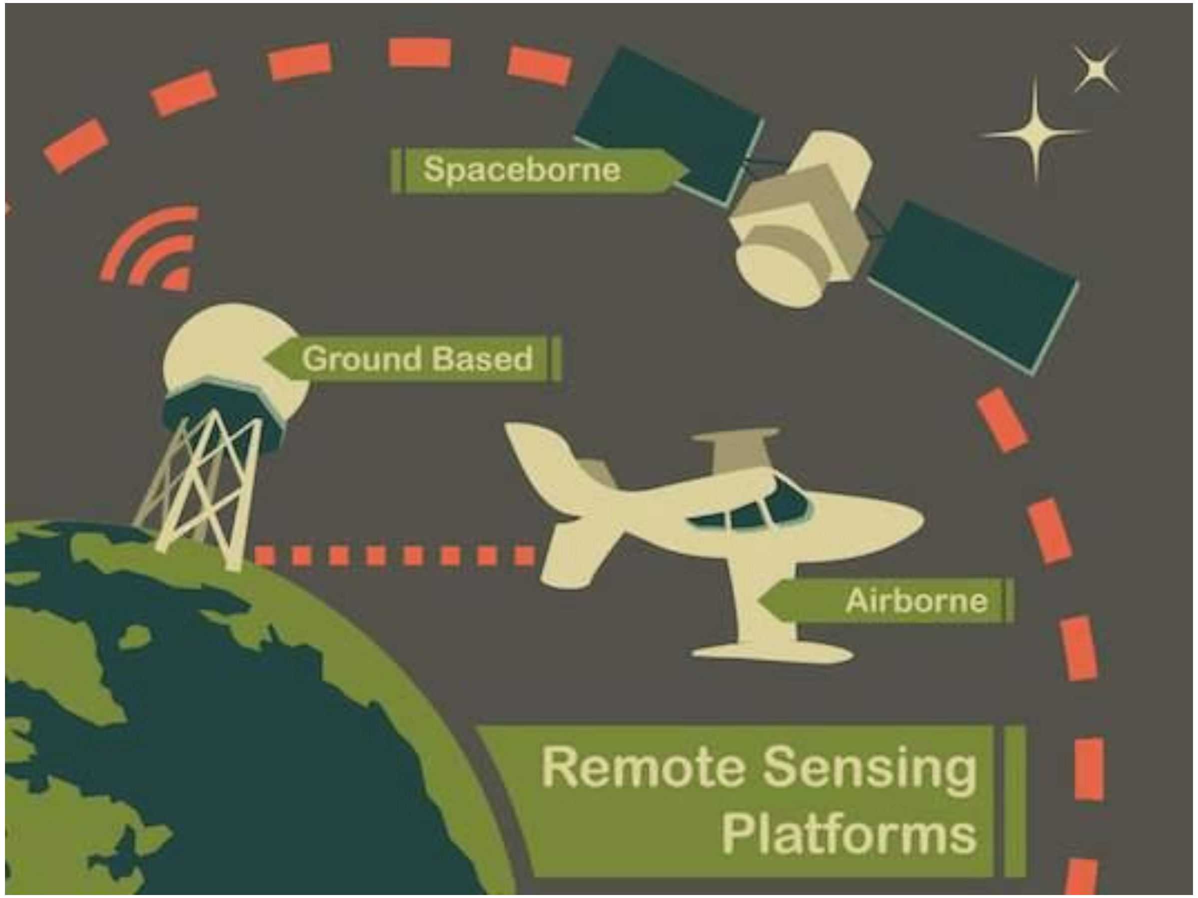
NASA ARSET

Outline

- Fundamentals of Remote Sensing
- Satellites and Sensors
  - Types
  - Resolution
- Satellite Data Processing Levels
- Projections and Coordinate Systems
- Advantages and Disadvantages of Remote Sensing
- Remote Sensing Terminology

Fundamentals of Remote Sensing

What is Remote Sensing?



Remote sensing is obtaining information about an object from a distance.

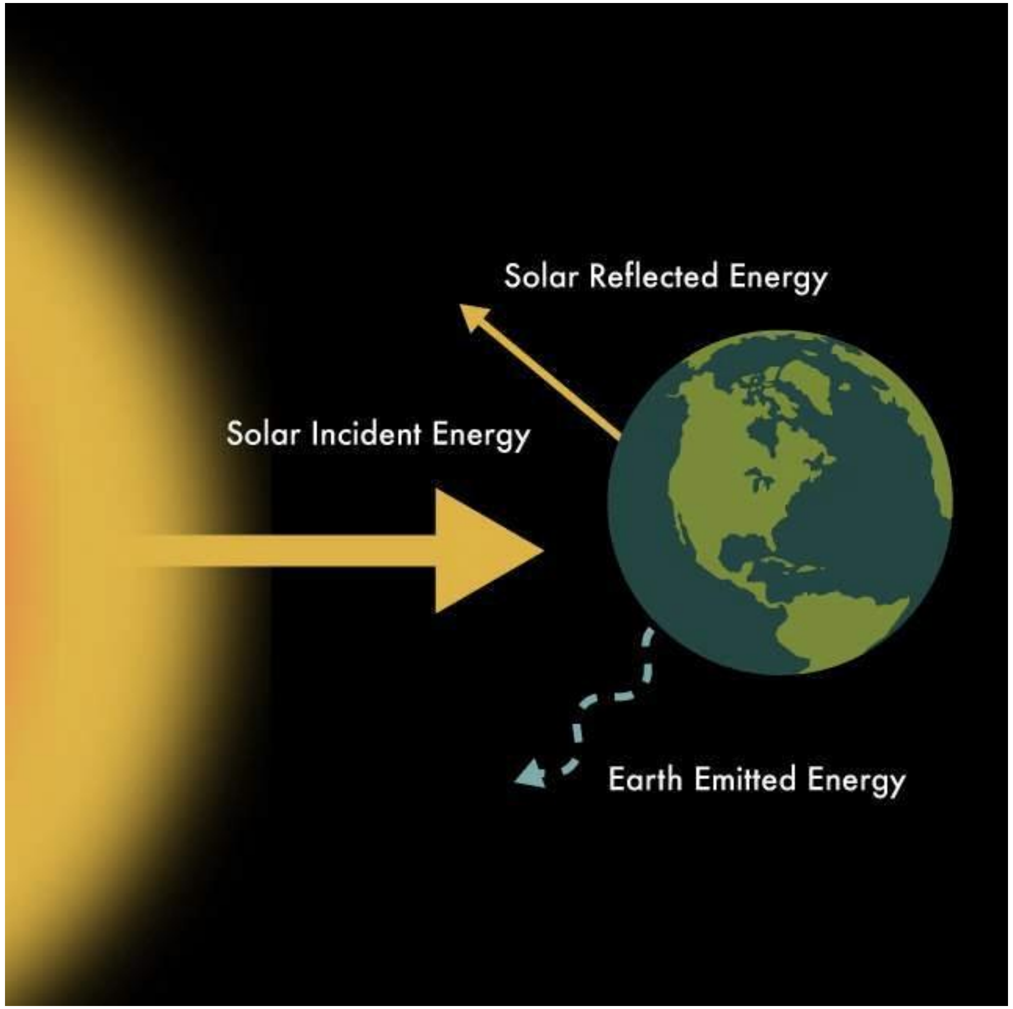
Photography is a very common form of remote sensing.

There are different ways to collect data, and different sensors are used depending on the application.

Some methods collect ground-based data, others airborne or spaceborne.

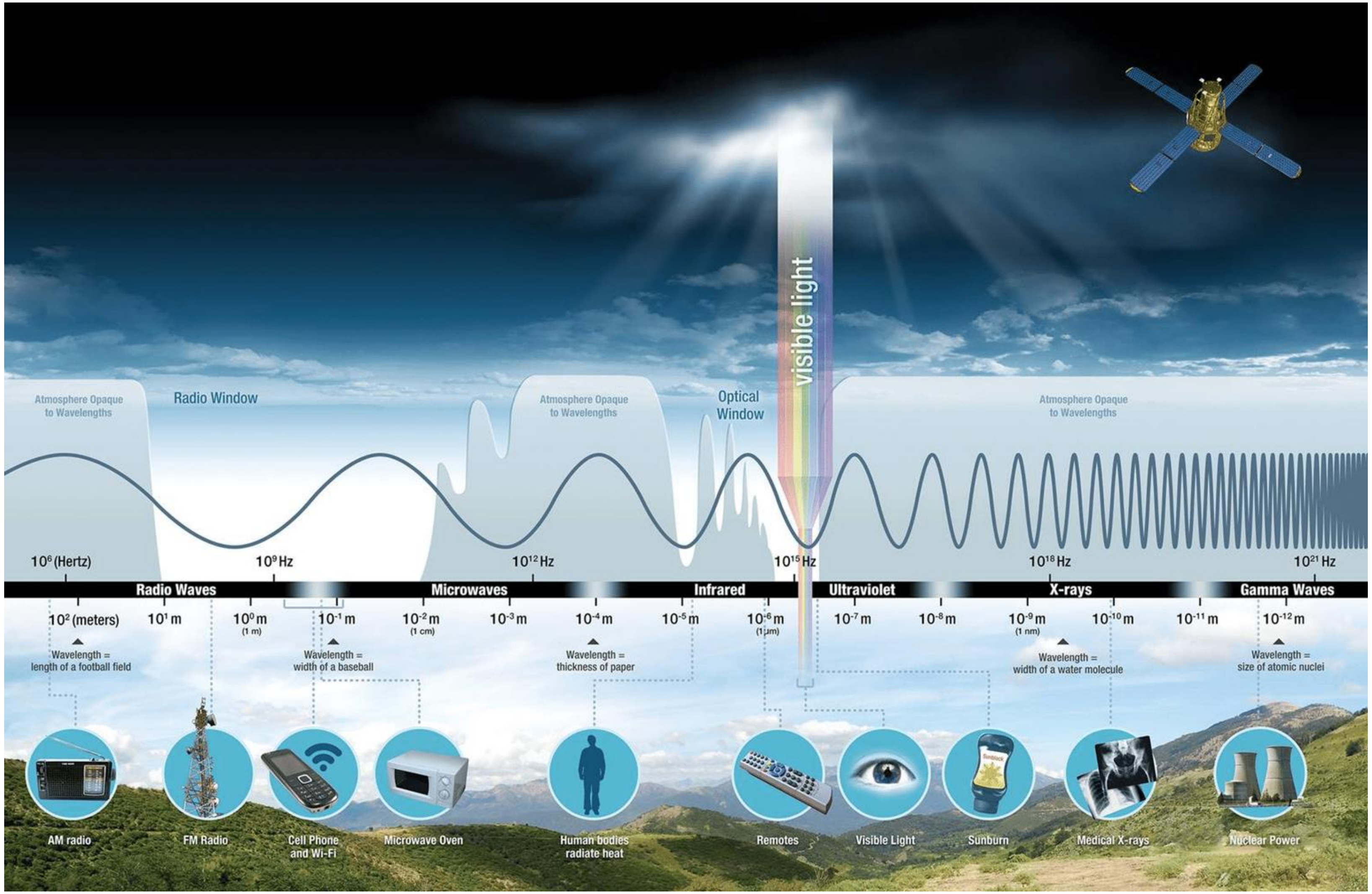
- What information do you need?
- How much detail?
- How frequently do you need the data?

What is Remote Sensing?



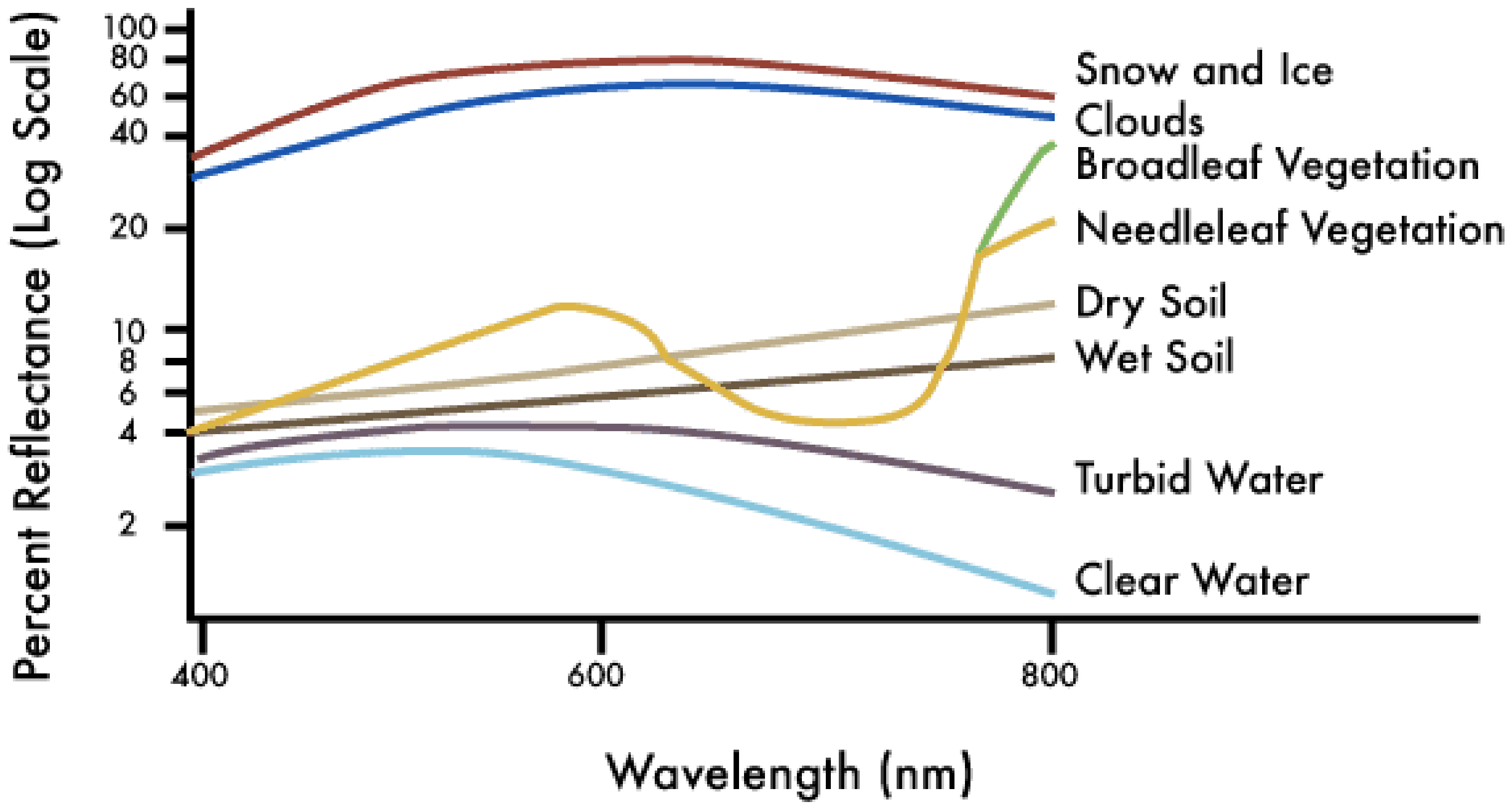
- The energy Earth receives from the sun is called **electromagnetic radiation**.
- Radiation is reflected, absorbed, and emitted by the Earth's atmosphere or surface, as shown by the figure on the left.
- Satellites carry instruments or sensors that measure electromagnetic radiation reflected or emitted from both terrestrial and atmospheric sources.
- With calibrated instruments, scientists can measure the height, temperature, moisture content (and more) for nearly every feature of the Earth's atmosphere, hydrosphere, lithosphere, and biosphere.

What is Remote Sensing?



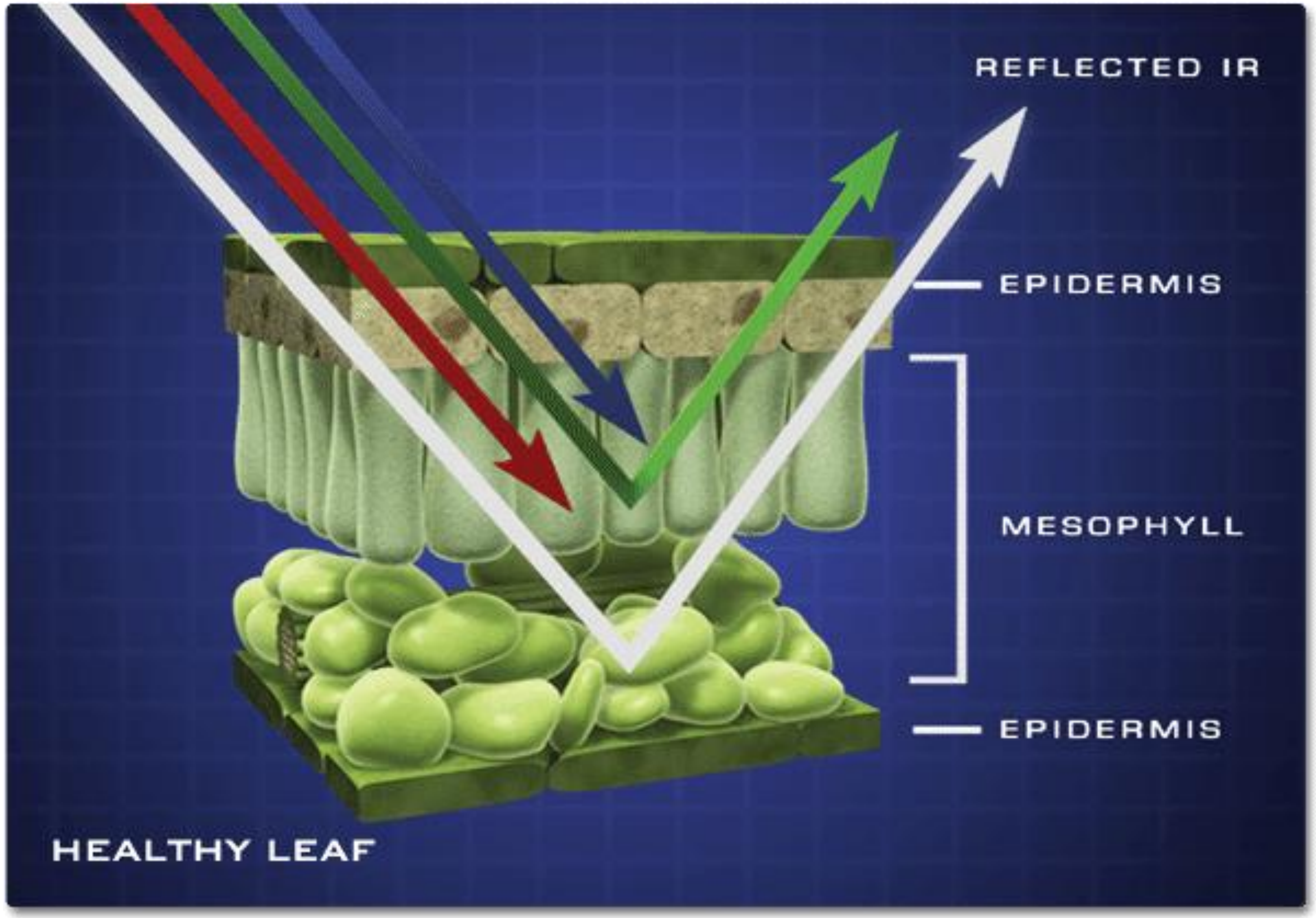
- The electromagnetic spectrum is simply the full range of **wave frequencies** that characterizes solar radiation.
- Although we are talking about light, most of the electromagnetic spectrum cannot be detected by the human eye. Even satellite detectors only capture a small portion of the entire electromagnetic spectrum.

What is Remote Sensing?



- Different materials reflect and absorb different wavelengths of electromagnetic radiation.
- You can look at the reflected wavelengths detected by a sensor and determine the type of material it reflected from. This is known as a **spectral signature**.
- In the graph on the left, compare the relationship between percent reflectance and the reflective wavelengths of different components of the Earth's surface.

What is Remote Sensing?



Vegetation

- Certain pigments in plant leaves strongly absorb wavelengths of visible (red) light.
- The leaves themselves strongly reflect wavelengths of near-infrared light, which is invisible to human eyes.
- As a plant canopy changes from early spring growth to late-season maturity and senescence, these reflectance properties also change.
- Since we can't see infrared radiation, we see healthy vegetation as green.

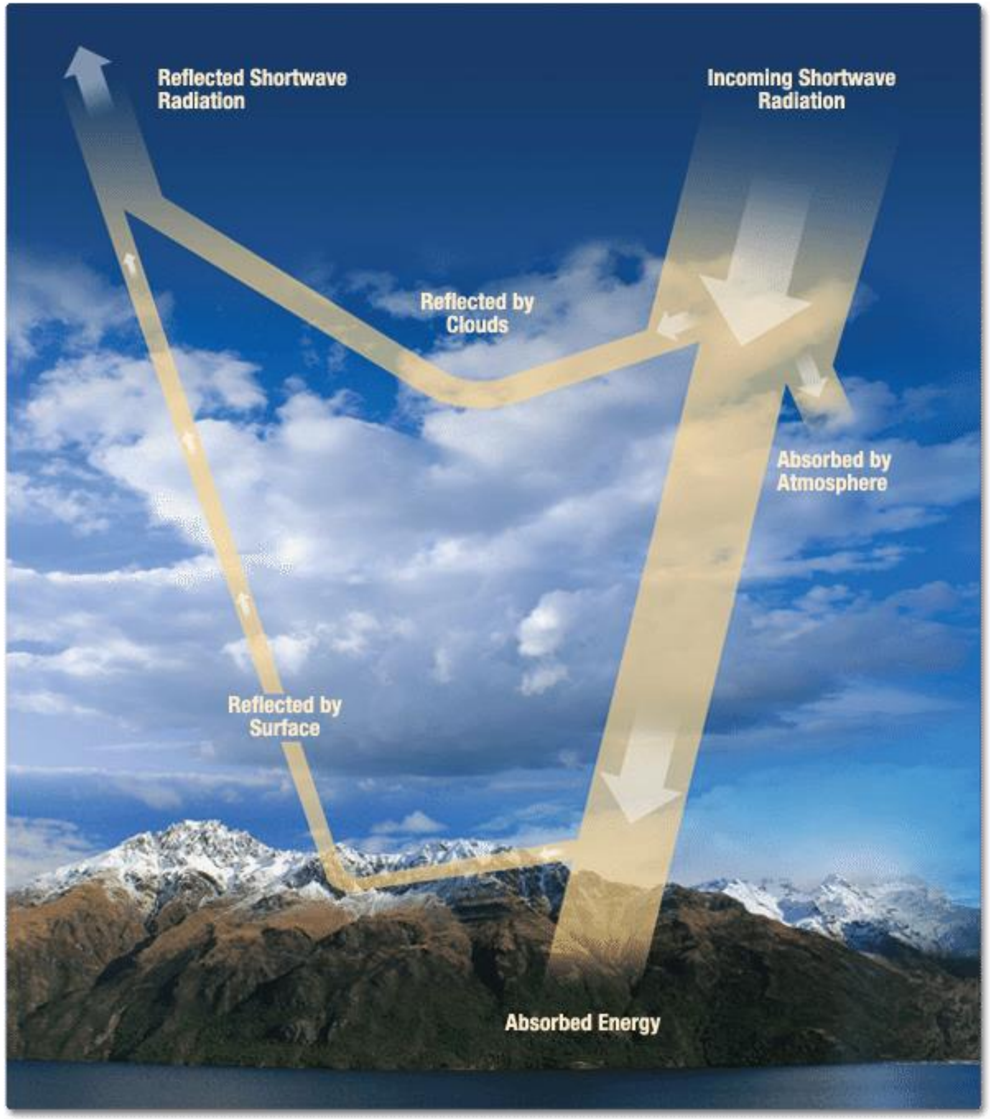
What is Remote Sensing?

Image Credit: NASA Earth Observatory, using Landsat data courtesy of USGS.

Water

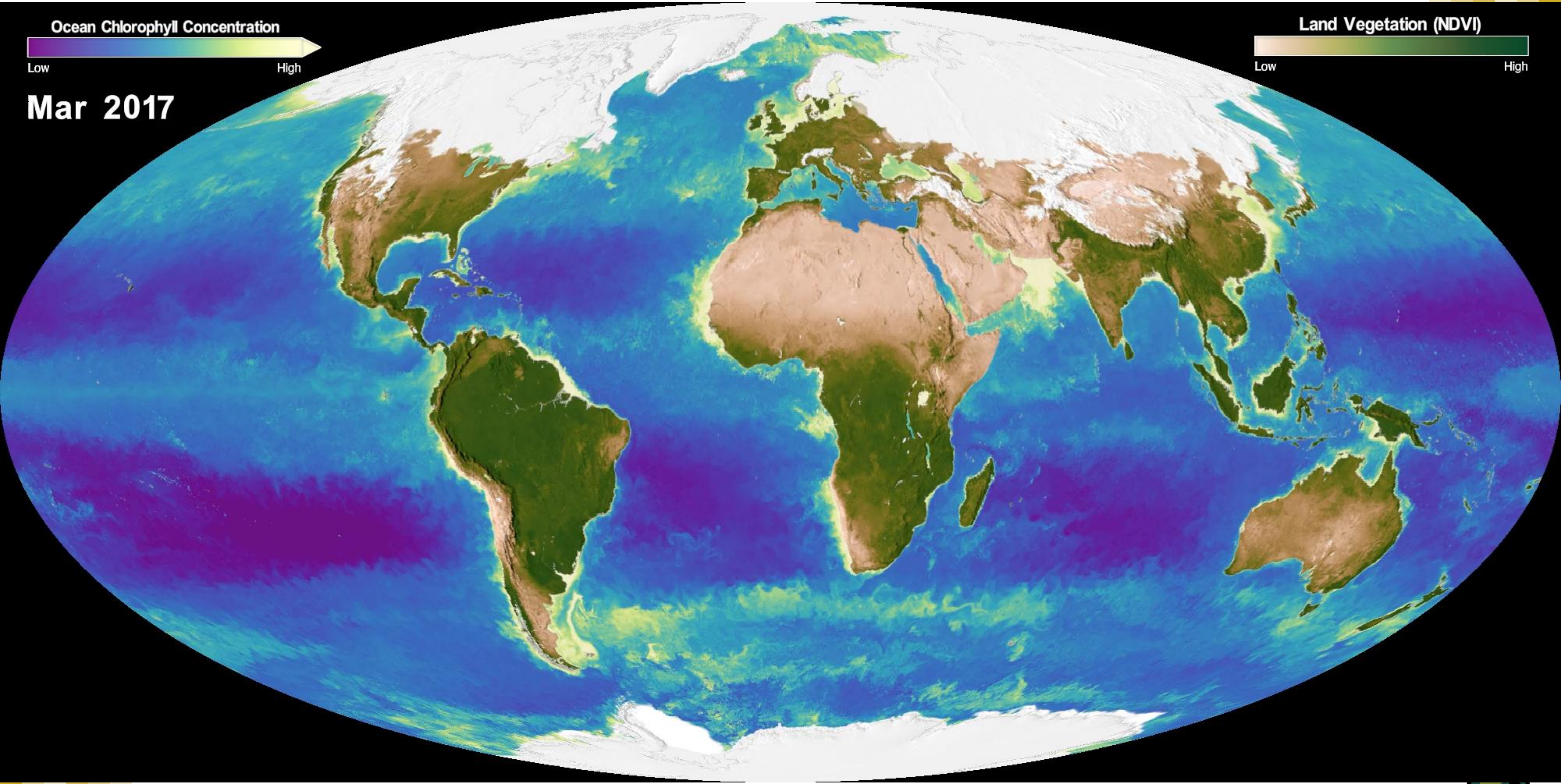
- Longer visible wavelengths (green and red) and near-infrared radiation are absorbed more by water than shorter visible wavelengths (blue) – so water usually looks blue or blue-green.
- Satellites provide the capability to map optically active components of upper water column in inland and near-shore waters.

What is Remote Sensing?



Atmosphere

- From the sun to the Earth and back to the sensor, electromagnetic energy passes through the atmosphere twice.
- Much of the incident energy is absorbed and scattered by gases and aerosols in the atmosphere before reaching the Earth's surface.
- Atmospheric correction removes the scattering and absorption effects from the atmosphere to obtain the surface reflectance characterizing surface properties.


Ocean Chlorophyll Concentration
Low
High
Mar 2017
Land Vegetation (NDVI)
Low
High

Satellites and Sensors

Satellites and Sensors

Satellites carry sensors or instruments. The names of sensors are usually acronyms that can include the name of the satellite.

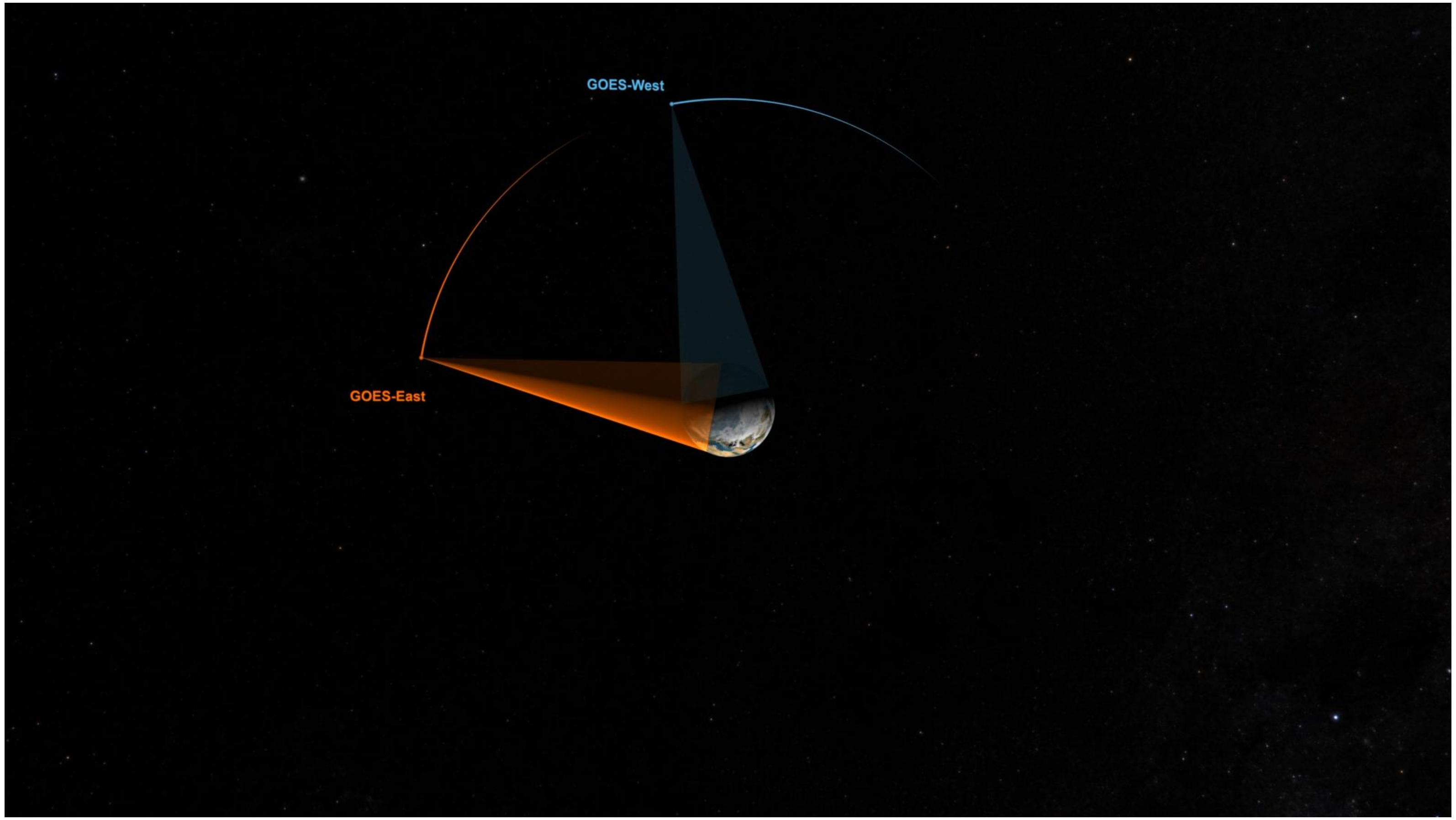
Landsat 9

Image Credit: NASA

Satellite Characteristics

- **Orbits:** Polar/Non-Polar Orbit vs. Geostationary
- **Energy Source:** Passive vs. Active
- **Solar and Terrestrial Spectra:** Visible, UV, IR, Microwave...
- **Measurement Technique:** Scanning; Non-Scanning; Imager; Sounders
- **Resolution Type and Quality:** Spatial, Temporal, Spectral, Radiometric
- **Application:** Weather, Ocean Color, Land Mapping, Air Quality, Radiation Budget, etc.

Satellite Characteristics



Video Credit: NASA

Geostationary Orbit

- Geostationary satellites typically orbit ~36,000 km over the equator with the same rotation period as Earth.
- Multiple observations/day
- Limited spatial coverage—observations are always of the same area
- Examples: Weather or communications satellites

Satellite Characteristics

Video Credit: NASA

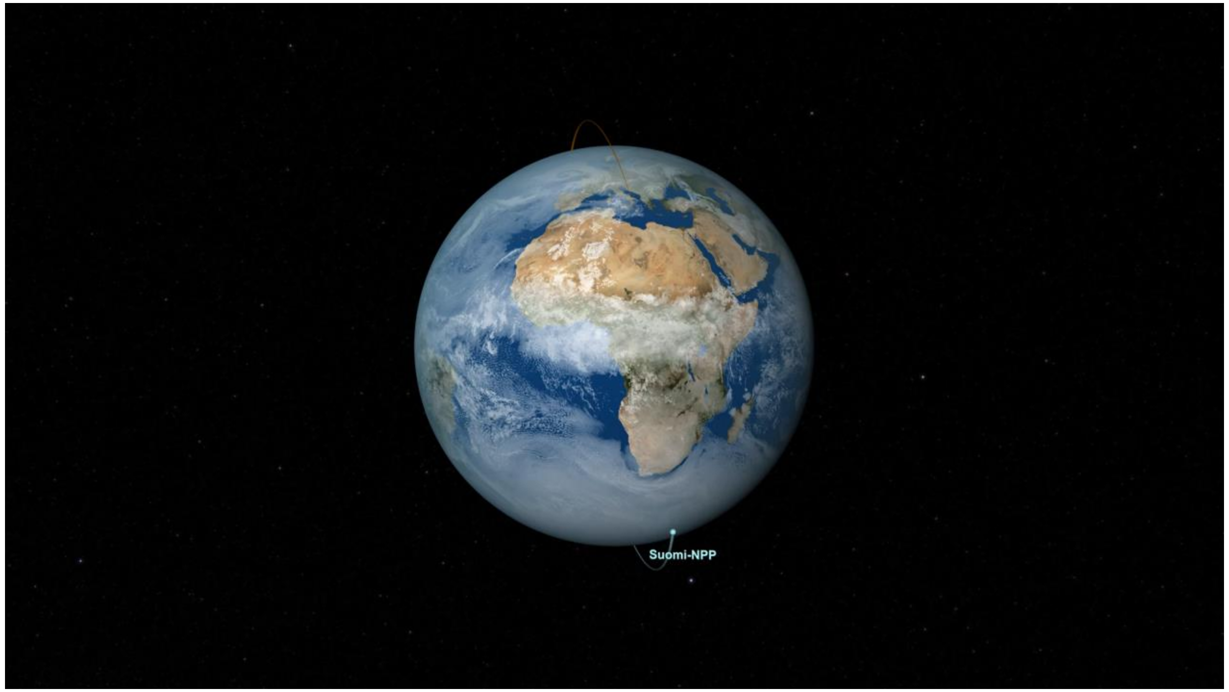
Low Earth Orbit (LEO)

- Orbit moving relative to Earth – can be polar or nonpolar
- Less frequent measurements
- Global (or near-global) spatial coverage
- Examples:
    - **Polar**: Landsat or Terra
    - **Nonpolar**: ISS or GPM

Satellite Characteristics

Polar Orbit & Sun-Synchronous Orbit (SSO)

- Global coverage
- Varied measurement frequency (once per day to once per month)
- Larger swath size means higher temporal resolution
- Satellites in SSO traveling over the polar regions are synchronous with the sun—this means that the satellite always visits the same spot at the same local time (e.g., passing the city of Paris every day at noon).



Video Credit: NASA

Satellite Characteristics

Satellite Sensors: Passive

- Passive remote sensors measure radiant energy **reflected** or **emitted** by the Earth-atmosphere system or changes in gravity from the Earth.
- Radiant energy is converted to bio-geophysical quantities such as temperature, precipitation, and soil moisture.
- Examples: Landsat OLI/TIRS, Terra MODIS, GPM GMI, GRACE, etc.
- https://earthdata.nasa.gov/learn/remote-sensors/passive-sensors

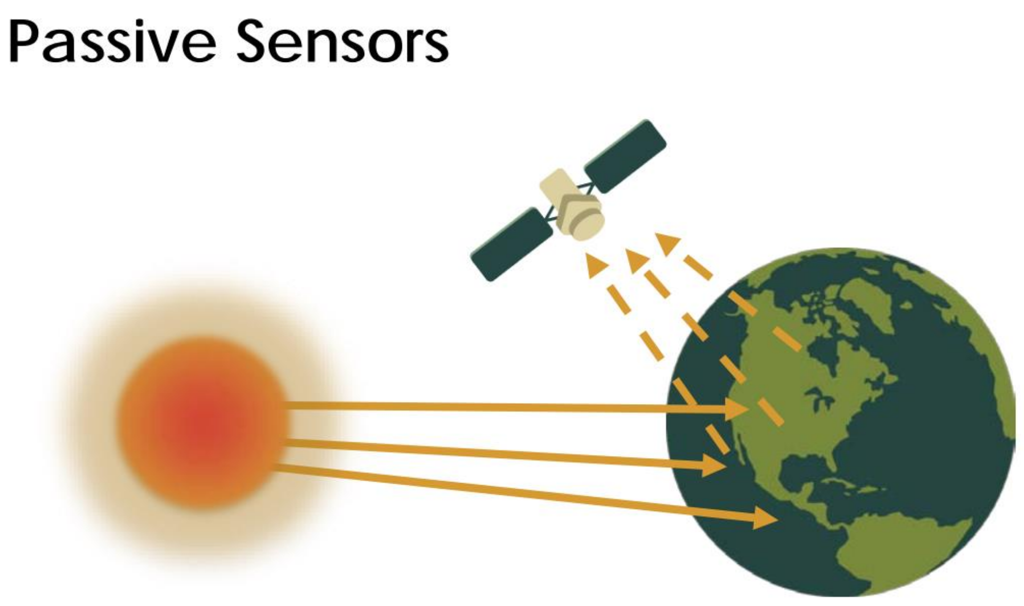


Image Credit: ARSET

Satellite Characteristics

Satellite Sensors: Active

- Active sensors provide their own energy source for illumination
- Most active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions and can be used day or night.
- Have a variety of applications related to meteorology and observation of the Earth's surface and atmosphere.
- Examples: Laser Altimeter, LiDAR, RADAR, Scatterometer, Sounder
- Missions: Sentinel-1 (C-SAR), ICESat-2 (ATLAS), GPM (DPR)
- https://earthdata.nasa.gov/learn/remote-sensors/active-sensors

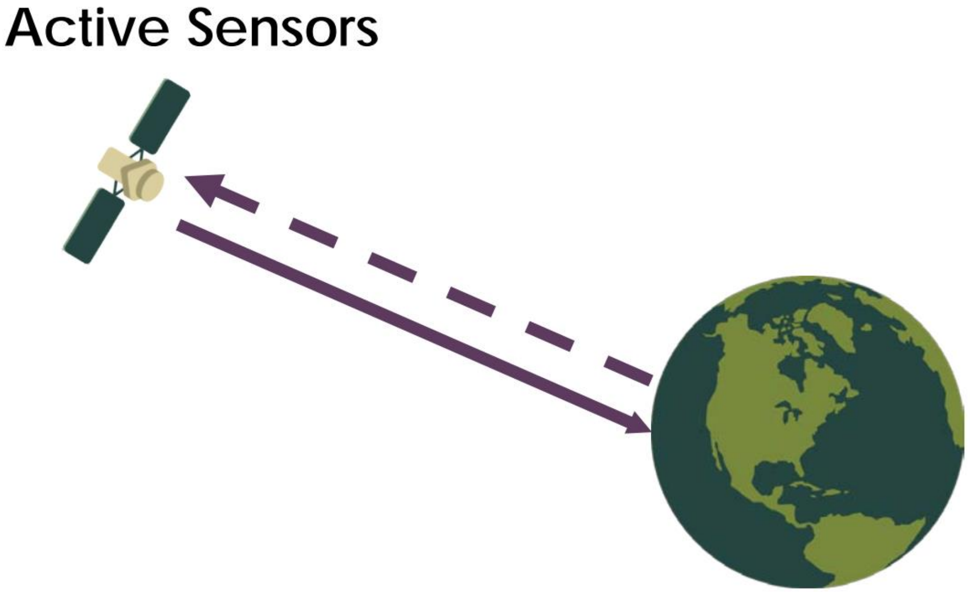
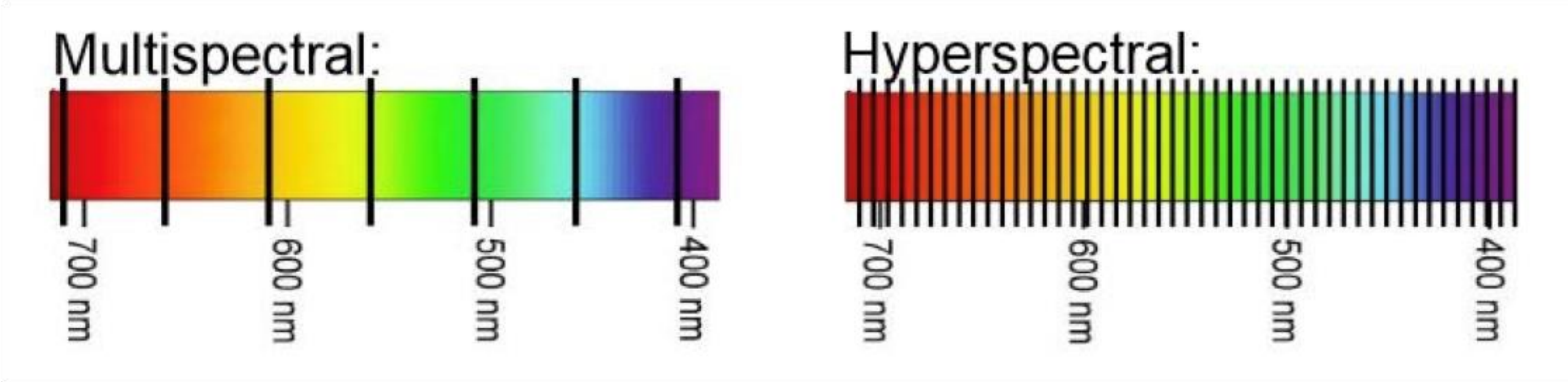


Image Credit: ARSET

Spectral Resolution

- Resolution depends upon satellite orbit configuration and sensor design. Different sensors have different resolutions.
- Signifies the number and width of spectral bands of the sensor. The higher the spectral resolution, the narrower the wavelength range for a given channel or band.
- More and finer spectral channels enable remote sensing of different parts of the Earth's surface.
- Typically, multispectral imagery refers to 3 to 10 bands, while hyperspectral imagery consists of hundreds or thousands of (narrower) bands (i.e., higher spectral resolution). Panchromatic is a single broad band that collects a wide range of wavelengths.



Spatial Resolution

- Resolution depends upon satellite orbit configuration and sensor design. Different sensors have different resolutions.
- Signifies the ground surface area that forms one pixel in the image. Sub-pixel objects can sometimes be resolved.
- It is usually presented as a single value representing the length of one side of a square.
- The higher the spatial resolution, the less area is covered by a single pixel.
- The image in the bottom right shows the same image at different spatial resolutions: (from left to right) 1 m, 10 m, and 30 m.

Sensor	Spatial Resolution
DigitalGlobe (and others)	<1 m - 4 m
Landsat	30 m
MODIS	250 m - 1 km
GPM IMERG	~10 km

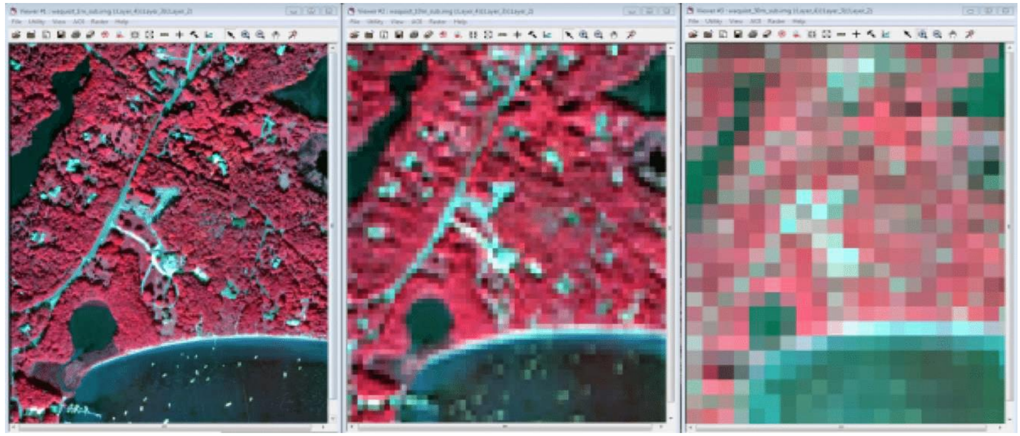
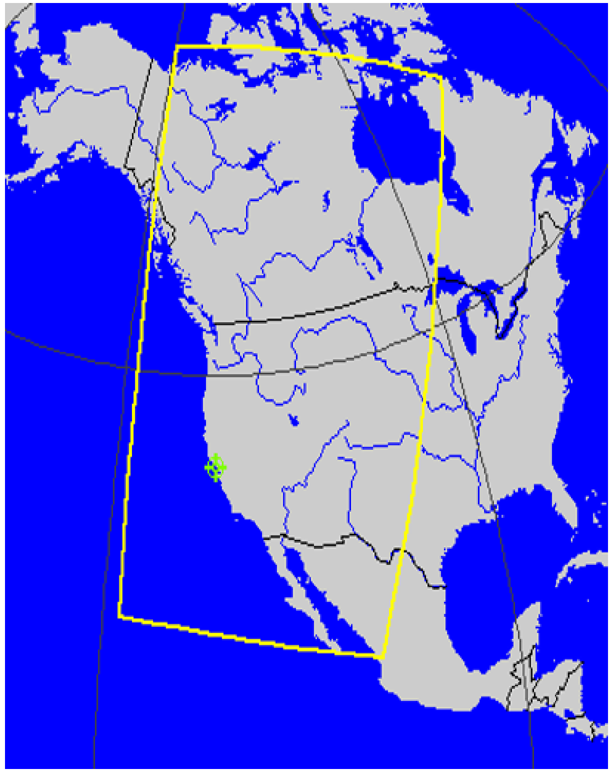


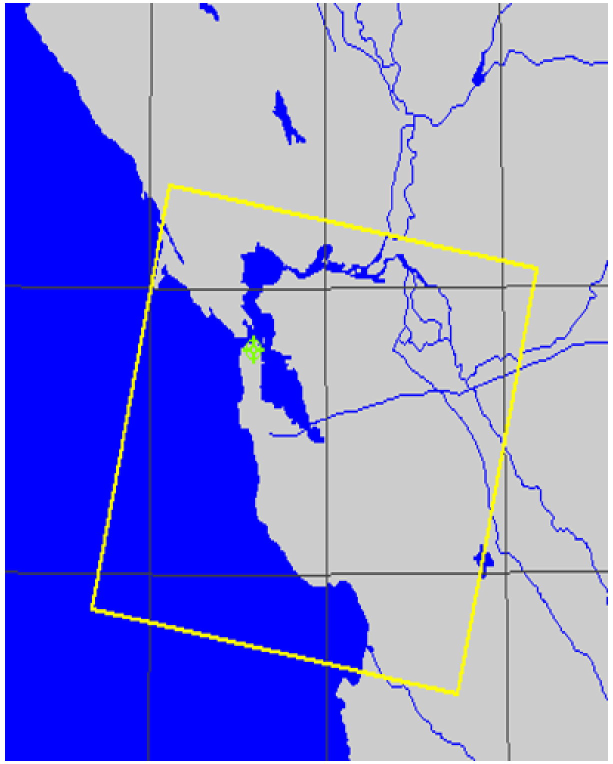
Image Credit: csc.noaa.gov

Spatial Resolution vs. Spatial Extent

- Generally, the higher the spatial resolution, the less area is covered by a single image.



MODIS (250 m - 1 km)

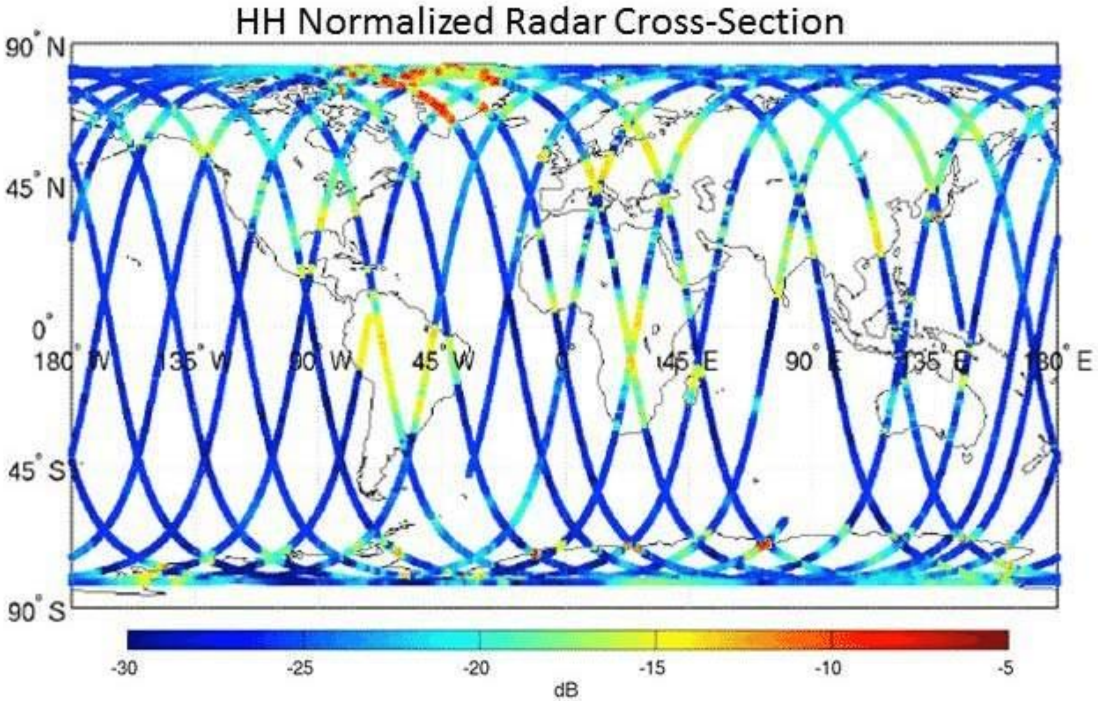


Landsat OLI (30 m)

Temporal Resolution

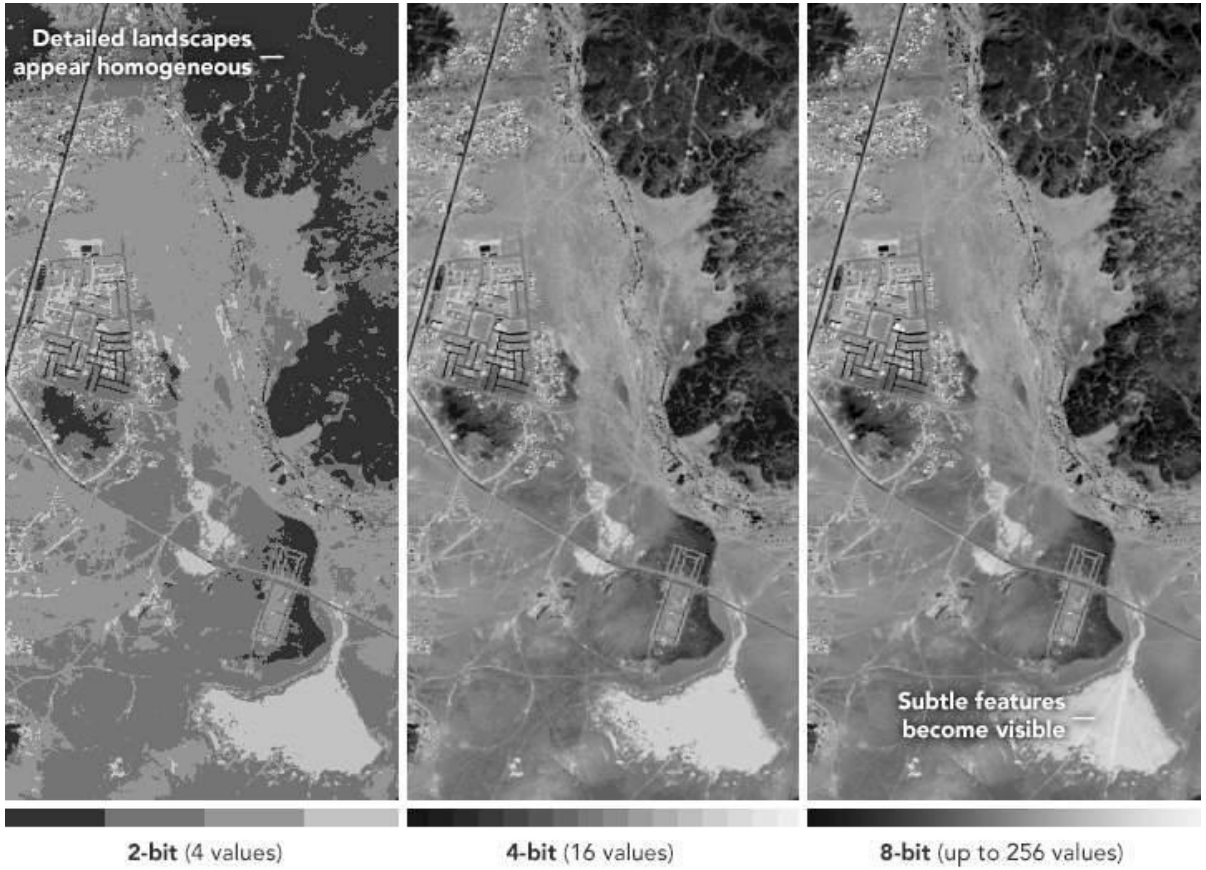
- The time it takes for a satellite to complete one orbit cycle—also called “revisit time”
- Depends on satellite/sensor capabilities, swath overlap, and latitude
- Some satellites have greater temporal resolution because:
  - They can maneuver their sensors
  - They have increasing overlap at higher latitudes

Sensor	Revisit time
Landsat	16-days
MODIS	2-days
Commercial (OrbView)	1-2 days



Radiometric Resolution

- Describes a sensor's ability to discriminate differences in energy (or radiance).
- The better the radiometric resolution, the more sensitive the sensor is to small differences in energy. The larger this number, the higher the radiometric resolution, and the sharper the imagery.
  - 12-bit sensor, 4,096 levels: Landsat OLI
  - 10-bit sensor, 1,024 levels: AVHRR
  - 8-bit sensor, 256 levels: Landsat TM
  - 6-bit sensor, 64 levels: Landsat MSS



The images show what the same scene looks like at different levels. From left to right: 2-bit, 4-bit, and 8-bit.
Image Credit: NASA's Earth Observatory

Satellite Data Processing Levels

Satellite Data Processing Levels

- Satellite data is available at different stages (or levels) of processing, going from raw data collected from the satellite to polished products that visualize information.
- NASA takes the data from satellites and processes it to make it more usable for a broad array of applications. There is a set of terminology that NASA uses to refer to the levels of processing it conducts:
  - **Level 0 & 1** is the raw instrument data that may be time-referenced. It is the most difficult to use.
  - **Level 2** is Level 1 data that has been converted into a geophysical quantity through a computer algorithm (known as retrieval). This data is geo-referenced and calibrated.
  - **Level 3** is Level 2 data that has been mapped on a uniform space-time grid and quality controlled.
  - **Level 4** is Level 3 data that has been combined with models or other instrument data.
  - Level 3 & 4 data is the easiest to use.

Projections and Coordinate Systems

The Shape of the Earth

- Although it is commonly thought of as a sphere, Earth is not perfectly spherical.
- Its actual shape is what we refer to as a "geoid."

- **Geoid:** The hypothetical shape of the Earth, coinciding with mean sea level and its imagined extension under (or over) land areas.

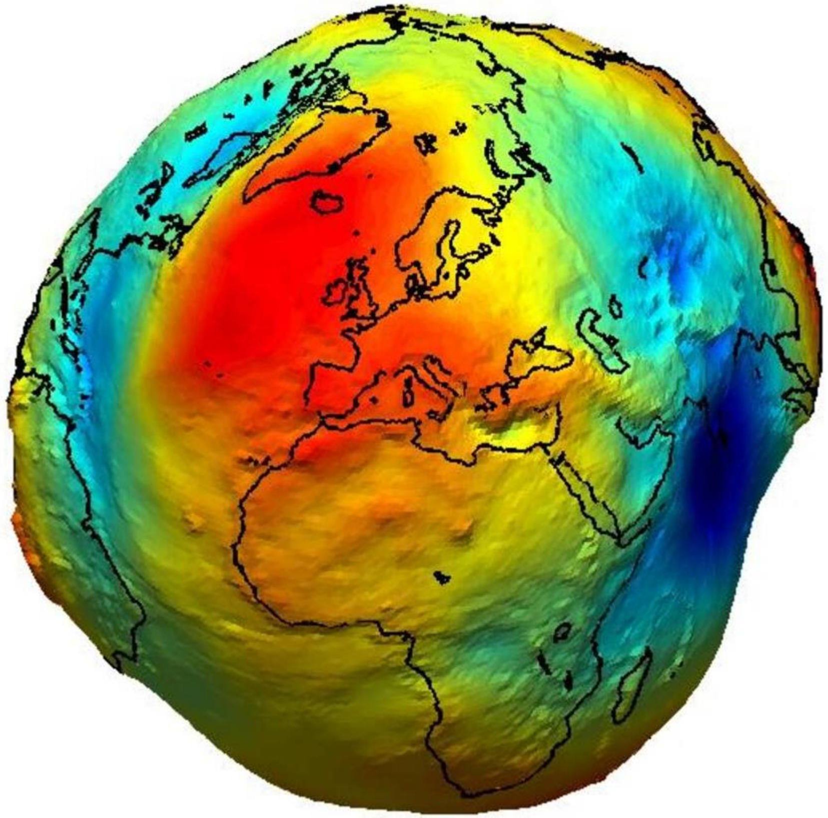


Image Credit: European Space Agency (ESA)

The Shape of the Earth

- For spatial data to be displayed in a spatially consistent way, we use an elliptical **spheroid** to approximate the surface of the Earth.
- No spheroid is a perfect fit, so many different approximations are used.
- Each approximation will fit one part of the Earth's surface better than others.
- Each of these spheroids is calculated using a specific **datum** as a reference point.

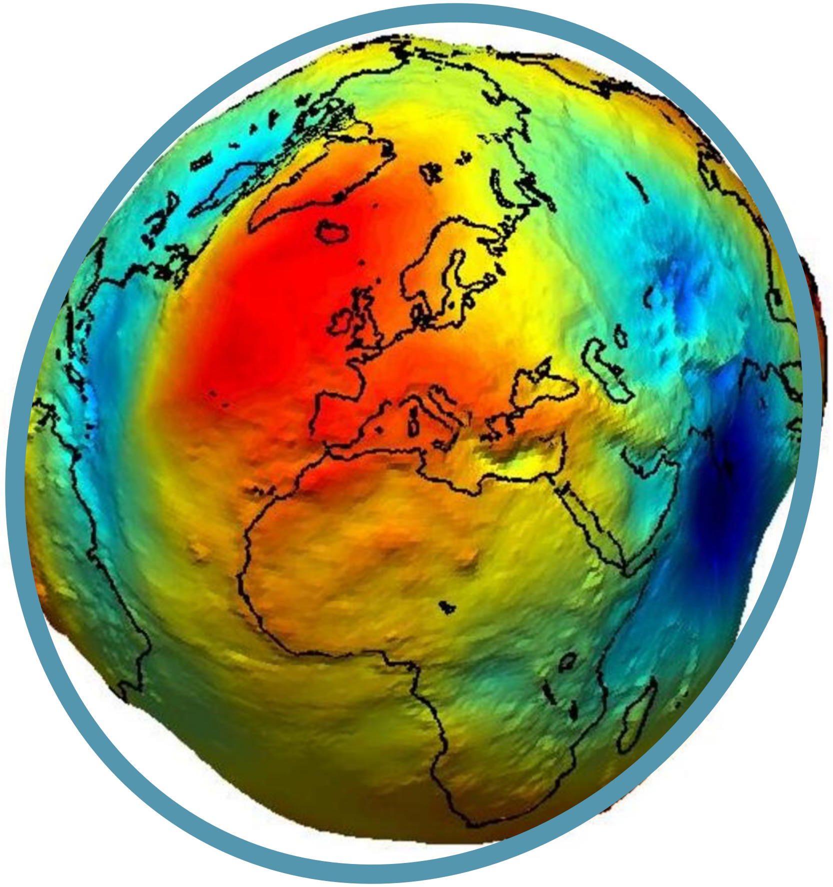


Image Credit: European Space Agency (ESA)

Datums

- A **datum** is a known point on Earth's surface or within its geometry that we can use as a reference point for all other locations.
- Because of the irregular shape of the planet, the use of datums is necessary to portray spatial data as accurately as possible.

- Example: **NAD 83** (North American Datum 1983)

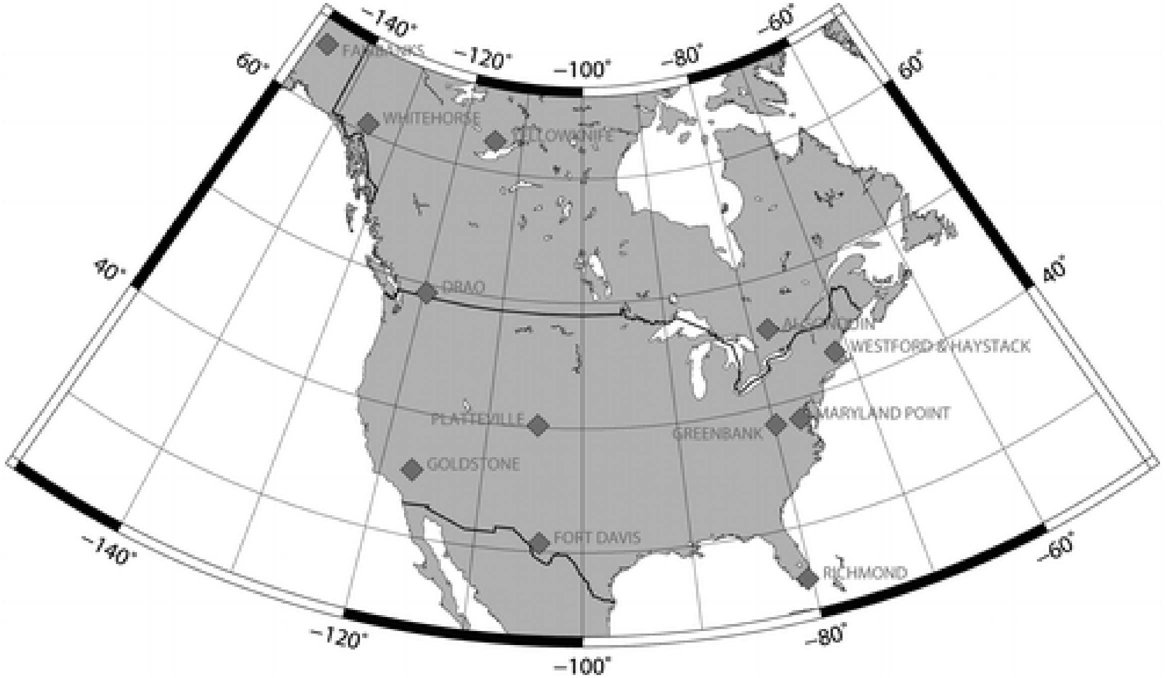


Image Credit: ascelibrary.org

Coordinate Reference Systems

- All spatial data, including satellite imagery, must be indexed, or **georeferenced**, to a fixed point on Earth's surface.
- Pairing a data point or pixel with a specific location on the ground requires a **coordinate reference system (CRS)**.
- Two types of coordinate systems are commonly used, **geographic** and **projected**.

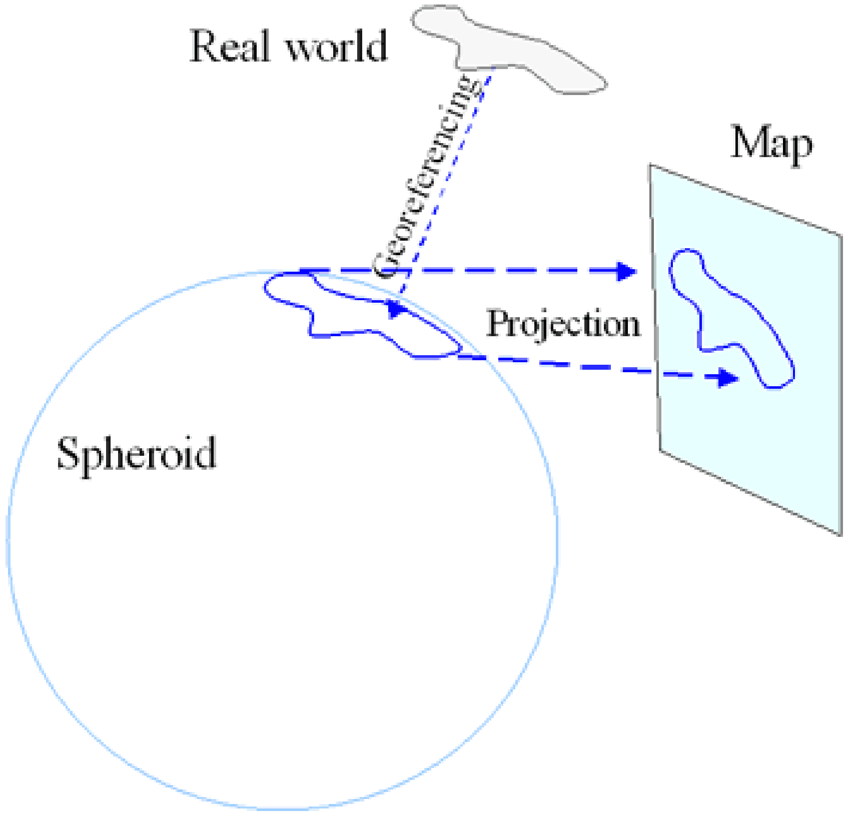


Image Credit: GIS Stack Exchange

Types of Coordinate Reference Systems

- **Geographic Coordinate Systems**
  - **Pros:**
    - Better for the entire Earth
    - Good for data with a large spatial extent
  - **Cons:**
    - Less accurate for specific regions
    - Bad for data with a small spatial extent
  - Example of a commonly-used Geographic Coordinate System: **WGS84**

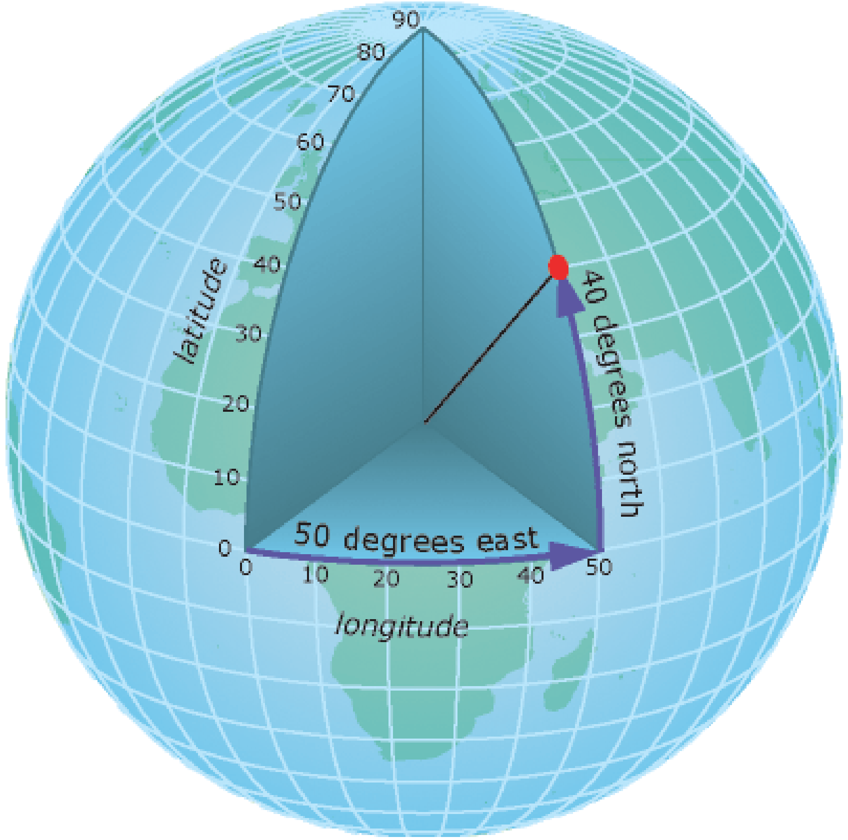


Image Credit: ArcGIS.com

Types of Coordinate Reference Systems

- **Projected Coordinate Systems**
  - **Pros:**
    - Better for specific locations
    - Good for data with a small spatial extent
  - **Cons:**
    - Accuracy is skewed to one specific location
    - Not useful for data with a large spatial extent
  - Example of a commonly used Projected Coordinate System: **UTM (Universal Transverse Mercator)**

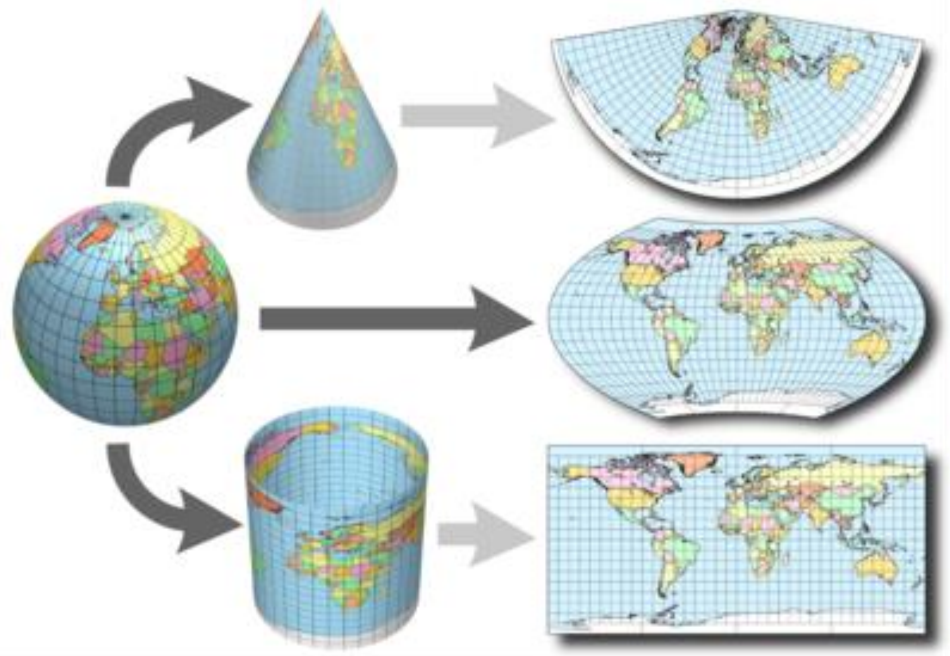


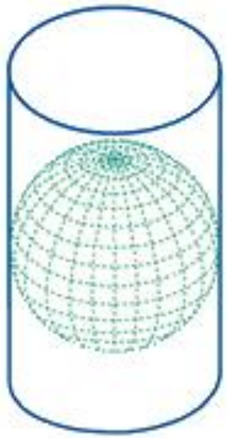
Image Credit: Earth Data Science

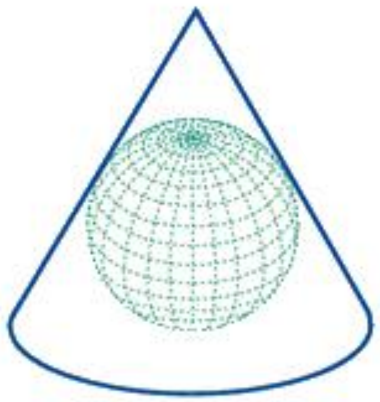
Types of Projected Coordinate Systems

- **Cylindrical**
  - Best for use in Equatorial Regions
  - Distortion occurs near poles
  - Great for medium spatial extents
  - Example: **UTM**

- **Conical**
  - Best for use in Polar regions
  - Distortion occurs farther from pole
  - Example: **Albers Equal Area Conic**

- **Planar**
  - Also known as "Azimuthal"
  - Projects data onto a flat plane
  - Great for small spatial extents
  - Example: **State Plane Coordinate System**





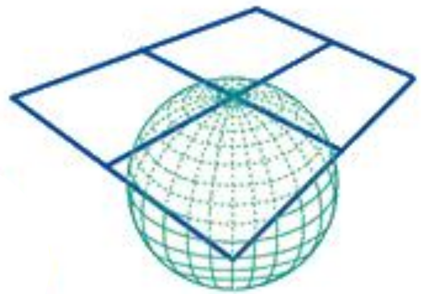
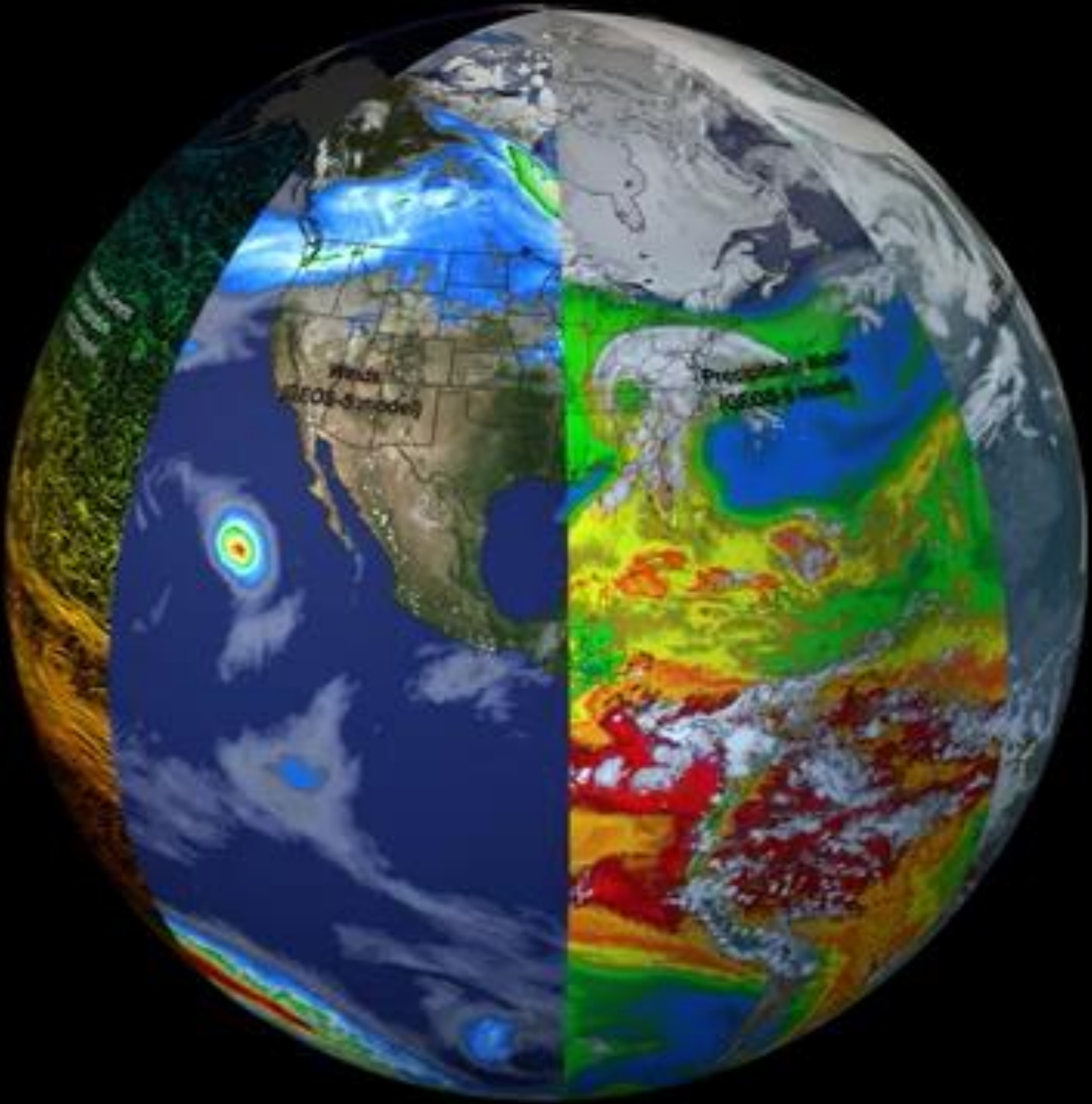


Image Credits: UN.org

Advantages and Disadvantages of Remote Sensing



Advantages of Remote Sensing

- Provides information where there are no ground-based measurements.
- Provides globally consistent observations.
- Provides continuous monitoring of our planet.
- Earth systems models integrate surface-based and remote sensing observations and provide uniformly gridded, frequent information of water resources data parameters.
- Data are freely available and there are web-based tools for data analysis.

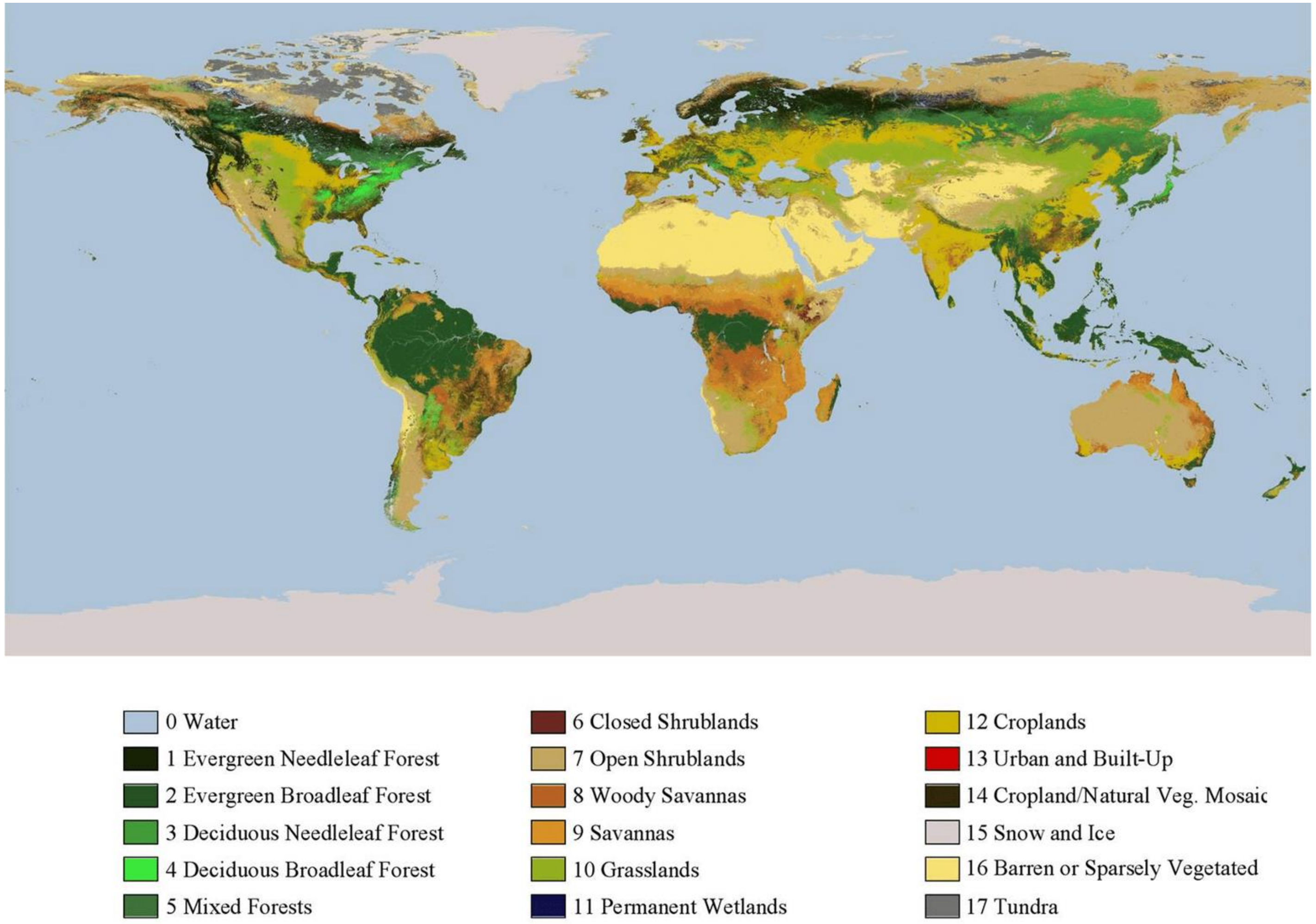


Image Credit: NASA GSFC

Disadvantages of Remote Sensing

- It is very difficult to obtain high spectral, spatial, temporal, and radiometric resolution all at the same time.
- Large amounts of data in a variety of formats can lead to more time and processing.
- Applying satellite data may require additional processing, visualization, and other tools.
- While the data are generally validated with selected surface measurements, regional and local assessment is recommended.

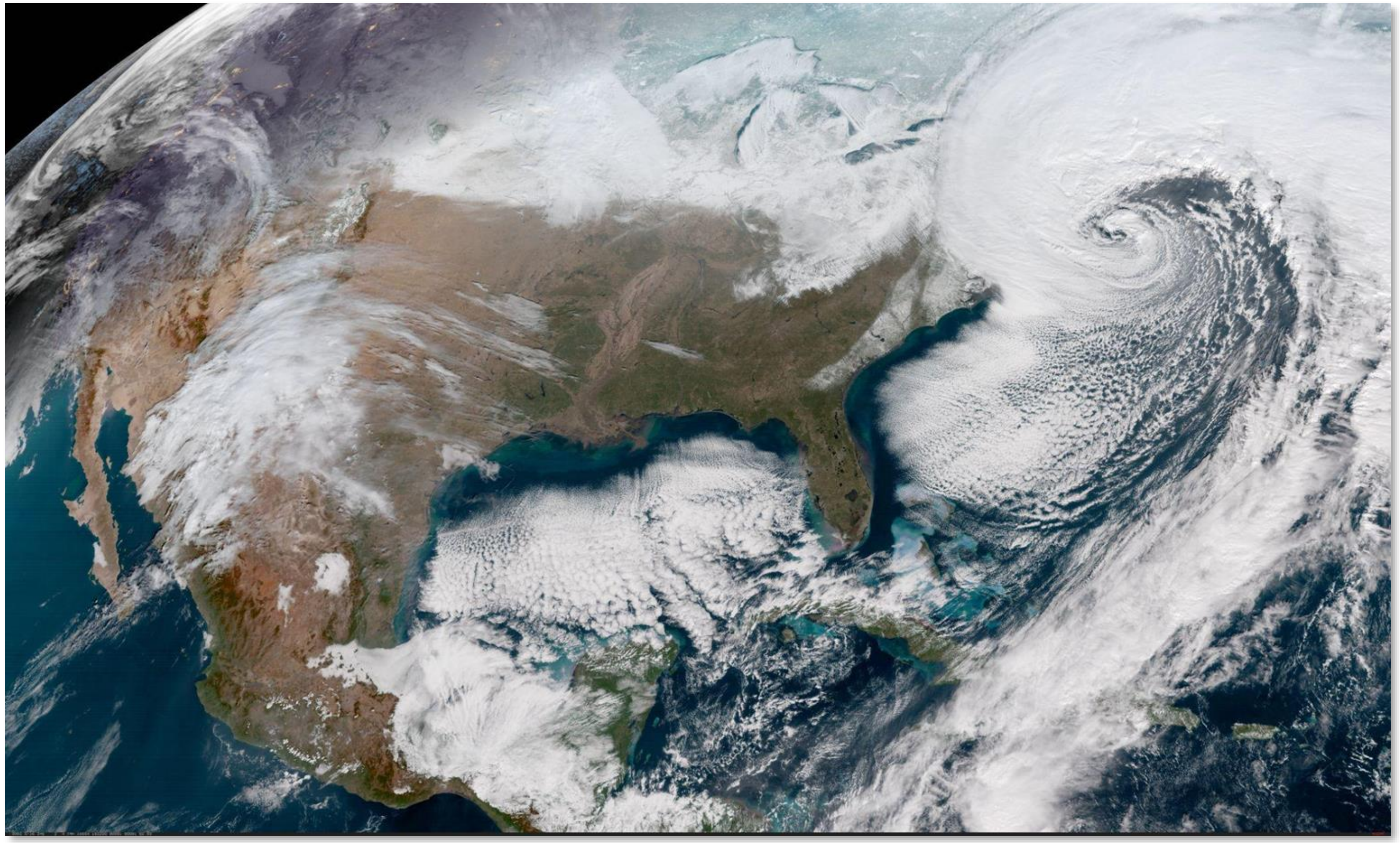


Image Credit: NOAA

Remote Sensing Terminology

Amplitude: The "height" of a wave or its maximum displacement from equilibrium.

Coordinate Reference System: A coordinate-based local, regional, or global system used to locate geographical entities.

Datum: A known point that can be used as a reference point for all other locations.

Electromagnetic Radiation: The energy the Earth receives from the Sun.

Frequency: The number of cycles of a wave passing a fixed point per unit of time.

Geodesy: The science of accurately measuring and understanding three fundamental properties of the Earth: its geometric shape, its orientation in space, and its gravity field.

Geodetic: Relating to geodesy.

Geoid: The hypothetical shape of the Earth, coinciding with mean sea level and its imagined extension under (or over) land areas.

Georeference: To link spatial data to its correct location.

Geostationary: Remaining fixed over a specific location on Earth's surface.

Gridded: Spatial data displayed over a uniform grid, often tied to specific locations.

Nadir: The point on the Earth's surface directly below the observing satellite.

Polar: A type of orbit that crosses the poles.

Polarization: The orientation of an electromagnetic wave.

Projection: The means by which you display the coordinate system and your data on a flat surface.

Radiometric Resolution: Describes a sensor's ability to discriminate differences in energy (or radiance).

Spatial Extent: The overall surface area covered by a given dataset.

Spatial Resolution: The ground surface area that forms one pixel in the image.

Spectral Resolution: The number and width of spectral bands of the sensor. The higher the spectral resolution, the narrower the wavelength range for a given channel or band.

Sun-Synchronous: The satellite always visits the same spot at the same local time.

Temporal Resolution: The time it takes for a satellite to complete one orbit cycle—also called "revisit time."

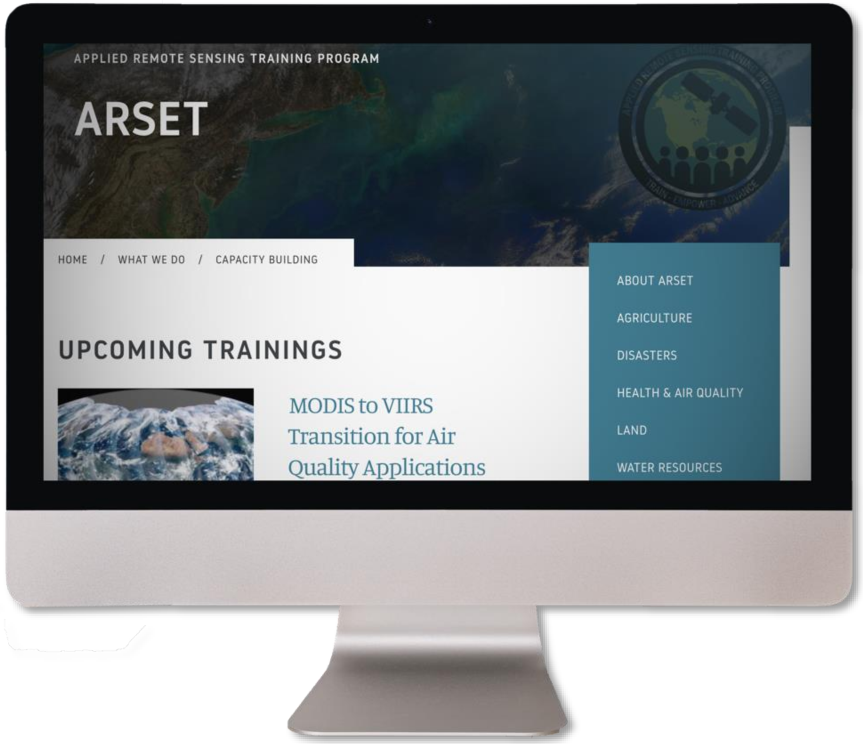
Contact Information

Contact: nasa.arset@gmail.com

Applied Remote Sensing Training (ARSET) Program: https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Twitter: @NASAARSET

YouTube: https://www.youtube.com/user/NASAgovVideo/playlists



Thank You!