Fundamentals of Satellite Remote Sensing

Pawan Gupta and Melanie Follette-Cook

Satellite Remote Sensing of Air Quality

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Objectives

By the end of this presentation, you will be able to:

• outline what the electromagnetic spectrum is
• outline how satellites detect radiation
• name the different types of satellite resolutions
What is remote sensing?

Collecting information about an object without being in direct physical contact with it
Remote Sensing: Platforms

• The platform depends on the end application
• What information do you want?
• How much detail do you need?
• What type of detail?
• How frequently do you need this data?
Remote Sensing of our Planet

- Geosynchronous Meteorological Satellites
- Major Satellite Missions
- HD Video
- Cubesats
- Sensors aboard the ISS
- Airborne Instruments
- Stratospheric Balloons
- Tethered Balloon
- UAVs
- Doppler Radar
- Smart Phones & Citizen Science
- Cell Signals
- Mobile Rovers
- Signals of Opportunity
- Near Surface
Electromagnetic Radiation

- Earth-Ocean-Land-Atmosphere System
  - Reflects solar radiation back into space
  - Emits infrared and microwave radiation into space
What do satellites measure?

- Sun
- Incident Solar Radiation
- Atmosphere
- Reflected Solar Radiation
- Satellite
- Forest
- Water
- Grass
- Bare Soil
- Paved Road
- Built-up Area

Reference: CCRS/CCT
The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions.

Thus, satellite measurements contain information about the surface and atmospheric conditions.

Credit: University of Maryland
The Remote Sensing Process

Satellite Measured Spectral Radiance

A Priori Information & Radiative Transfer Theory

Retrieval Algorithm

Geophysical Parameters Applications
Satellites, Sensors, and Orbits
Satellites vs. Sensors

Earth-observing satellite remote sensing instruments are named according to:

1. the satellite (platform)
2. the instrument (sensor)

Aqua Satellite
Characterizing Satellites and Sensors

• Orbits
  – Polar vs. Geostationary

• Energy Sources
  – Passive vs. Active

• Solar and Terrestrial Spectra
  – Visible, UV, IR, Microwave…

• Measurement Techniques
  – Scanning, Non-Scanning, Imager, Sounders...

• Resolution (Spatial, Temporal, Spectral, Radiometric)
  – Low vs. High

• Applications
  – Weather, Land Mapping, Atmospheric Physics, Atmospheric Chemistry, Air Quality, Radiation Budget…
Common Orbit Types

**Geostationary Orbit**
- Has the same rotational period as Earth
- Appears ‘fixed’ above Earth
- Orbits ~36,000 km above the equator

**Polar Orbit**
- Fixed, circular orbit above Earth
- Sun synchronous orbit ~600-1,000 km above Earth with orbital passes are at about the same local solar time each day
Aqua Satellite Orbiting the Earth
Observation Frequency

Polar Orbiting Satellites: 1-3 observations per day, per sensor

Geostationary Satellites: Every 30 sec. to 15 min.
Future Geo satellites: TEMPO, GEMS, Sentinel-4
Satellite Coverage – Swath Width

- VIIRS, 3,000 km
- MODIS, 2,300 km
- MISR, 380 km
- Calipso (Spaceborne LIDAR), 1 km
Satellite Coverage

MODIS

VIIRS

MISR
Active & Passive Sensors

Passive Sensors

• Remote sensing systems that measure naturally available energy are called passive sensors
  • MODIS, MISR, OMI, VIIRS

Active Sensors

• The sensor emits radiation directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.*
  • CALIPSO

*Text Source: Natural Resources Canada
Active & Passive Sensors

**Passive** | Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

**Active** | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.
Remote Sensing – Types of Resolution

• **Spatial Resolution**
  – Smallest spatial measurement

• **Temporal Resolution**
  – Frequency of measurement

• **Spectral Resolution**
  – Number of independent channels

• **Radiometric Resolution**
  – Sensitivity of the detectors

Each depends on the satellite orbit configuration and sensor design. Resolutions are different for different sensors.
• A digital image is comprised of a two dimensional array of individual picture elements – called pixels – arranged in columns in rows
• Each pixel represents an area on the Earth’s surface
• A pixel has an intensity value and a location address in the 2D image
• Spatial resolution is defined by the size of a pixel

*Text Source: Center for Remote Imaging, Sensing & Processing
Why is spatial resolution important?

- **MODIS**
  - 250 m – 1 km
- **MISR**
  - 275 m – 1.1 km
- **OMI**
  - 13x24 km
- **VIIRS**
  - 375 m

Source: Introductory Digital Image Processing, 3<sup>rd</sup> edition, Jensen, 2004
Spectral Resolution

- Spectral resolution describes a sensor’s ability to define fine wavelength intervals
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band

- Multispectral Sensors
  - MODIS
  - Low spectral resolution

- Hyperspectral Sensors
  - OMI, AIRS
  - High spectral resolution
Why is spectral resolution important?

Image Credit: Indian Institute of Science
Radiometric Resolution

- Imagery data are represented by positive digital numbers that vary from 0 to (one less than) a selected power of 2
- The maximum number of brightness levels available depends on the number of bits (represents radiometric resolution) used in representing the energy recorded
- The larger this number, the higher the radiometric resolution

<table>
<thead>
<tr>
<th>Bits</th>
<th>Values</th>
<th>Gray Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Bit</td>
<td>$2^1 = 2$ (0-1)</td>
<td><img src="gray_value_1.png" alt="Gray Value 1" /></td>
</tr>
<tr>
<td>4Bit</td>
<td>$2^4 = 16$ (0-15)</td>
<td><img src="gray_value_15.png" alt="Gray Value 15" /></td>
</tr>
<tr>
<td>8Bit</td>
<td>$2^8 = 256$ (0-255)</td>
<td><img src="gray_value_255.png" alt="Gray Value 255" /></td>
</tr>
</tbody>
</table>

*Text Source: Natural Resources Canada*
Radiometric Resolution

• Detects the difference in brightness levels
• The more sensitive the sensor - the higher the radiometric resolution
• If radiometric precision is high, an image will be sharp
• Expressed in bits

• NASA Satellite Sensor Examples:
  – 12 bit sensor (MODIS, MISR): $2^{12}$ or 4,096 levels
  – 10 bit sensor (AVHRR): $2^{10}$ or 1,024 levels
  – 8 bit sensor (Landsat TM): $2^{8}$ or 256 levels (0-255)
  – 6 bit sensor (Landsat MSS): $2^{6}$ or 64 levels (0-63)
In classifying a scene, different classes are more precisely identified if radiometric resolution is high.

**MODIS has 4,096 levels**
Temporal Resolution

• How frequently a satellite can provide observation of the same area on the earth

• It mostly depends on swath width of the satellite – the larger the swath – the higher the temporal resolution

Global coverage in….
• MODIS
  – 1-2 days
• OMI
  – 1 day
• MISR
  – 6-8 days
• VIIRS
  – 1 day
• Geostationary
  – 30 sec – 1 hr
Remote Sensing Tradeoff

It is very difficult to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions, all at the same time.
References and Further Reading


- EOS-Goddard: [http://fas.org/irp/imint/docs/rst/Front/tofc.html](http://fas.org/irp/imint/docs/rst/Front/tofc.html)

- Spectral Resolution: [http://web.pdx.edu/~jduh/courses/Archive/geog481w07/Students/Cody_SpectralResolution.pdf](http://web.pdx.edu/~jduh/courses/Archive/geog481w07/Students/Cody_SpectralResolution.pdf)