A short introduction to Satellite Remote Sensing

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Includes material from “A Canada Centre for Remote Sensing Remote Sensing Tutorial”
(one) Definition of Remote Sensing

- 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.

... and atmosphere, oceans, sub-surface ..
Example of a satellite based remote sensing system

A – Energy source or illumination
B – Atmospheric medium
C – Target
D – Sensor
E – Transmission and processing
F – Interpretation and analysis
G – Production and application
Electromagnetic Radiation

- $\lambda$ - Wavelength
- $\nu$ - Frequency
- $c$ – Speed of light ($3 \times 10^8$ m/s)

$\lambda \nu = c$
Figure 1.4.1 The bands used in remote sensing
Interactions with the Atmosphere

- **Scattering**
  - **Raileigh** – Particles smaller than wavelength – Short w.l. scatter more (.. Blue sky!)
  - **Mie** – Particles about same size of w.l.
  - **Non-selective** - Particles larger than wavelength – All w.l. scatter about the same (.. White clouds!)

- **Absorption**
  - Different constituents absorb at specific different w.l.
  - Ozone, carbon dioxide, and water vapour are the three main constituents for absorption.
Radiation-Target Interactions

- Incident = Reflection + Absorption + Transmission

In Remote Sensing at Vis and near-IR bands, what is measured is mainly the Reflection.

Specular Reflection

Diffuse Reflection
Example 1: Leaves

Example 2: Water
Sensors: Passive vs. Active

- **Passive sensors** detect naturally reflected or radiated energy (e.g. Radiometer).
- **Active sensors** supply, or send out, their own electromagnetic energy and then record what comes back to them (e.g. Radar).

Choice from **measured bands** (naturally available energy) and **required characteristics of images**
Satellite characteristics: Orbits and Swaths

- **Geostationary orbits**: revolve at same speed of earth, ~36,000 km altitude, stationary vs. earth surface, continuous monitoring of same area (e.g. weather, communications).

- **Near-polar orbits**: follow a low (~1,000 km) orbit (basically north-south) which, in conjunction with the Earth's rotation, allows them to cover most of the Earth's surface over a certain period of time. Many of these satellite orbits are also sun-synchronous such that they cover each area of the world at a constant local time (same illumination conditions).
As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the **swath**. Imaging swaths for space borne sensors generally vary between tens and hundreds of kilometers wide.

The satellite **revisit time** is the time elapsed between observations of the same point on earth. It depends on the satellite's orbit, target location, and swath of the sensor.
IKONOS - Average Revisit Time for Point Targets

Average Revisit (days)

Target Latitude (deg)

- 75.0 elev, 13.5 obliq, 0.86 GSD
- 72.0 elev, 16.2 obliq, 0.88 GSD
- 60.0 elev, 26.9 obliq, 1.00 GSD
- 50.0 elev, 35.5 obliq, 1.18 GSD
- 45.0 elev, 39.7 obliq, 1.32 GSD
- 30.0 elev, 51.5 obliq, 2.05 GSD
Spatial resolution and pixel size

- The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected.

- Spatial resolution of passive sensors (we will look at the special case of active microwave sensors later) depends primarily on their Instantaneous Field of View (IFOV).

- The Ground-projected Instantaneous Field of View (GIFOV) is often termed Ground Sample Distance (GSD).

- Pixel size of the image is limited by, but not necessarily equal to, GSD.
A full range of sensors and systems
Spectral resolution

- The wavelength width of the different frequency bands recorded – usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The hyperspectral Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

Radiometric resolution

- The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of colour, in each band.
Multispectral Scanning

Across-track scanners scan in a series of lines, oriented perpendicular to the direction of motion (i.e. across the swath), using a rotating mirror (A). Successive scans build up a two-dimensional image of the Earth’s surface. A bank of internal detectors (B) detects and measures the energy for each spectral band and then, from an on-board processor, they are converted to digital data.

Along-track scanners also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image. However 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.
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. Because of the relatively long wavelength of thermal radiation (compared to visible radiation), atmospheric scattering is minimal. However, absorption by atmospheric gases normally restricts thermal sensing to two specific regions - 3 to 5 μm and 8 to 14 μm.

Because energy decreases as the wavelength increases, thermal sensors generally have large IFOVs to ensure that enough energy reaches the detector in order to make a reliable measurement.

Therefore the spatial resolution of thermal sensors is usually fairly coarse, relative to the spatial resolution possible in the visible and reflected infrared. Thermal imagery can be acquired during the day or night (because the radiation is emitted not reflected).
Microwave sensing encompasses both active and passive forms of remote sensing, in the range from approximately 1cm to 1m in wavelength. Longer wavelength microwave radiation can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall. This property allows detection of microwave energy under almost all weather and environmental conditions.
Microwave Remote Sensing

- **Passive microwave sensing** is similar in concept to thermal remote sensing. All objects emit microwave energy of some magnitude, but the amounts are generally very small. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object or surface.

- The microwave energy recorded by a passive sensor can be emitted by the atmosphere, reflected from the surface, emitted from the surface, or transmitted from the subsurface. Because the wavelengths are so long, the energy available is quite small compared to optical wavelengths. Thus, the fields of view must be large to detect enough energy to record a signal (low spatial resolution).
Microwave Remote Sensing

- **Active microwave sensors** provide their own source of radiation to illuminate the target. Active microwave sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of imaging active microwave sensors is **RADAR**. RADAR is an acronym for **RAdio Detection And Ranging**.

- The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal.
- The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target.
Non-Imaging Microwave Sensors

- **Altimeters**
  Transmit short microwave pulses and measure the round trip time delay to targets to determine their distance from the sensor. Generally altimeters look straight down at nadir below the platform and thus measure height or elevation (if the altitude of the platform is accurately known).

- **Scatterometers**
  Are used to make precise quantitative measurements of the amount of energy backscattered from targets. The amount of energy backscattered is dependent on the surface properties (roughness) and the angle at which the microwave energy strikes the target. Scatterometry measurements over ocean surfaces can be used to estimate wind speeds based on the sea surface roughness.
Radar Basics

- The transmitter generates successive short bursts (or pulses of microwave (A) at regular intervals which are focused by the antenna into a beam (B). The radar beam illuminates the surface obliquely at a right angle to the motion of the platform. The antenna receives a portion of the transmitted energy reflected (or backscattered) from various objects within the illuminated beam (C). As the sensor platform moves forward, recording and processing of the backscattered signals builds up a two-dimensional image of the surface.

- When discussing microwave energy, the polarization of the radiation is also important. Polarization refers to the orientation of the electric field:
  - HH - for horizontal transmit and horizontal receive,
  - VV - for vertical transmit and vertical receive,
  - HV - for horizontal transmit and vertical receive, and
  - VH - for vertical transmit and horizontal receive.
Radar Basics: Viewing Geometry

- A – Flight direction
- B – Nadir
- C – Swath
- D – Range dimension
- E – Azimuth dimension

- A – Incident angle
- B – Look angle
- C – Slant range distance
- D – Ground range distance
Radar Basics: Spatial resolution

- Unlike optical systems, a radar's spatial resolution is a function of the specific properties of the microwave radiation and geometrical effects. If a Real Aperture Radar (RAR) is used for image formation a single transmit pulse and the backscattered signal are used to form the image. In this case, the resolution is dependent on the effective length of the pulse in the slant range direction and on the width of the illumination in the azimuth direction.

- The **range or across-track resolution** is dependent on the length of the pulse (P). Two distinct targets on the surface will be resolved in the range dimension if their separation is greater than half the pulse length. For example, targets 1 and 2 will not be separable while targets 3 and 4 will. Slant range resolution remains constant, independent of range. However, when projected into ground range coordinates, the resolution in ground range will be dependent of the incidence angle. Thus the ground range resolution will decrease with increasing range.
Radar Basics: Spatial resolution

- The **azimuth or along-track resolution** is determined by the angular width of the radiated microwave beam and the slant range distance. This beamwidth (A) is a measure of the width of the illumination pattern. As the radar illumination propagates to increasing distance from the sensor, the azimuth resolution increases (becomes coarser). In this illustration, targets 1 and 2 in the near range would be separable, but targets 3 and 4 at further range would not. The radar beamwidth is inversely proportional to the antenna length (also referred to as the aperture) which means that a longer antenna (or aperture) will produce a narrower beam and finer resolution.
Synthetic Aperture Radar (SAR)

- Finer range resolution can be achieved by using a shorter pulse length. Finer azimuth resolution can be achieved by increasing the antenna length. However, the actual length of the antenna is limited by what can be carried on an airborne or spaceborne platform. To overcome this size limitation, the forward motion of the platform and special recording and processing of the backscattered echoes are used to simulate a very long antenna and thus increase azimuth resolution.

- As a target (A) first enters the radar beam (1), the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam (2) some time later, determines the length of the simulated or synthesized antenna (B). Targets at far range, where the beam is widest will be illuminated for a longer period of time than objects at near range. The expanding beamwidth, combined with the increased time a target is within the beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath.
Radar Basics: Image distortions

- Radar is fundamentally a distance measuring device (i.e. measuring range), and hence radar imagery has certain specific distortions.

- **Slant-range distortion** occurs because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground. This results in a varying image scale, moving from near to far range. Although targets A1 and B1 are the same size on the ground, their apparent dimensions in slant range (A2 and B2) are different. This causes targets in the near range to appear compressed relative to the far range.
Radar Basics: Image distortions

- **Foreshortening** occurs when the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top. Because the radar measures distance in slant-range, the slope (A to B) will appear compressed and the length of the slope will be represented incorrectly (A' to B'). Maximum foreshortening occurs when the radar beam is perpendicular to the slope such that the slope, the base, and the top are imaged simultaneously (C to D). The length of the slope will be reduced to an effective length of zero in slant range (C'D'). The foreshortened slopes appear as bright features on the image.
Radar Basics: Image distortions

- Layover
  occurs when the radar beam reaches the top of a tall feature (B) before it reaches the base (A). The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and "lays over" the base of the feature (B' to A'). Layover effects on a radar image look very similar to effects due to foreshortening. As with foreshortening, layover is most severe for small incidence angles, at the near range of a swath, and in mountainous terrain.
Radar Basics: Target Interactions

- The brightness of features in a radar image is dependent on the portion of the transmitted energy that is returned back to the radar from targets on the surface. The magnitude or intensity of this backscattered energy is dependent on how the radar energy interacts with the surface, which is a function of several variables or parameters. These can be grouped in:
  - Surface roughness of the target
  - Radar viewing and surface geometry relationship
  - Moisture content and electrical properties of the target
Radar Basics: Speckle

- Speckle appears as a grainy "salt and pepper" texture in an image. This is caused by random constructive and destructive interference from the multiple scattering returns that will occur within each resolution cell.

- Speckle is essentially a form of noise which degrades the quality of an image. Speckle reduction can be achieved in two ways:
  - multi-look processing (on board)
  - spatial filtering (postprocessing).
http://en.wikipedia.org/wiki/List_of_Earth_observation_satellites
From data to products: The Ground Segment
Updated version of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC published -- including revised list of GCOS Essential Climate Variables

The Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC was updated and published on 31 August 2010. This 2010 update also includes the revised list of GCOS Essential Climate Variables (ECVs). It is important that all 139 actions recommended in the Implementation Plan be fully implemented, as these actions will substantially improve the availability of the observational information needed by all governments to understand, predict, and manage their response to climate and climate change. This responds to Articles 4 and 5 of the United Nations Framework Convention on Climate Change (UNFCCC). read more

GCOS and WCRP Call for Strengthening Collaboration on Climate Data Records

In a joint letter, the Directors of the Global Climate Observing System and the World Climate Research Programme (GCOS/WCRP) are asking the worldwide organizations to support the international expert groups involved in scientific analysis, intercomparison and review of climate data records. Such effort is essential for world-class climate science and sound decision-making. The latter calls, inter alia, for adherence by groups and institutions involved in climate data record generation to the new Guideline for the Generation of Datasets and Products Meeting GCOS Requirements, to support transparency, traceability and scientific review.

List of recipients (4 June 2010): ▲PDF

Upcoming events

GCOS newsletter
National News

Development of Meteosat Third Generation to start

18 November 2010  Marking a significant milestone for Europe's next fleet of meteorological satellites, ESA has given the go-ahead to Thales Alenia Space in France to start work on developing the Meteosat Third Generation.

Call for Media: Graduation ceremony for ESA’s new astronauts

17 November 2010  ESA PR 25-2010 On Monday 22 November 2010, the European Space Agency (ESA) will hold, at the European Astronaut Centre (EAC) in Cologne, Germany, the official ceremony for its new astronauts, marking the completion of their Basic Training.

Satellites tracking Mt Merapi volcanic ash clouds

15 November 2010  Since its latest series of deadly eruptions, Java’s Mt Merapi has been spewing volcanic ash clouds into the air. Satellite data are crucial for assessing the eruption’s danger to air traffic and public safety.
http://www.eumetsat.int/Home/index.htm
http://www.gmes.info/

GMES (Global Monitoring for Environment and Security) is the European Initiative for the establishment of a European capacity for Earth Observation.

This website is dedicated to the EU-funded R&D activities that support the implementation of the GMES Initiative. It is operated by SWIFT, a FP7 Coordination and Support Action funded by the European Commission.

The views expressed on this website are those of the authors and do not necessarily represent those of the European Commission or of the European Space Agency. Official information on GMES is available on the GMES institutional portal.

What's New:
- 17 Nov 2010: GMES and Africa
  GMES & Africa side event to the 3rd Africa-EU Summit
- 16 Nov 2010: Volcanic Eruption in Java
  Mount Merapi volcanic ash clouds tracked by the satellites
- 16 Nov 2010: GMES and Africa
  Successful first GARNET-E training workshop
- 09 Nov 2010: Volcanic eruption on Java
  MACC provides pre-operational plume forecasts

Focus Event:
The future of GMES after 2014 from a regional perspective
01 December 2010
Brussels, Belgium

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