Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

Remote Sensing

Introduction

Welcome to this course on remote sensing! In this course, we will explore a variety of remote sensing topics.

We assume that you have no prior experience working with remotely sensed data. We will explore key concepts assuming no prior knowledge of remote sensing.

In this introductory module, we introduce remote sensing and some of the key concepts in the field.

Module Topics

1. Introduction to remote sensing
2. Types of sensors
3. Types of resolution
4. Grain vs. extent

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These are the topics covered in this module.

What is Remote Sensing?

- Taking measurements or collecting observations without coming into contact with the feature of interest

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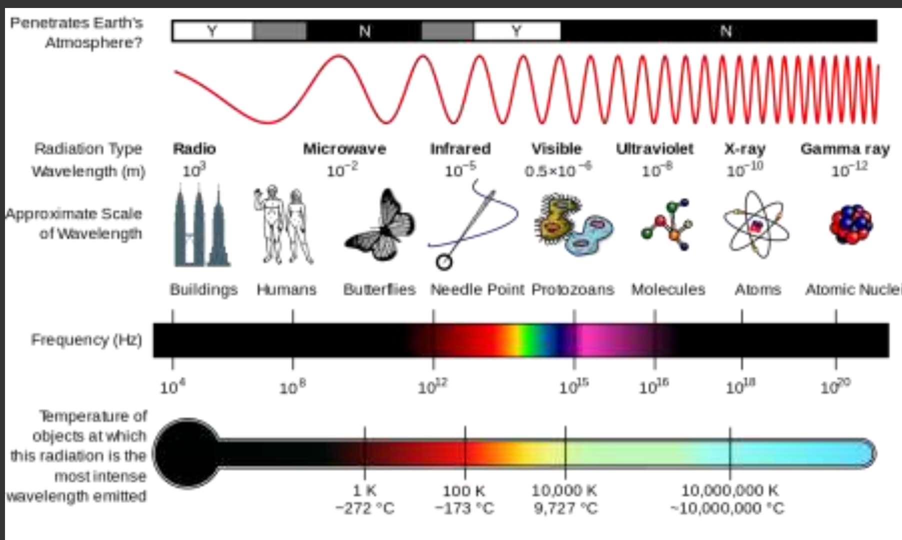
Remote sensing consists of collecting observations about an object without coming into physical contact with the object. In this course, we will focus on remote sensing of the Earth's surface, as opposed to remote sensing of objects in space or the Earth's atmosphere.

Remote sensing techniques are in common use. For example, taking a picture with your camera or phone is remote sensing: you are collecting information about an object, light energy reflecting off of it, without coming into contact with the object. Human vision is essentially remote sensing.

For Earth observation, remote sensing relies on sensors that are attached to a platform, such as a satellite, aircraft, or unmanned aerial vehicle (drone). These sensors are designed to measure or sense different portions of the electromagnetic spectrum.

Electromagnetic (EM) Radiation



https://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_edit.svg

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Remote sensing measures reflected or emitted electromagnetic radiation, which we will discuss in detail in a later module.

For now, it is important to understand that there are different types of electromagnetic radiation, and we can design sensors to detect them specifically.

Different types of electromagnetic radiation can provide unique information about the Earth’s surface and its processes.

Visible light is one type of electromagnetic radiation.

Optical

- Passive
- Makes use of the visible, near infrared, and/or shortwave infrared spectrum
- Data collected using frame-based or scanning sensors
- Reflected radiation
- Types Include
  - Panchromatic
  - True Color (RGB)
  - Color Infrared
  - Hyperspectral

QuickBird Image

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The most common type of remote sensing relies on detection of reflected electromagnetic radiation in the optical ranges of visible, near infrared, and shortwave infrared radiation.

This is a type of passive remote sensing because the sensor is not creating the energy source. Instead, the source of energy is the Sun. Also, optical sensors measure reflected radiation, as opposed to emitted radiation.

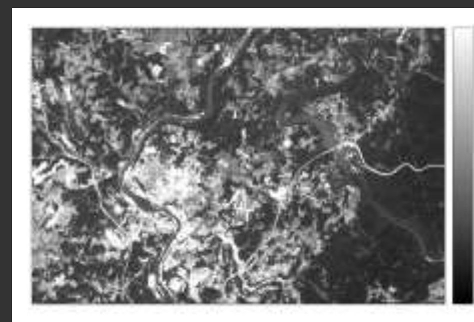
In contrast to passive remote sensing, active sensors create their own energy source. Think of taking a photograph with flash, active sensing, vs. using natural light, passive sensing.

There are different types of optical data, which we will discuss in detail in this course.

Thermal

- Passive
- Makes use of thermal radiation
- Generally measuring emitted radiation

https://www.flir.com/



Landsat 7 ETM+
12 September 1999, Approximately 10 AM

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Thermal remote sensing is similar to optical remote sensing in that it is passive. However, the goal is to sense emitted thermal or heat radiation from an object or the Earth’s surface as opposed to reflected visible, near infrared, or shortwave infrared radiation.

We will discuss thermal remote sensing and its applications in the later part of the course.

Radar

- Radio Detection and Ranging
- Active
- Uses microwaves
- Measure backscatter
- Create terrain models

https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-1

https://www.jpl.nasa.gov/missions/shuttle-radar-topography-mission-srtm/

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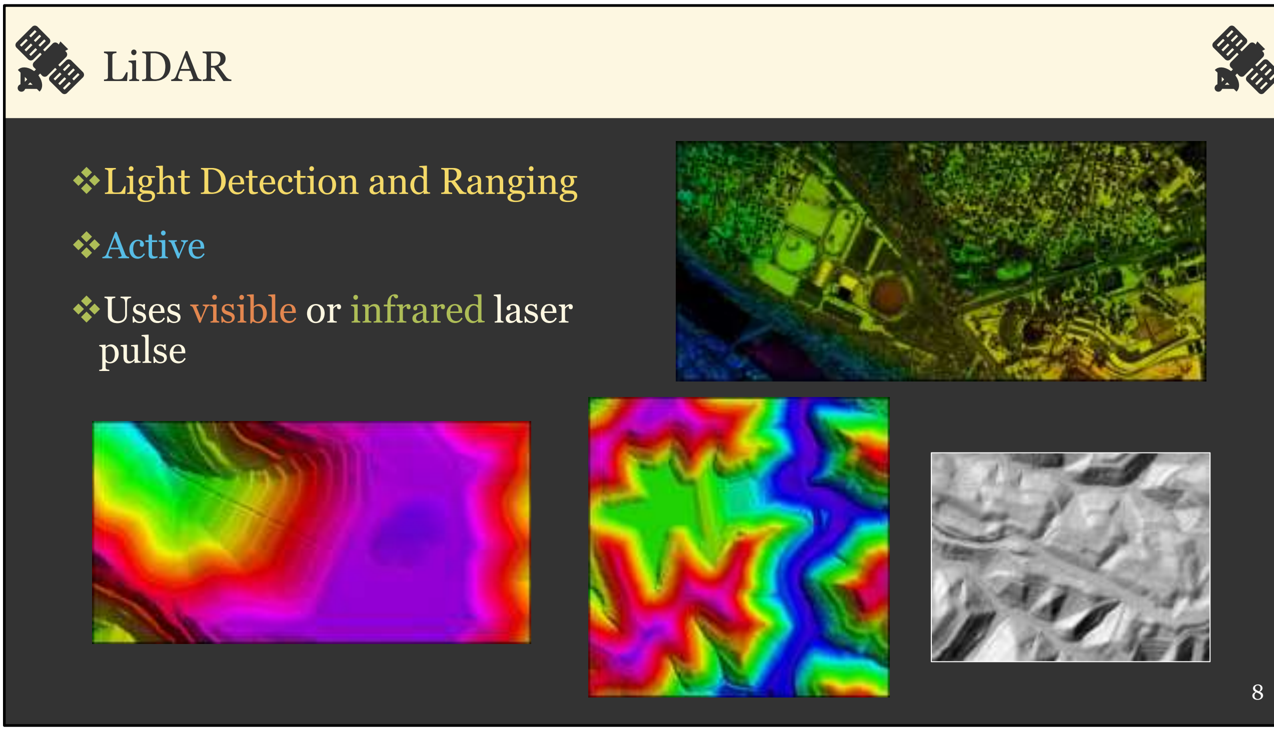
Radar, or Radio Detection and Ranging, is a form of active remote sensing because the sensor produces a radio wave or microwave signal and then measures the returned backscatter. Although there are different types of radar remote sensing systems, such as speed detectors used by police officers, we will specifically focus on imaging radar.

Measuring the backscatter of microwaves can offer some unique information about the land surface that is not provided by optical or thermal data. These technologies can even be used to map elevation or the terrain surface.

We will discuss these types of data towards the end of the course.



Another form of active remote sensing is LiDAR, or Light Detection and Ranging. Similar to radar, LiDAR is an active technique; however, instead of using radio waves or microwaves, visible or near infrared laser pulses are transmitted and the returning energy is measured.

LiDAR has revolutionized digital terrain mapping and has many additional applications, such as self driving or autonomous vehicles.

Image Data

- Raster data, cell-based
- Georeferenced, multidimensional array of measurements
- Pixel = picture element

Data from Landsat 7 ETM+

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Remotely sensed data are commonly represented as raster grids or images, which are an array of numeric values stored in cells or pixels.

These data arrays are georeferenced, or referenced to the surface of the Earth, and can be multidimensional, which allows for multiple measurements to be stored at the same pixel location.

The image provided on the slide represents a Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image of a fire scar in the Black Hills of South Dakota, USA. When we zoom in to the data, you can see the individual pixels or measurements that make up the image.

In this course, you will get used to working with images and raster data. Note that there are some other data models that you will encounter in this course, such as 3D point clouds.

Resolution

Spatial Resolution = ground area represented by one pixel (5 m, 10 m, 30 m, 250 m, etc.)

Spectral Resolution = bands or number of wavelengths measured

Radiometric Resolution = ability of a sensor to measure differences in energy or brightness (8-bit, 11-bit, 16-bit, etc.)

Temporal Resolution = how often a sensor returns to the same area (daily, weekly, twice a month, etc.)/length of historic record

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We will end this introductory section with a discussion of resolution. When we think of resolution, such as the resolution of your computer monitor or TV, we are specifically referencing spatial resolution. However, there are other types of resolution that are important in remote sensing. We will differentiate these types in the following slides.

Scale

- Grain = the finest level of measurement, the degree of detail, or the sampling unit
- Extent = range over which measurements are made
- Generally, gain and extent are inversely related

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The concept of scale consists of two components: grain and extent.

Grain relates to the finest level of measurement, the degree of detail, or the sampling unit. In contrast, extent relates to the range over which measurements are made.

Generally, grain and extent are inversely related: as grain goes up, extent goes down (and vise versa). However, this is not always the case, especially with new sensors.

We will now discuss these two concepts in the context of the four types of resolution.

Spatial

Grain = instantaneous field of view (IFOV) and ground sampling distance

Extent = area represented in a single imaged scene

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Spatial resolution is commonly what we think of when we discuss resolution.

Grain relates to the instantaneous field of view (IFOV) and ground sampling distance of the data. More simply, it relates the size of each pixel. So, the higher the grain, the more spatial detail that is captured, or the smaller the pixel size or extent.

Extent relates to the area represented in an image scene. For example, a small extent could represent a single parking lot where a large extent could be an image of an entire county or state.

Based on spatial scale, you should see why grain and extent are commonly inversely related. If an image has both a large spatial grain and extent, then there would be a lot of measurements or pixels, which would result in a very large file. For example, a 1-meter image of the entire continent of North America would be an extremely large file made up of many, many pixels.

Spatial

Pixel Size (m)	Spatial Grain	Example
< 1	Very fine	World View
1-10	Fine	IKONOS
10-100	Moderate	LANDSAT, SPOT, ASTER, Sentinel-2
100-1000	Coarse	MODIS
>1000	Very Coarse	AVHRR, GOES

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Sensors can be categorized based on their spatial grain, as shown in this table. For example, moderate spatial grain sensors have pixel sizes between 10 and 100 meters while coarse sensors have a resolution between 100 and 1,000 meters. In remote sensing, spatial grain is generally expressed this way. When we say that data have a resolution of 5 meters, this means that each pixel measures 5-by-5 meters in the x and y directions.

Note that these breaks are not universally defined. You will likely see different definitions for moderate vs. fine spatial grain, for example, from different sources.

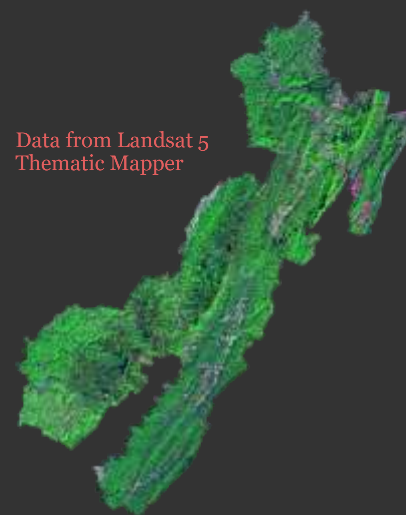
You may think that coarse and very coarse data are not very useful. However, this is not true. In fact, these types of datasets are very important for global scale monitoring and modeling. They are used extensively to understand weather, climate, and the energy budget of the planet.

No spatial grain is better than another. Instead, it is important to use the appropriate grain to address specific questions or needs.

Spectral

- How many bands or what spectral ranges are sensed
- Panchromatic = Single band for entire visible spectrum (or visible and CIR)
- True Color = Red, Green, and Blue bands (RGB)
- Color Infrared = Red, Green, Blue, and Near Infrared (CIR)
- Multispectral = Multiple spectral bands collected
- Hyperspectral = Tens to hundreds of spectral bands

Data from Landsat 5 Thematic Mapper



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Spectral grain has to do with the number of bands or wavelength ranges measured or collected by the sensor while spectral extent relates to the range of wavelengths measured (such as just the visible spectrum vs. the visible through shortwave spectrum).

Panchromatic images are black-and-white, single-band images that do not provide separate channels or bands. A wide range of wavelengths are sensed and recorded as a single gray-scale image. Although this is a bit limiting, panchromatic images are still used. In fact, panchromatic images are commonly collected along with multispectral data. The panchromatic image is generally collected at a higher spatial grain and can be used to pansharpen multispectral data, a process we will discuss in this course.

True color images are designed to mimic or simulate human vision. Your eyes contain red, green, and blue cones. Your visual system can then combine the primary colors to create a color view of the world. A true color camera works similarly. The red, green, and blue channels are collected separately and stored in separate bands. They are combined to produce a color at each pixel. Most of the images we collect on a daily basis, such as pictures taken with a cell phone, are true color images.

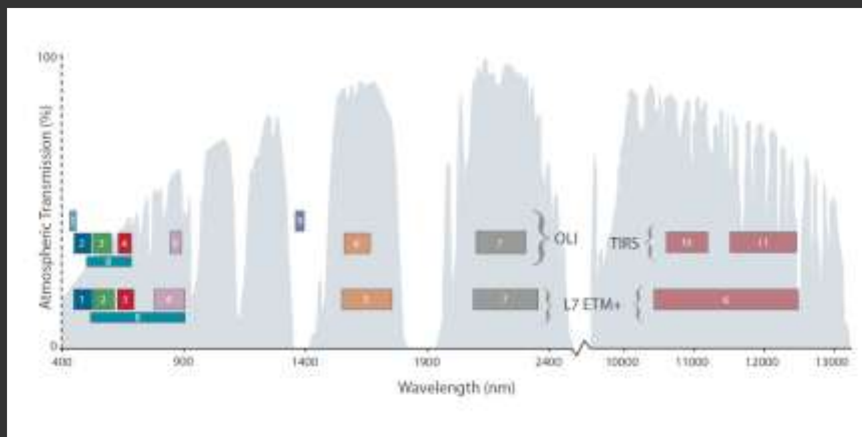
Color infrared, or CIR, images collect visible bands and a near infrared band.

As previously discussed, near infrared wavelengths can be useful for differentiating and mapping vegetation and vegetation health. So, collecting this information can be of value. Older film-based methods were able to collect green, red, and near infrared data. Modern digital sensors can collect four bands of data: blue, green, red, and near infrared.

Multispectral images generally collect more than four bands. For example, the Landsat 5 Thematic Mapper sensor provides one blue, one green, one red, one near infrared, two shortwave infrared, and one thermal infrared band.

Hyperspectral images can provide tens or hundreds of bands as a data cube that more closely approximates the full spectral reflectance curve at a pixel location.

Spectral



https://landsat.gsfc.nasa.gov/landsat-data-continuity-mission/

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This image provides comparisons of spectral resolution for the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor and the Landsat Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS).

The ETM+ sensor offers eight bands: panchromatic, blue, green, red, one infrared, two shortwave infrared, and one thermal infrared band.

In contrast, the OLI and TIRS sensors offer 11 bands: blue edge, blue, green, red, cirrus cloud, near infrared, two shortwave infrared, and two thermal infrared bands.

Also, the spectral ranges or wavelengths sensed for comparable bands vary. For example, the NIR band provided by ETM+ senses a wider spectral range than that provided by the OLI.

Radiometric

- Integer = Only holds whole numbers
- Float = Can hold decimals
- Signed = can hold negative values
- Unsigned = cannot hold negative values
- Pixel Type/Pixel Depth
  - 4-bit = 2^4 (16) unique values
  - 8-bit = 2^8 (256) unique values
  - 16-bit = 2^{16} (65,536) unique values
  - 32-bit = 2^{32} (4,294,967,296) unique values
  - 1-bit, 2-bit, 11-bit, 12-bit, etc.

Can think of this as the degree of brightness difference that can be quantified

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Radiometric resolution has to do with what levels in brightness can be differentiated.

This relates to the pixel type or pixel depth of an image. For example, a 4-bit image can differentiate 16, or 2 to the 4^{th} power, discrete levels of brightness. In contrast an 8-bit image can differentiate 256, or 2 to the 8^{th} power, discrete levels of brightness.

A 16-bit image can differentiate a large number of discrete brightness differences.

As an extreme case, a 1-bit image can only differentiate 2 to the 1^{st} power, or 2, levels of brightness. So, the result would be black and white, or on and off.

You can think of this as the precision of the measurement. As an analogy, increasing radiometric resolution is like making length measurements to the nearest millimeter as opposed to the nearest meter; you will be able to differentiate smaller differences in length.

Many older sensor recorded 8-bit data. However, modern sensors are increasingly providing 11-bit or 16-bit data. Again, this allows for more precise differentiation of brightness or spectral reflectance. The trade-off is larger file size and greater data volumes.

Radiometric

- Grain = fineness of the divisions between successive brightness levels or sensor measurements (number of bits)
- Extent = range of brightness levels over which the sensor can differentiate change is radiance
- Signal-to-Noise Ratio = minimal radiance change that can be detected reliably

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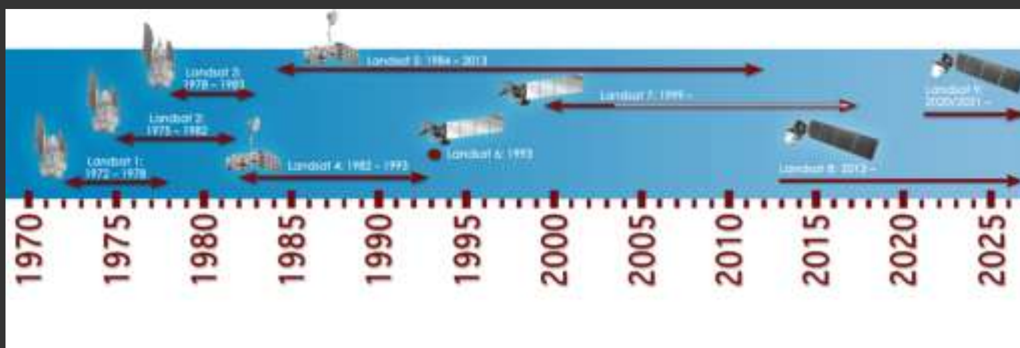
For radiometric resolution, grain relates to the fineness of the divisions between successive brightness levels or sensor measurements. In other words, it relates to the smallest difference in brightness that can be detected or quantified.

In contrast, extent relates to the range of brightness levels that can be detected. A sensor may not be able to detect a signal if it is too faint. If the signal is too strong, the measurement may become oversaturated. Think of the loss of detail in the dark shadows of an image or areas of glare or over exposure.

A related concept is the signal-to-noise ratio, which relates to how reliably we can separate signal, in this case differences in brightness, from random or instrument noise.

Temporal

- ❖Grain = period between image acquisitions
- ❖Extent = period of time covered



https://landsat.gsfc.nasa.gov/a-landsat-timeline/

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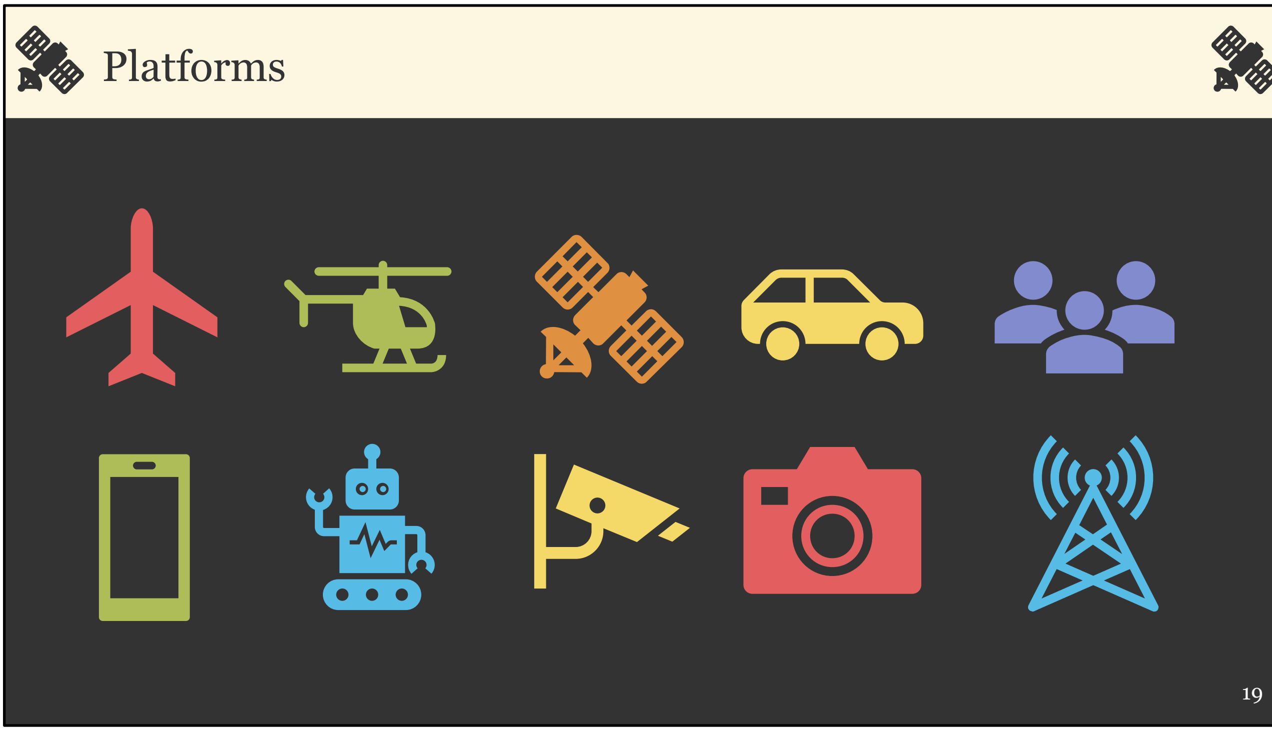
Lastly, temporal resolution relates to both how often data are collected, grain, and the historic extent covered.

For example, the first Landsat mission was launched in 1972, and there is currently an active mission (Landsat 8). So, the temporal extent of the Landsat program covers nearly five decades. The temporal grain of Landsat is roughly 16 days for a single sensor; a satellite images the same location on the Earth's surface roughly twice a month.

There is generally an inverse relationship between temporal and spatial grain: data that are collected often, such as daily, tend to have a larger cell size. In contrast, images with a small cell size tend to be collected less frequently. However, this relationship is not always true. For example, modern microsatellite constellations can offer both high spatial and temporal grain since data are collected by many satellites.



Lastly, we can collect remotely sensed data from a variety of platforms including aircraft (airplanes, helicopters, and UAVs), satellites, vehicles (think of Google Street View imagery), people, phones, robots, stationary cameras, and towers.

In this course, we will primarily focus on data collected from aerial or satellite platforms, as these are the most common platforms currently used for Earth observation.

This is the end of this lecture module.

Please return to the West Virginia View Webpage for additional content.

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Thanks! Hope you found this useful.