Lecture 2: Geospatial Technologies in Agriculture

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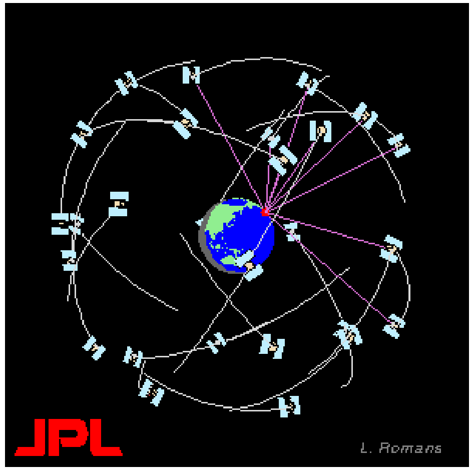
What Are Geospatial Technologies?

- Set of tools used to capture, analyze, and visualize geographic data, which is data linked to specific locations on earth
- Essential for understanding and managing **spatial relationships** and **patterns** across various fields, including **agriculture**, urban planning, environmental management, and disaster response
- Examples: Global Positioning System (GPS), Geographic Information Systems (GIS), Remote Sensing, Unmanned Aerial Vehicles (UAVs), Satellites, Spatial Data Analytics software, etc.

Global Positioning System (GPS)

- Satellite-based navigation system that provides real-time **location** and **time** information anywhere on earth.
- Currently **31 GPS satellites (at least 24 required)** orbit the Earth at an altitude of approximately **11,000 miles** providing users with accurate information on position, velocity, and time anywhere in the world and in all weather conditions
- Operated and maintained by the **Department of Defense (DoD)**
- The **Federal Aviation Administration (FAA)** oversees the use of GPS in civil aviation receives problem reports from aviation users.



US department of transportation: Federal Aviation Administration

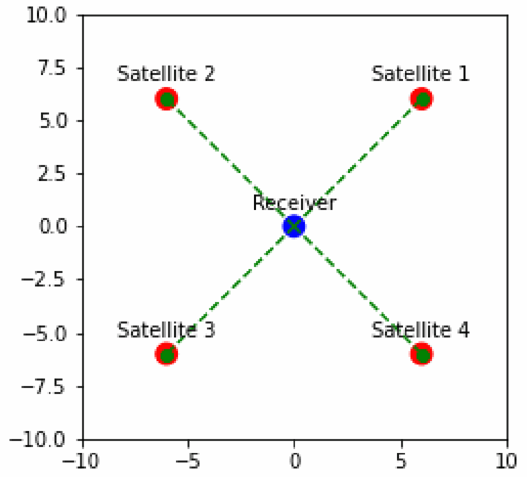
Global Positioning System (GPS)

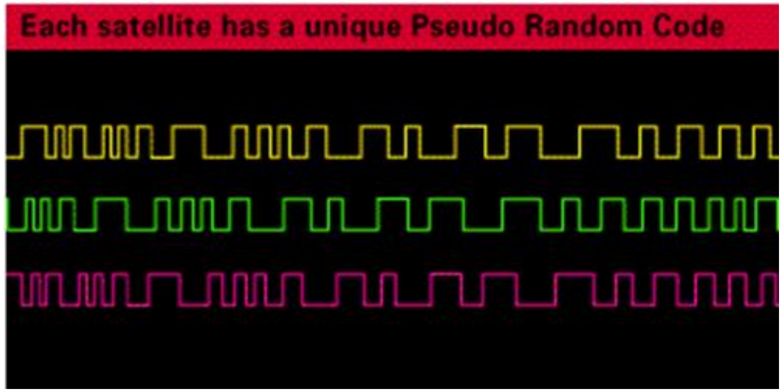
- Formal name: **Navstar Global Positioning System**
- Was a joint civil/military technical program in 1973
- Satellites send data to earth that are picked up by receivers
- Since the distance to each satellite is different, signals arrive at the receivers at different times
- Signal bandwidth: L1 (**1575.42 MHz**)
- Each GPS satellite has highly accurate atomic clock.

Global Positioning System (GPS)

How GPS Determines Time?

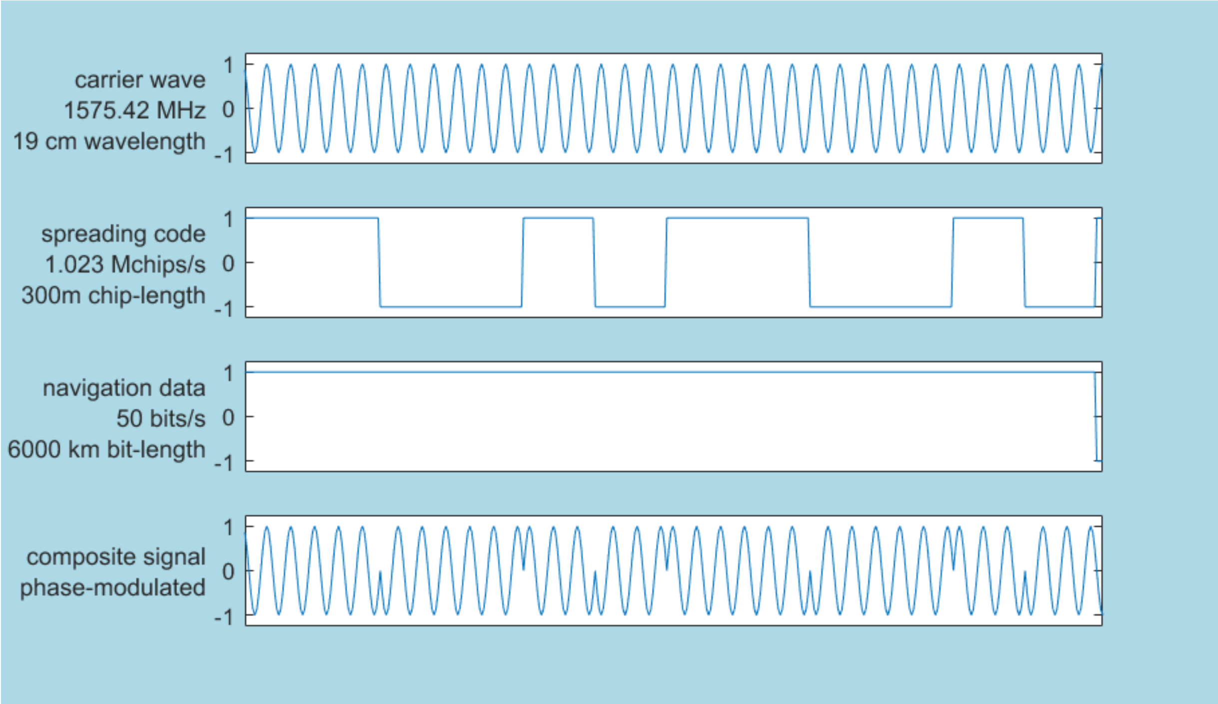
- GPS receivers synchronize their internal atomic clocks with Coordinated **Universal Time (UTC)**
- Each GPS satellite continuously transmits a unique signal known as a "**pseudo-random noise (PRN)"** code
- The **PRN** code is a complex sequence of binary digits that is unique to each satellite, allowing the receiver to distinguish signals from different satellites.
- The GPS receiver is pre-programmed with information about each satellite's pseudo-random code and the exact time each code is transmitted
- This information is essential for the receiver to identify which satellite the signal is coming from and to compare it with its internal clock.

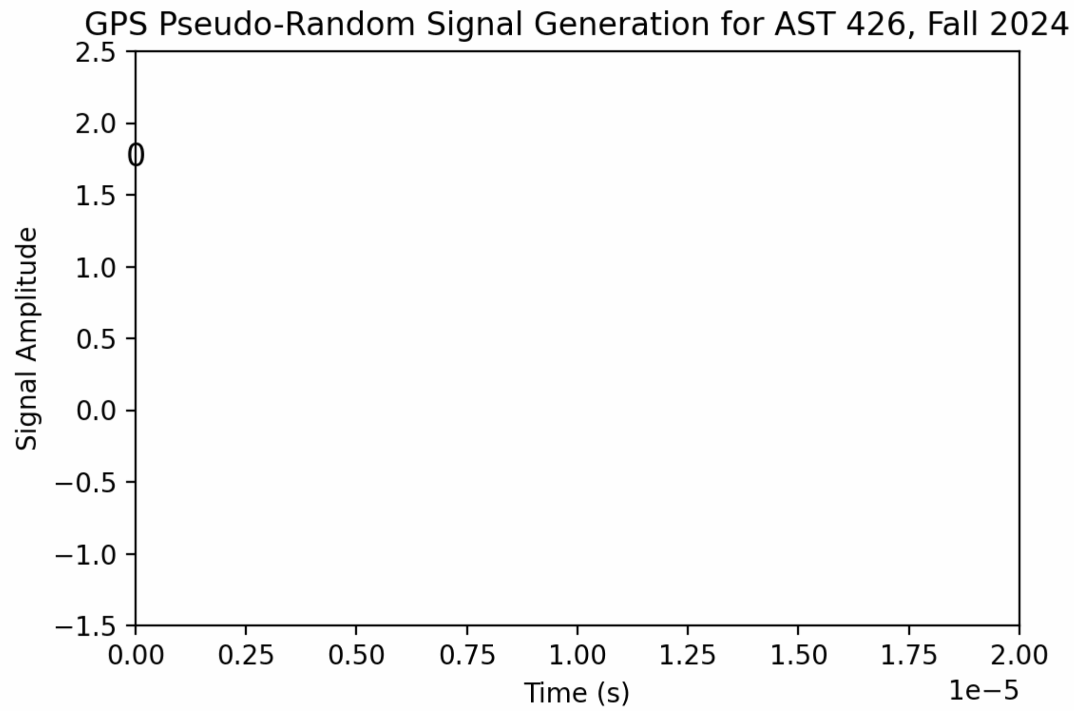




Global Positioning System (GPS)

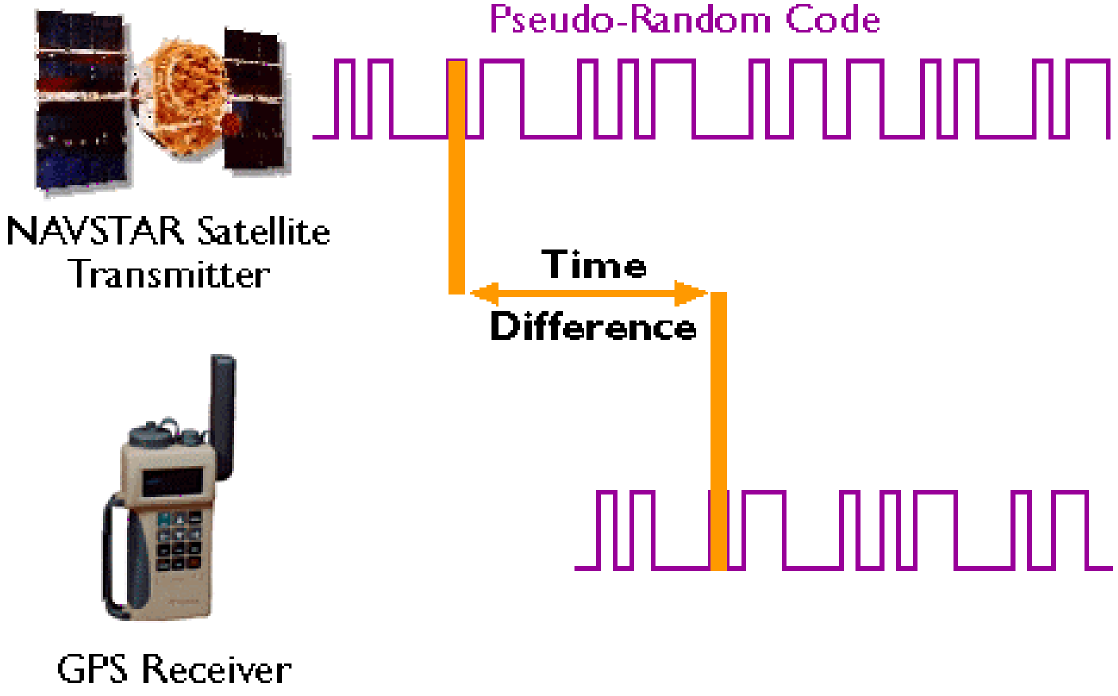
GPS signals example



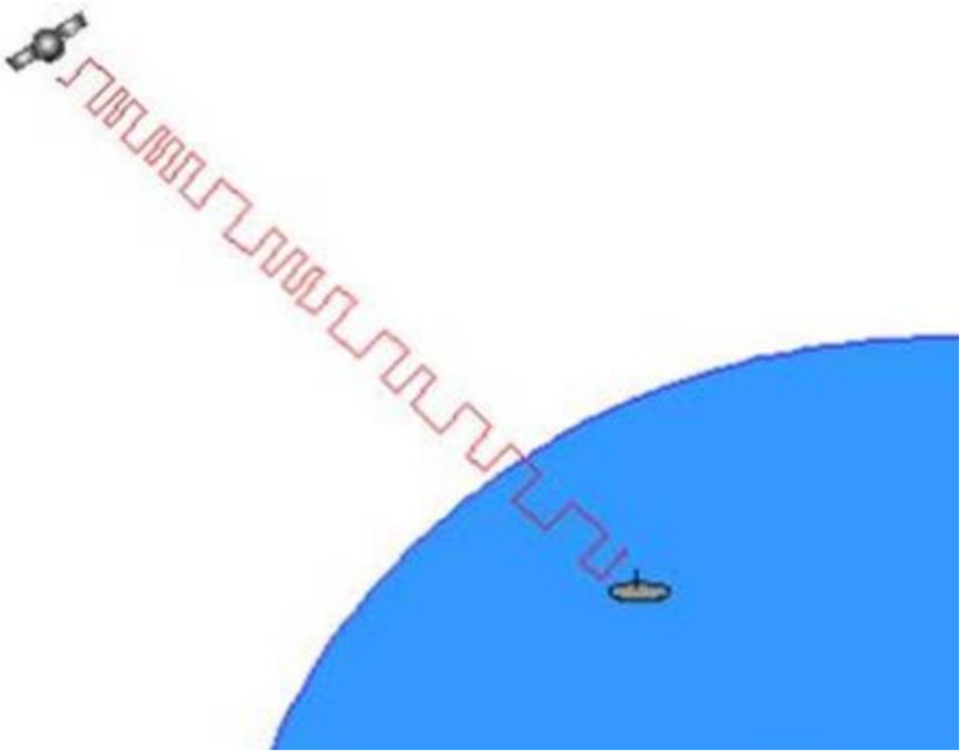


Global Positioning System (GPS)

How GPS Determines Distance?



Distance = Speed of Light • Time Difference



Global Positioning System (GPS)

- When the GPS receiver receives the signal from a satellite, it compares the received **PRN** code with the expected **PRN** code
- By determining the time delay (**the difference between when the code was sent and when it was received**), the receiver **can calculate the time** it took for the signal to travel from the satellite to the receiver
- The **time delay** calculated by the receiver directly corresponds to the time it takes for the signal to travel from the satellite to the receiver.
- Since the speed of the signal (which is the speed of light) is constant, this time delay allows the receiver to accurately **determine the distance to the satellite**.
- Using this information **from multiple satellites**, the receiver can **precisely determine its position** and **synchronize its clock with UTC**.

Quiz

- A GPS satellite is **20,200 Km** away from a GPS receiver on earth. The speed of light (the speed at which the signal travels) is approximately **$3x10^8$ m/s** meters per second. How long does it take for the GPS signal to travel from the satellite to the receiver?

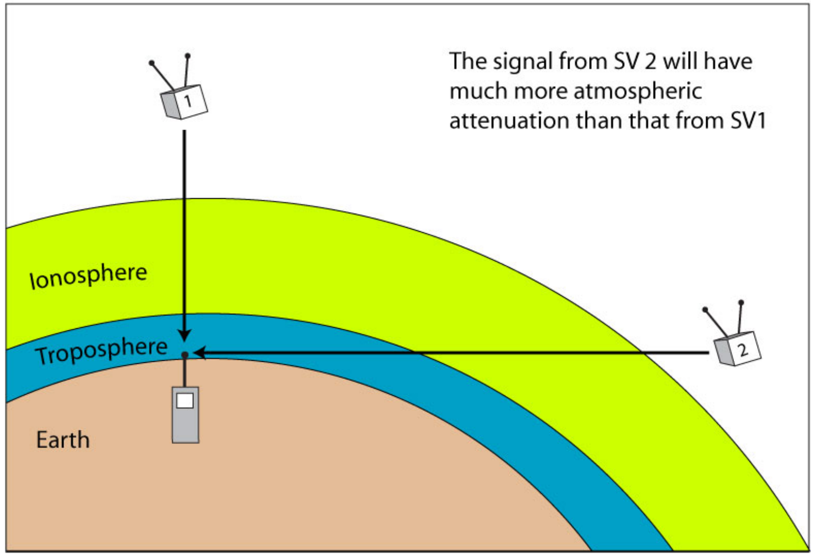
$$
\begin{aligned}
Distance &= 20{,}200\ Km \\
&= 20{,}200 \times 10^3\ m
\end{aligned}
$$

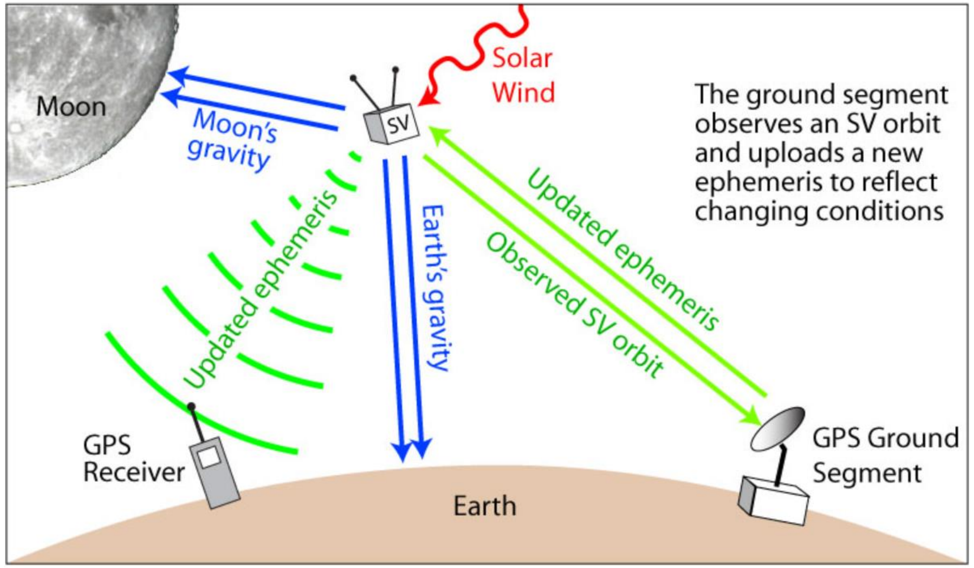
$$
\begin{aligned}
Time &= \frac{Distance}{Speed} \\
&= \frac{20{,}200 \times 10^3}{3 \times 10^8} \\
&= \mathbf{0.0673\ s}
\end{aligned}
$$

Sources of Errors in GPS signals

- **Atmospheric errors** : Charged Particles in the Ionosphere, Water Molecules in the Troposphere
- **Ephemeris errors**: Caused by the gravitational pull of the sun, moon, and solar radiation
- **Multipath Error:** Caused by buildings, mountains, etc.

Atmospheric Error

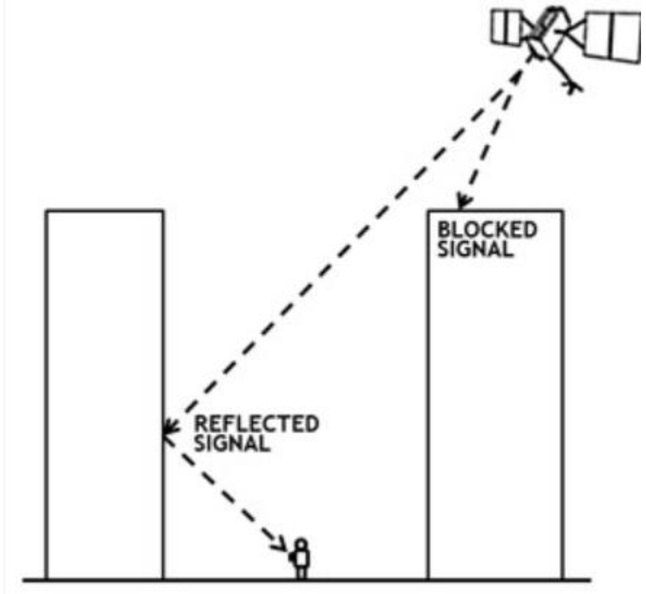




https://www.albany.edu/faculty/jmower/geog/gog530Python/src/GNSSErrorSources/GPSErrorSources.html

Quiz

What type of GPS error does this image represent?



Global Positioning System (GPS)

GPS Error Calculation

A GPS signal is reflected off a building before reaching a GPS receiver. The direct path from the satellite to the receiver is **20,200 km**, but the reflected path is **20,205 km**. Calculate the time delay caused by the multipath effect. Assume the speed of light is **3×10^{8} m/s**.

$$Difference\ in\ path\ length = (20{,}205 - 20{,}200) \times 10^{3} = 5{,}000\ \mathrm{m}$$

$$Time\ Delay = \frac{Difference\ in\ path\ length}{Speed\ of\ light}$$

$$= \frac{5000}{3 \times 10^{8}}$$

$$= \mathbf{1.67 \times 10^{-5}\ s = 16.7\ \mu s}$$

Global Positioning System (GPS)

NMEA (National Marine Electronics Association) Standard

- Standard used in GPS technology to define how GPS data is formatted and transmitted between GPS receivers and other devices, such as computers, smartphones, and navigation systems

$GPGGA,**123519,4807.038,N,01131.000,E**,1,08,0.9,**545.4,M**,46.9,M,,*47

$GPGGA: Identifier indicating the type of data (GPS Fix Data).
123519: UTC time of fix (12:35:19).
4807.038,N: Latitude (48°07.038' North).
01131.000,E: Longitude (11°31.000' East).
1: Fix quality (1 = GPS fix).
08: Number of satellites being tracked.
0.9: Horizontal dilution of precision (HDOP).
545.4,M: Altitude, in meters, above mean sea level.
46.9,M: Height of geoid (mean sea level) above WGS84 ellipsoid.
*47: Checksum for error detection.

Global Positioning System (GPS)

Quiz

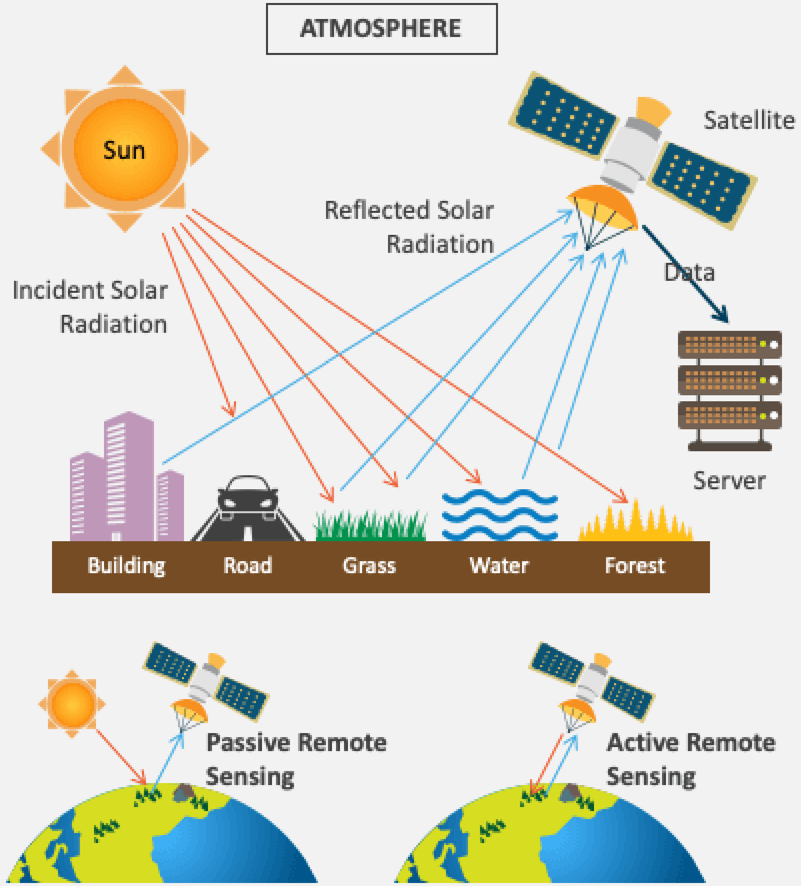
Determining Latitude, Longitude, Time, and Height Above Mean Sea Level from GPS Data

$GPGGA,123456,3741.821,N,12224.548,W,1,08,0.9,15.6,M,-25.0,M,,*47

Remote Sensing Technologies

REMOTE SENSING

What is Remote Sensing?



REMOTE SENSING

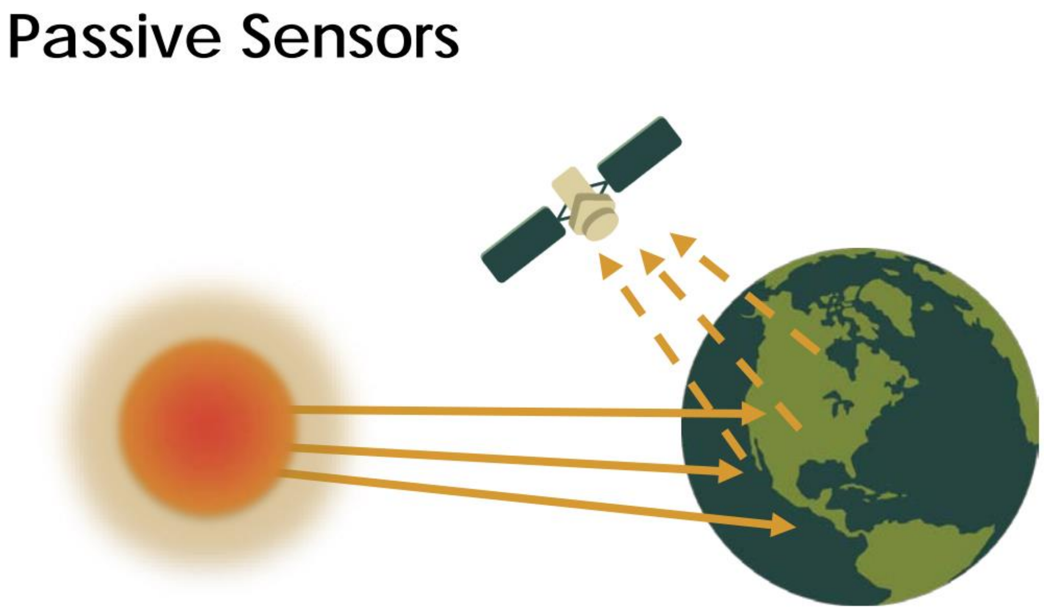
Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. The term is applied especially to acquiring information about Earth and other planets. Remote sensing is used in numerous fields, including geophysics, geography, land surveying, and most Earth science disciplines.

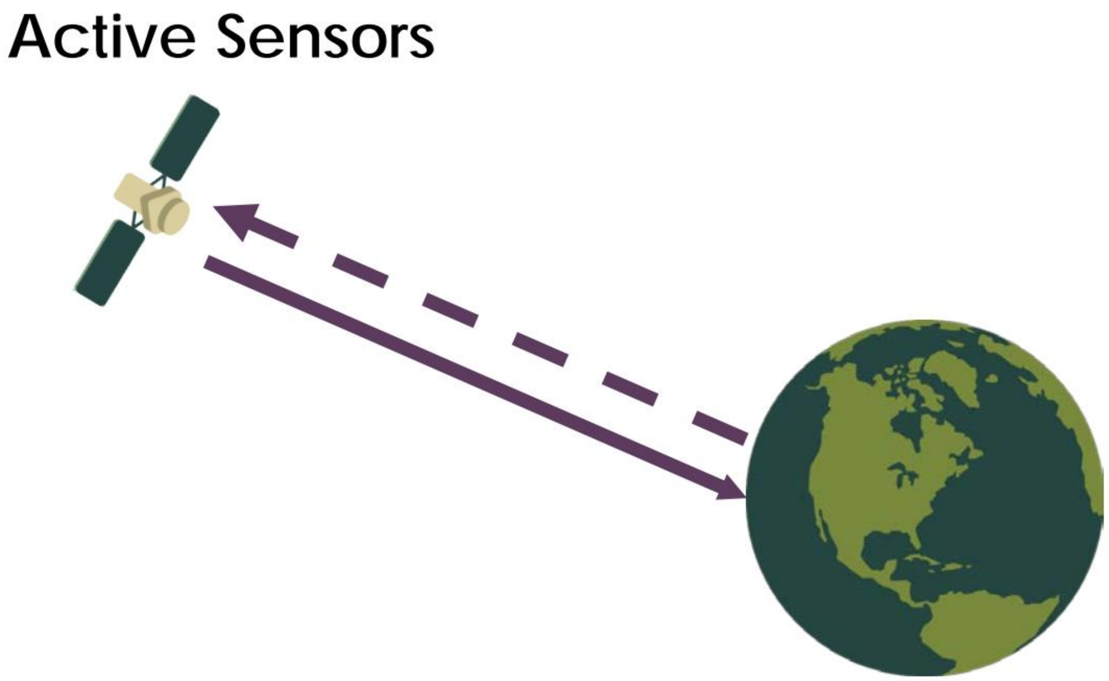
(E.g. exploration geophysics, hydrology, ecology, meteorology, oceanography, glaciology, geology)

https://www.collidu.com/presentation-remote-sensing

Remote Sensing Technologies

Types of Remote Sensing





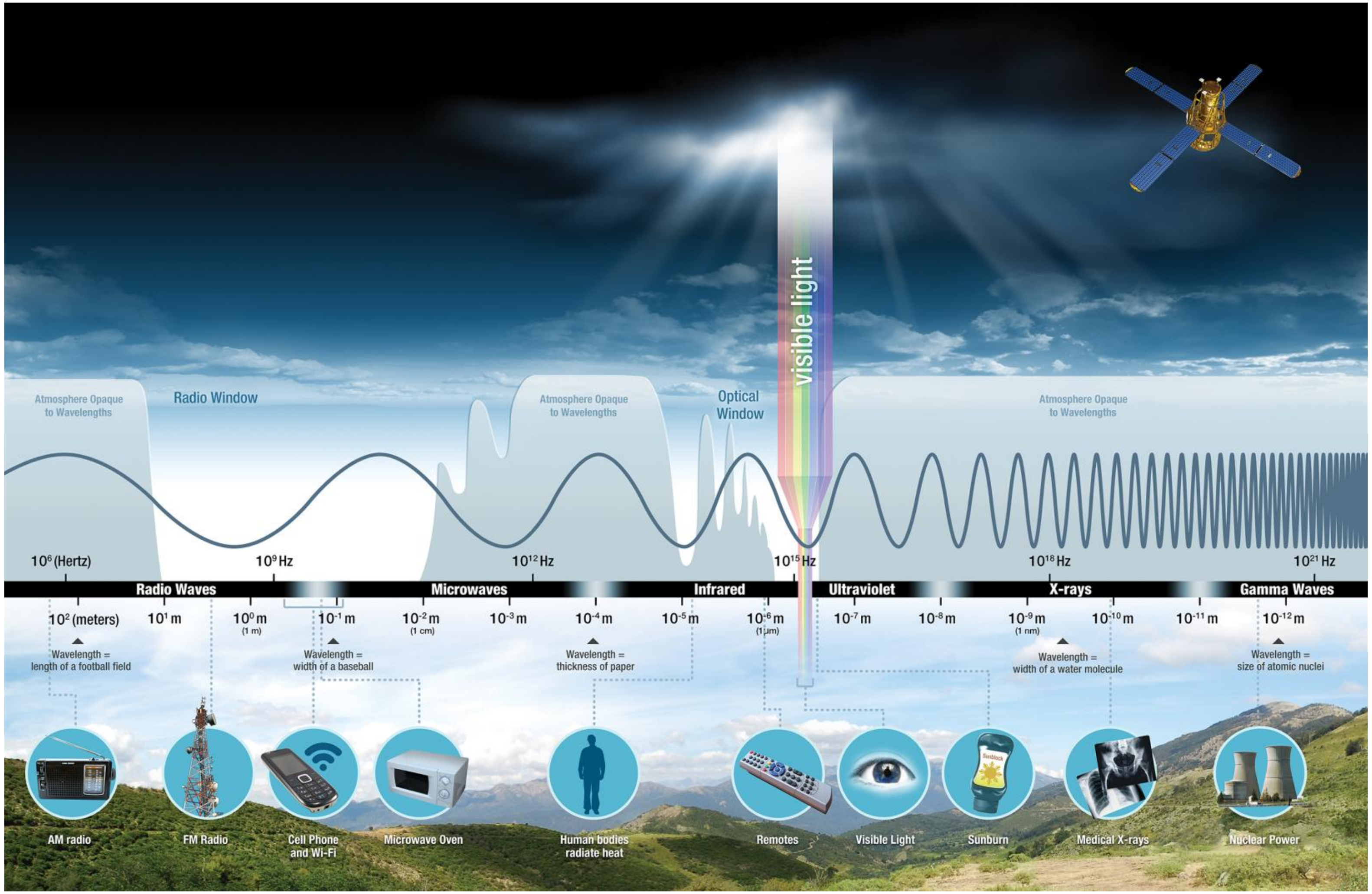
Optical sensors, multispectral and hyperspectral imaging

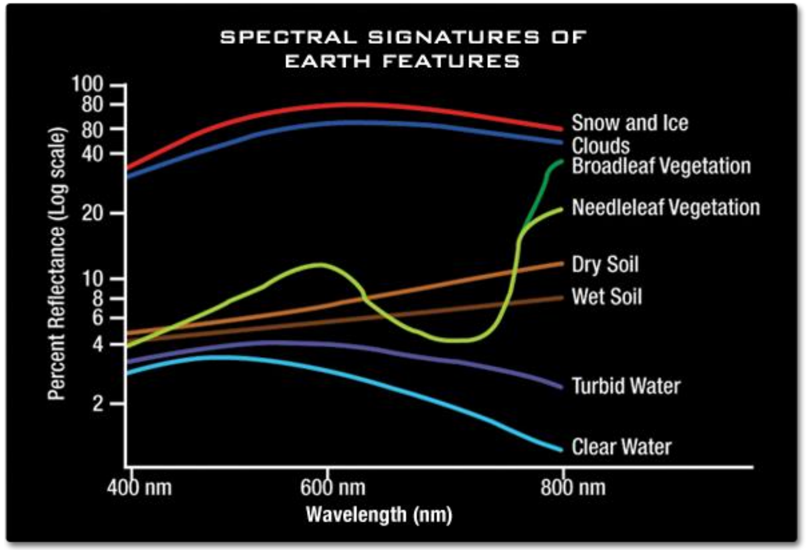
LiDAR (Light Detection and Ranging), RADAR (Radio Detection and Ranging)

https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing

Remote Sensing Technologies

Electromagnetic Spectrum in Remote Sensing





https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing

Remote Sensing in Agriculture

- U.S. Department of Agriculture (USDA)-Agricultural Research Service (ARS) and NASA formally began remote sensing research in 1965.
- To characterize the reflectance and emission signatures of different land covers (crops and range)
- Led to the design of the first sensors carried on **Landsat 1** (originally named Earth Resources Satellite-1)
- Sensor: **Multispectral Scanner (MSS)**
- Spectral range: **0.5 – 1.1 µm** (green, red, and two infrared bands)

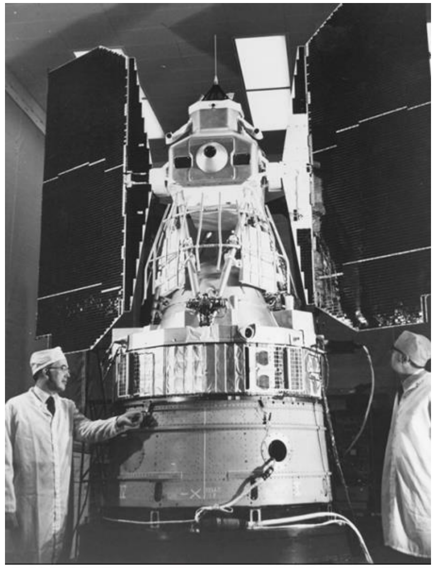


Image Credit: NASA

NASA's Applied Remote Sensing Training Program

Remote Sensing Technologies

Satellites & Sensors for Agricultural Applications

Satellite	Sensor	Scientific Products						
		Land Surface Reflectance	Evapotranspiration	Land Surface Temperature	Precipitation	Soil Moisture	Vegetation Greenness	Structure
Terra	MODIS	X	X	X			X	
Aqua	MODIS	X	X	X			X	
Suomi-NPP	VIIRS	X		X			X	
NOAA-20	VIIRS	X		X			X	
Landsat 8	OLI	X					X	
Sentinel 2	MSI	X					X	
Landsat 8 & Sentinel 2	HLS	X					X	
International Space Station	ECOSTRESS		X					
Land Data Assimilation System	Modeled output		X			X		
Global Precipitation Measurement	GMI, DPR				X			
CHIRPS	Multiple				X			
Soil Moisture Active Passive	L-band radar					X		
Sentinel 1	C-band radar							X

[Applied Remote Sensing Training Program | NASA Applied Sciences]

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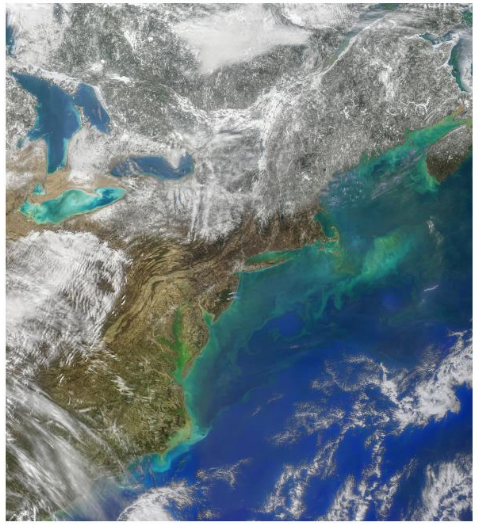
Satellites & Sensors for Land Surface Reflectance - MODIS

- Moderate Resolution Imaging Spectroradiometer (MODIS)
- Provide an estimate of surface spectral reflectance as measured at ground level by accounting for atmospheric effects like aerosol scattering and thin clouds
- Useful for measuring the greenness of vegetation

- **Spatial Resolution**: 250 m, 500 m, 1 km
- **Spectral Resolution**: 36 bands, ranging in wavelengths from 0.4 µm to 14.4 µm
- **Temporal Resolution**: Daily, 8-day, 16-day,monthly, yearly



MODIS composite of the eastern U.S. captured on February 23, 2020 by NASA's Aqua satellite.
Image credit: NASA Earth Observatory

Three moments in a tumultuous year for farming north of St. Louis, MO, as seen in NASA-USGS Landsat 8 data. On the left is May 7, 2019, as heavy rains delayed planting for many farms. Sept 12, 2019, in the middle, shows bright green signifying growing vegetation, although with a fair amount of brown, bare fields. On the right, Oct. 14, 2019, the light brown indicates harvested fields while darker brown are fields that have not been seeded or fallow all summer.
Image Credit: NASA-USGS Landsat

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Remote Sensing Technologies

Satellites & Sensors for Land Surface Reflectance –Landsat 8

- Launched on February 11, 2013
- Instruments: Operational Land Imager (OLI)
  Thermal Infrared Sensor (TIRS)
- Spatial Resolution: 30 m
- Spectral Resolution: 9 bands ranging in wavelengths from 430 nm to 2290 nm
- Temporal Resolution: 16 days

Landsat 8 OLI image captured on September 9, 2013 showing the border between Kazakhstan and China
Image Credit: NASA Earth Observatory

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Remote Sensing Technologies

Satellites & Sensors for Evapotranspiration - MODIS

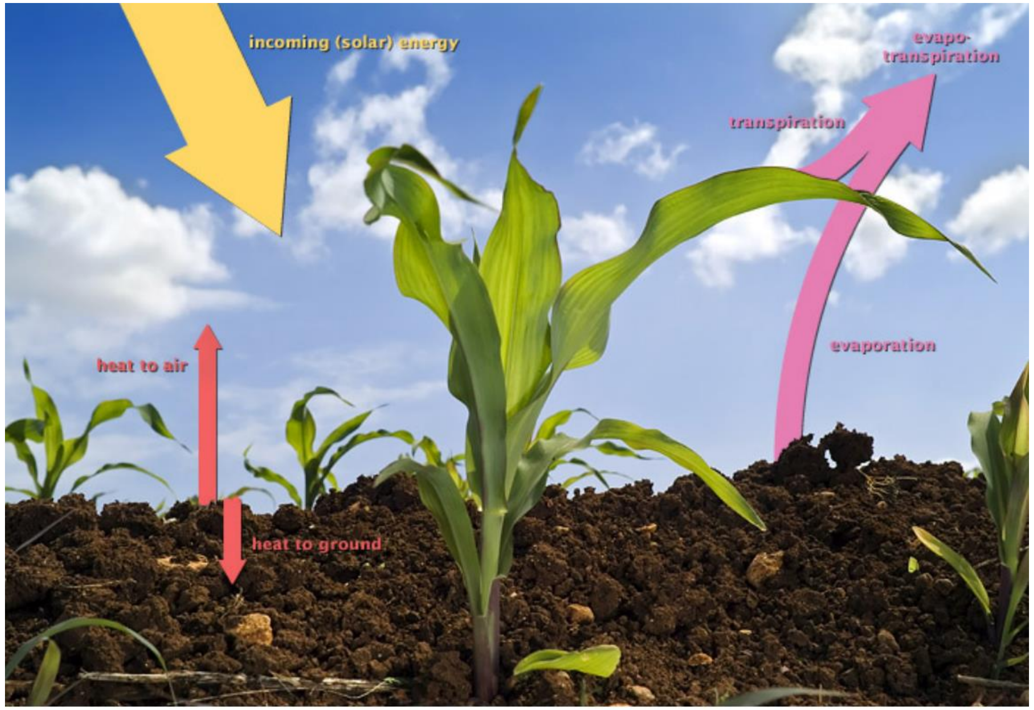
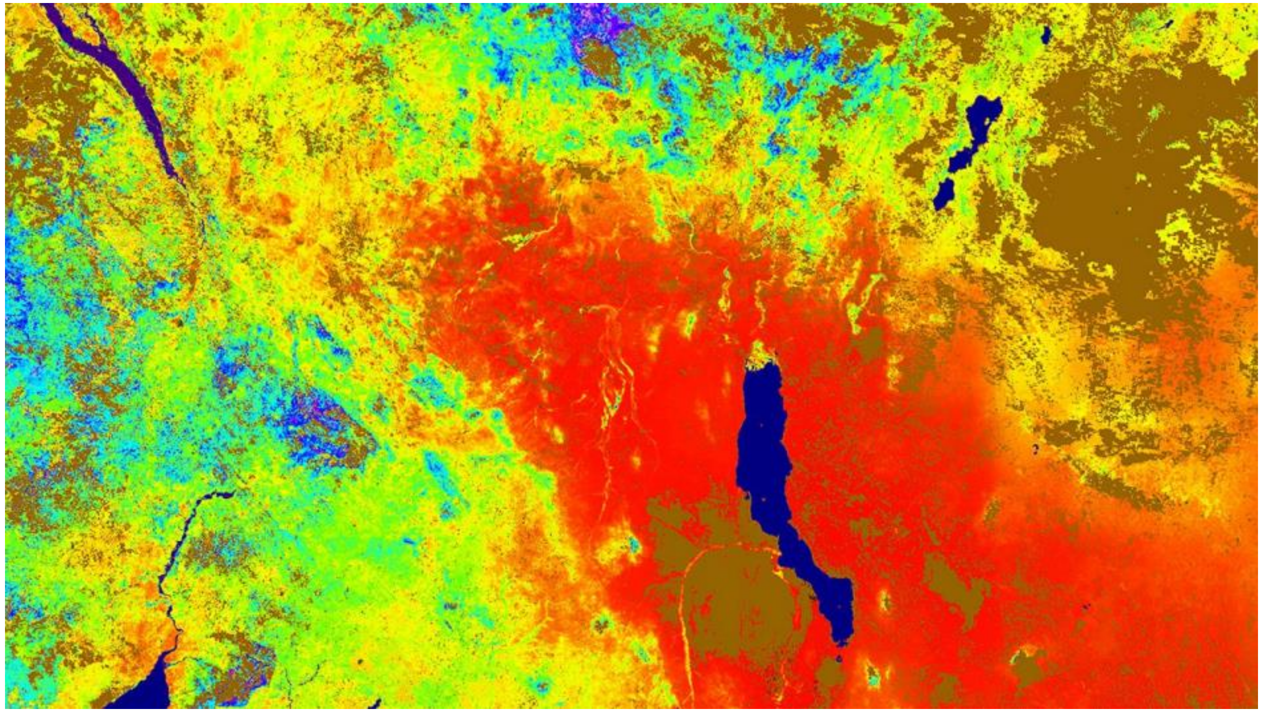


Image Credit: NASA



- MOD16: Level 4
- Evapotranspiration/Latent Heat Flux
- Temporal resolution: 8-day, yearly intervals
- Spatial Resolution: 500 m

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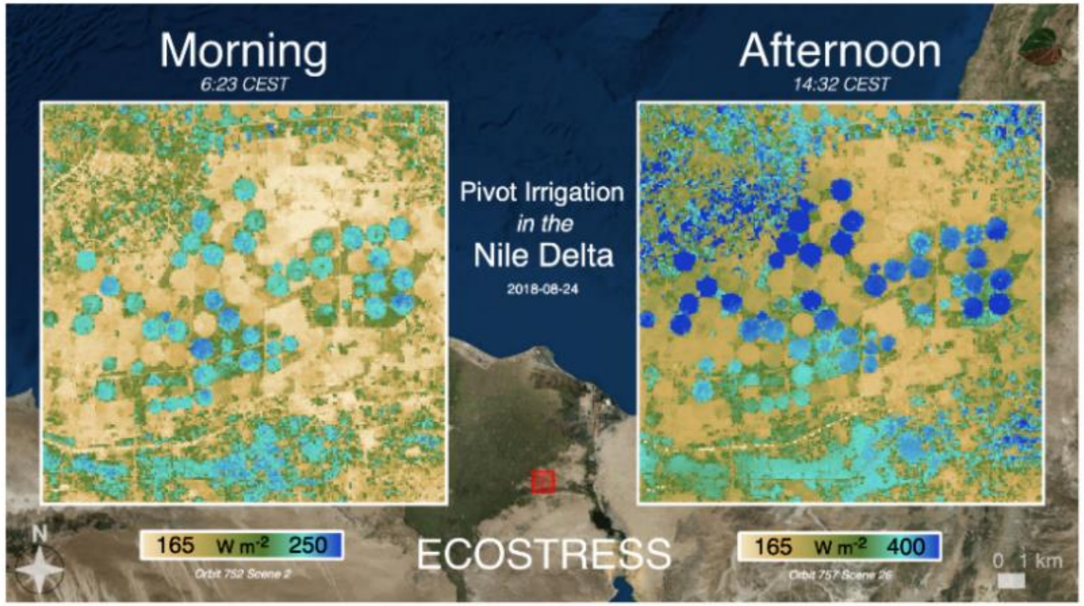
Remote Sensing Technologies

Satellites & Sensors for Land Surface Reflectance –ECOSTRESS

- ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)
- Instrument mounted to the International Space Station (ISS)
- Measures **agricultural water consumption** over continental U.S. (CONUS) at spatio-temporal scales **for drought estimation**



NASA's ECOSTRESS imaged the Nile Delta, Egypt on August 24, 2018. ECOSTRESS captured changes in evapotranspiration from agricultural fields within the same day. The image on the left is from 6:23 CEST, and the image on the right is from 14:32 CEST. Much more ET is shown in the afternoon image (blue colors), though there are larger differences between the fields than in the morning.
Credit: Simon Hook, NASA

NASA’s Applied Remote Sensing Training Program

Remote Sensing Technologies

Satellites & Sensors for Soil Moisture - SMAP

- Soil Moisture Active Passive (SMAP)
- Spatial Resolution: 9 km
- Temporal Resolution: 3-hourly, Daily

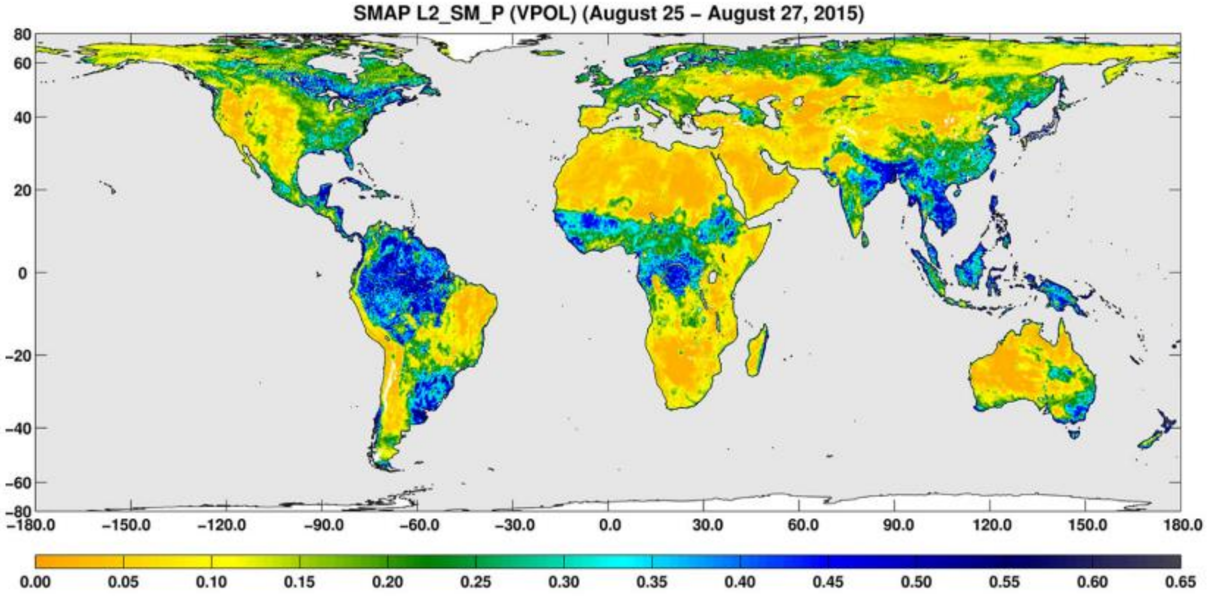
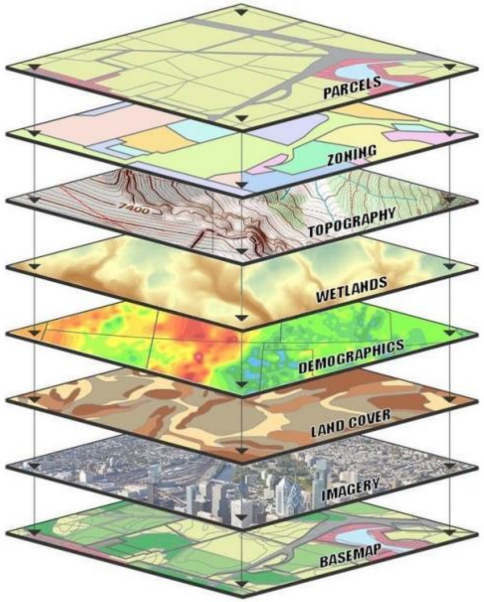


Image Credit: NASA

NASA's Applied Remote Sensing Training Program

Geographic Information System (GIS)

- Any framework for gathering, managing, and analyzing geospatial data
- Any discipline that uses maps uses GIS
- **Spatial Data** - Any data with a spatial component
- Examples of Spatial Data: GPS, satellite imagery, weather data, etc.
- GIS Data is organized into layers



https://www.wiu.edu/SevereWeather/images/presentations/GIS_Presentation.pdf

Geographic Information System (GIS)

GIS in Agriculture

- GIS **integrates various data layers**, such as soil types, crop health, weather conditions, and topography, to support decision-making in precision agriculture.
- GIS helps in mapping different crops within a field, **identifying zones with similar characteristics**, and monitoring crop health.
- GIS allows farmers to **manage specific areas of their fields** based on the unique conditions of each zone. For example, areas with poor soil quality can be identified and treated accordingly.

https://eos.com/blog/gis-in-agriculture/

Next Lecture

Sensing Technologies for Precision Farming I