Course: Introduction to Digital Agro
Lead instructor: Dr. Maria Pukalchik
Lecture: 08

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Remote sensing in Earth environmental monitoring

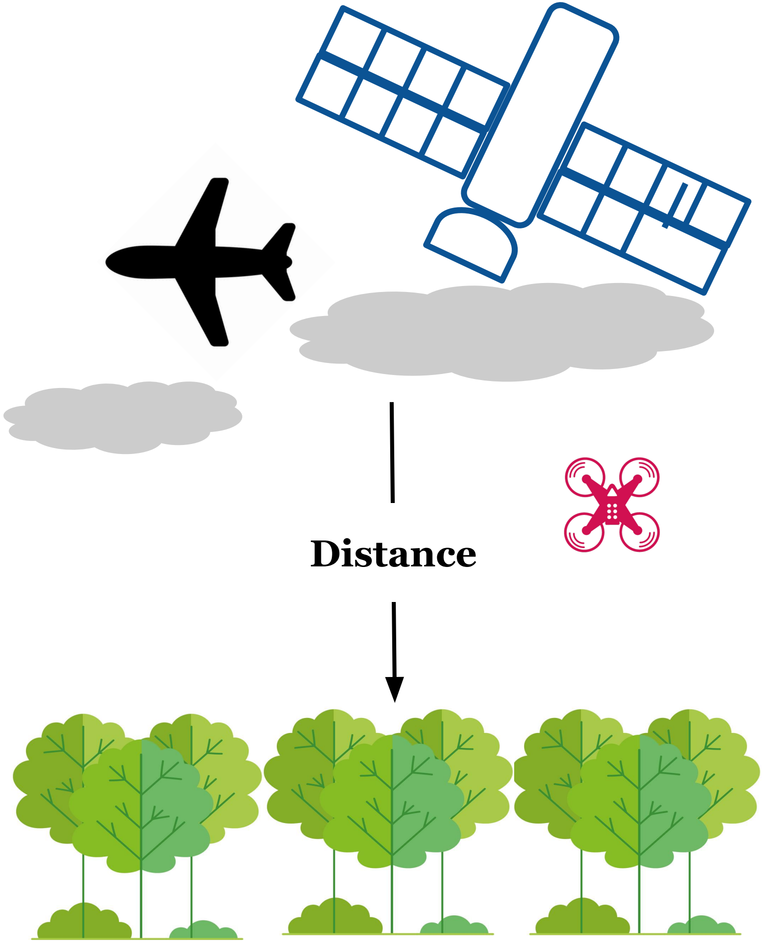
Plan of the lecture

1. What is remote sensing?
2. Remote sensed data (RSD): types and details, basic ideas, sources
3. Remote sensing in agriculture and environmental issues: tasks and tools
4. Remote sensing in forestry

What is remote sensing?

“In the broadest sense, the measurement or acquisition of information of some property of an object or phenomena, by a recording device that is not in physical contact with the object or phenomenon under study; e.g., the utilization at a distance (as from aircraft, spacecraft, or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, magnetometers, and scintillation counters”

by American Society for Photogrammetry and Remote Sensing



Platforms for remote sensing

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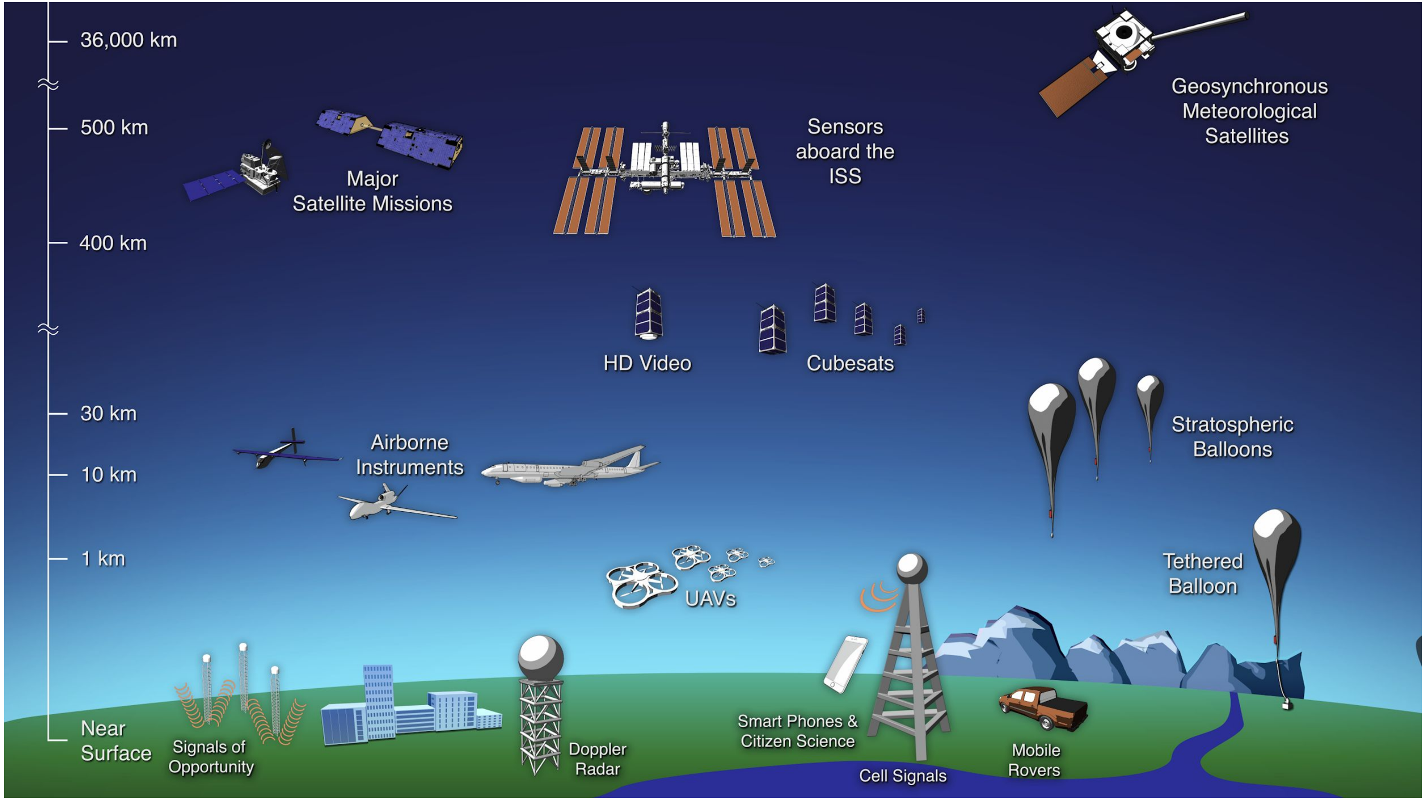
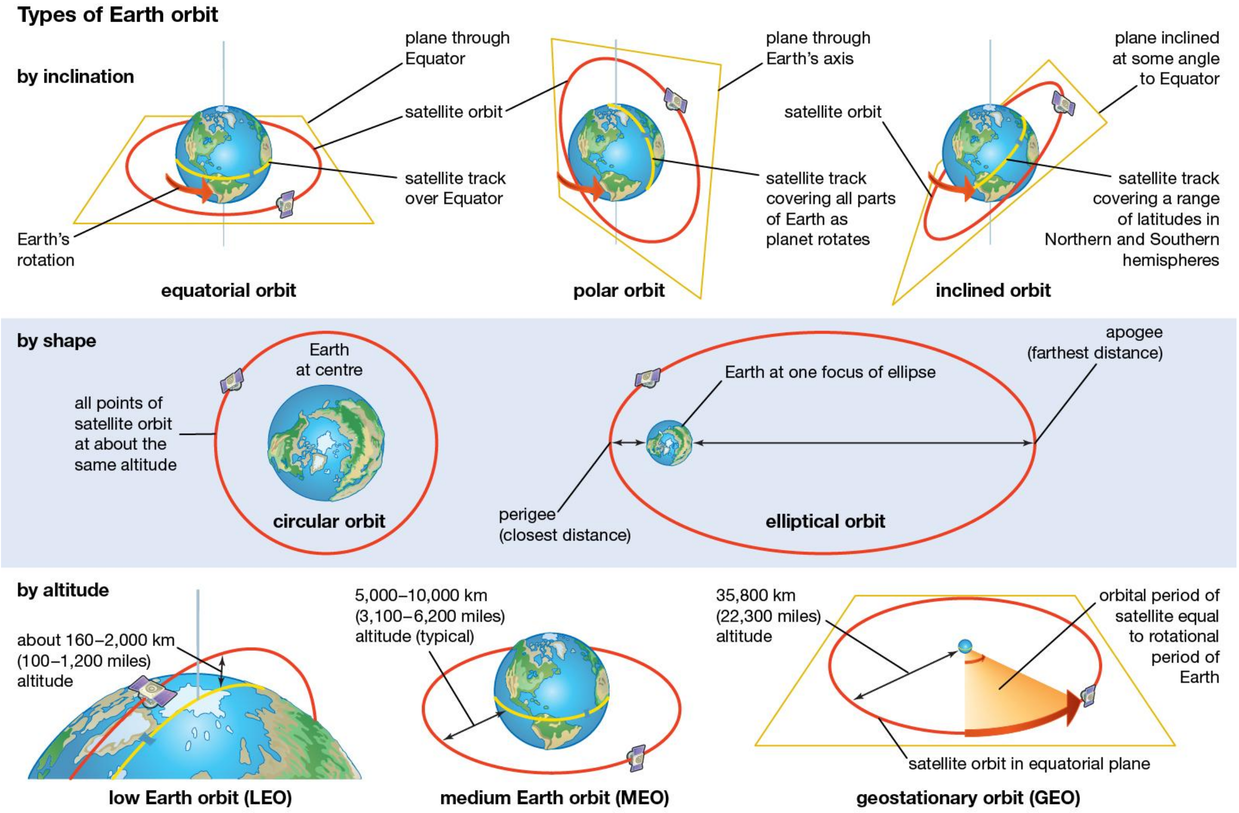


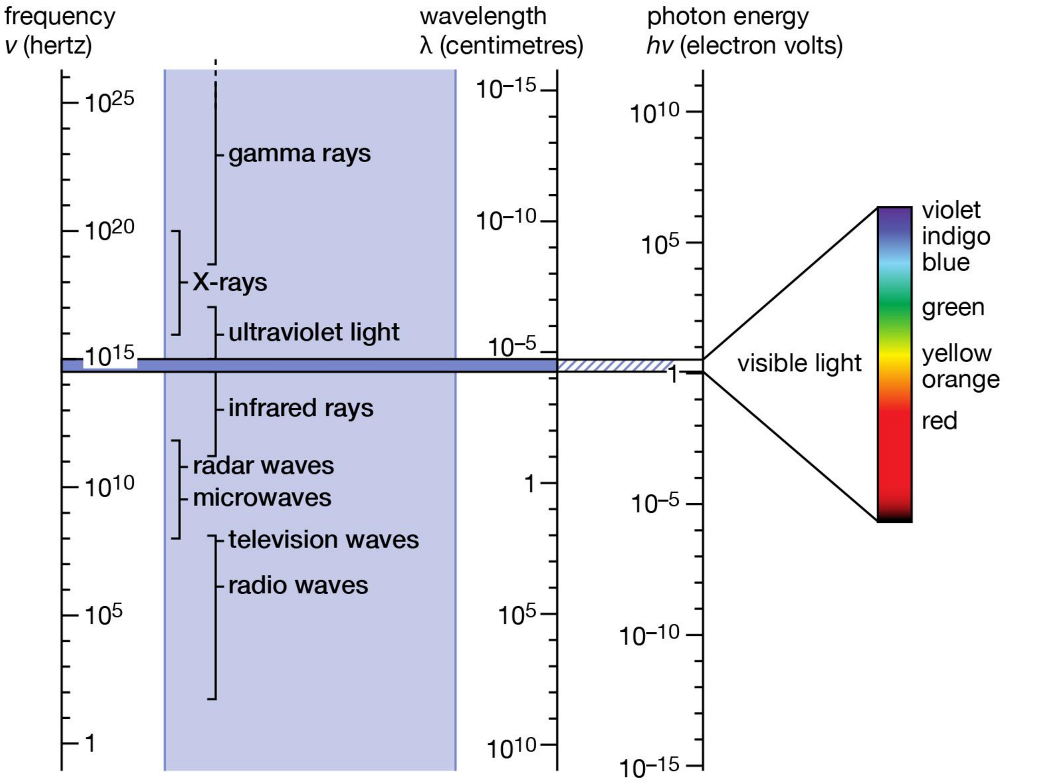
Picture source NASA's Applied Remote Sensing Training Program

Types and examples of satellites/sensors

- Source type: active sensors (e.g. radar,lidar, sonar) and passive sensors (e.g. microwave, visible, near-infrared, infrared);
- Orbit type (most common -- polar and geostationary);
- Type of spectra;
- Measurement techniques.



Principles of remote sensing



<u>Basic assumption:</u> specific study targets (different types of soils, water having different degrees of impurities, rocks of different lithologies, or vegetation of various species) have an <u>individual and characteristic</u> manner of interacting with incident radiation that is described by the <u>spectral response of that study target</u>.

The levels of reflection and absorption of each object on the earth’s surface vary and each object uniquely interacts with the electromagnetic energy.
Changes in how <u>surface</u> (mostly) objects behave under different EM energy spectra can be linked to the characteristics of objects.

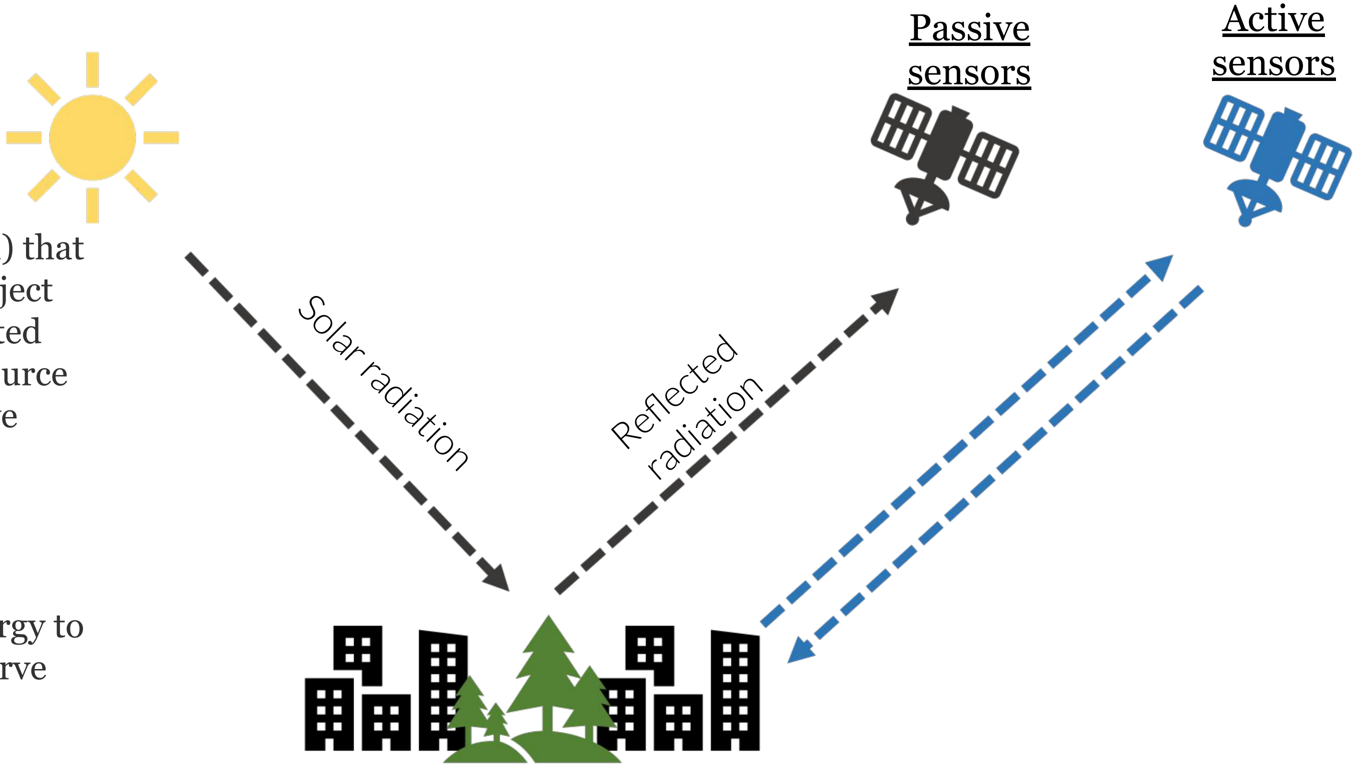
Types of energy source: create or not create

Passive sensors:

detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Reflected sunlight is the most common source of radiation measured by passive sensors.

Active sensors:

provide their own source of energy to illuminate the objects they observe



active sensors (e.g. radar and lidar)
passive sensors (e.g. microwave, visible, near-infrared, infrared)

Passive sensors vs active sensors

	Advantages	Limitations
Active	Weather independent: artificial microwave radiation can penetrate clouds, light rain and snow. Sunlight independent: can be operated day and night. Radar penetrates vegetation and soil: can gain information about surface layer from mm to m depth.	The pulse power is mostly low and can be influenced or interfered by other radiation sources. Complicated analysis, cost-intensive.
Passive	Optical data are easy to use for visual interpretation, as the images represent Earth's surface the same way as the human eye views Earth. This type of imagery has been available since the 1970s, and well-established processing algorithms are available for automated feature extraction and classification.	Require the sun's illumination for imaging sensors feature specific wavelength sensitivity, acquisitions with an optical instrument are separated into several images, depending on the mode cloud coverage can hamper image collection, as the sunlight is reflected by the clouds and recorded by the sensors.

Radiation and the Earth

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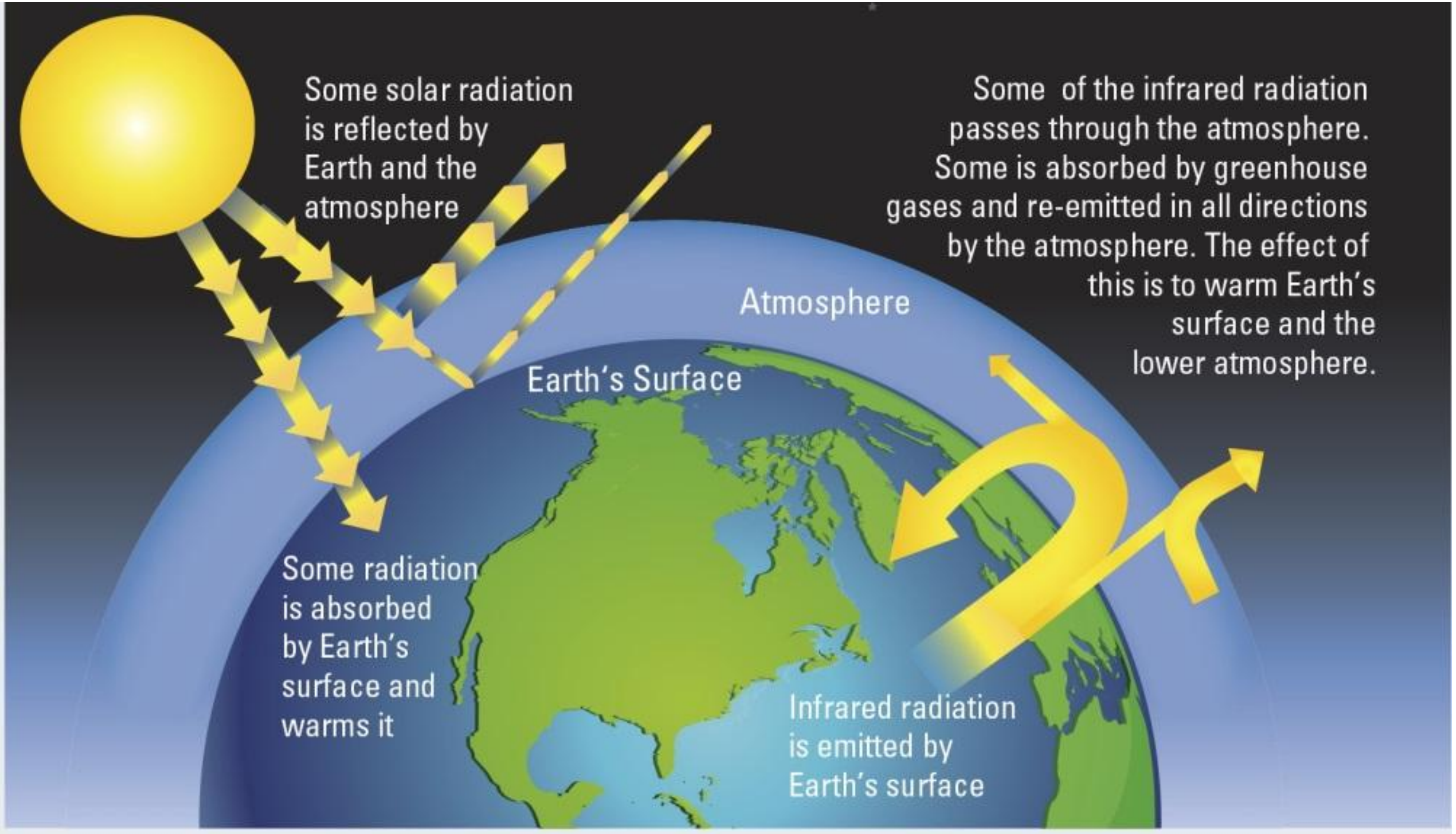
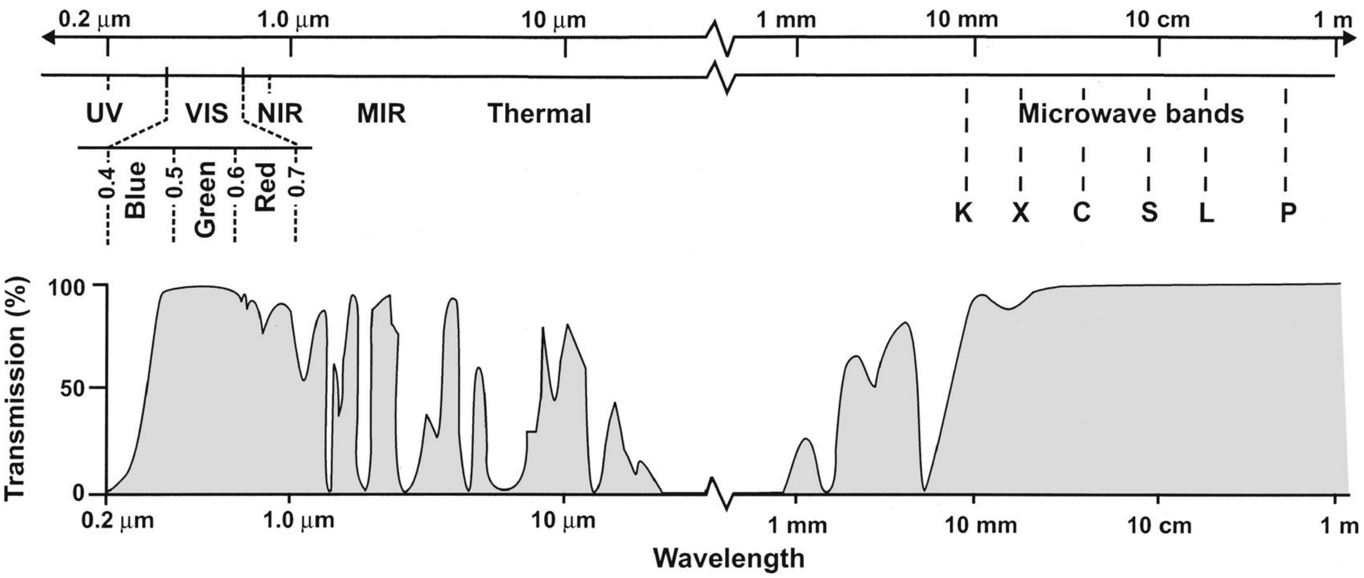


Basics of remote sensing (I)

General statements:

- Earth atmosphere **absorb** or **reflect** most of the solar radiation. **Greenhouse gases in the atmosphere (such as water vapor and carbon dioxide) ***absorb*** most of the Earth's emitted radiation. This keeps our planet generally warm and comfortable.*
- An atmospheric window is the portion of the electromagnetic spectrum that can be transmitted through the atmosphere. Atmospheric transmittance is an opposite to the atmosphere absorption and opacity.



Basics of remote sensing (II)

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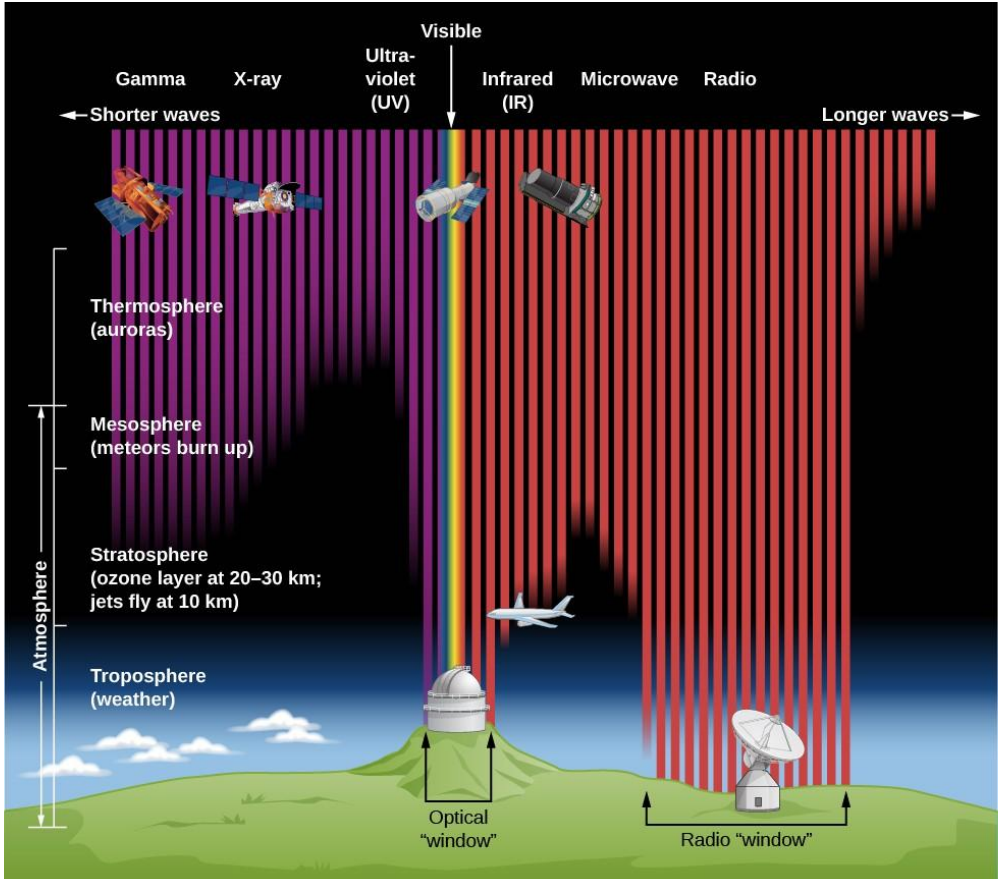
- <u>Most remote sensing systems are designed to collect reflected radiation</u>.
- Most remote sensing instruments on aircraft or space-based platforms operate in one or more of these windows by making their measurements with detectors tuned to specific frequencies that pass through the atmosphere.

**Some sensors, especially those on meteorological satellites, directly measure absorption phenomena, such as those associated with carbon dioxide (CO_2) and other gases.*

**Weather radars are able to detect clouds and precipitation because they are tuned to observe backscattered radiation from liquid and ice particles).*



Chandra mission website and Space Telescope Science Institute

Resolution and accuracy

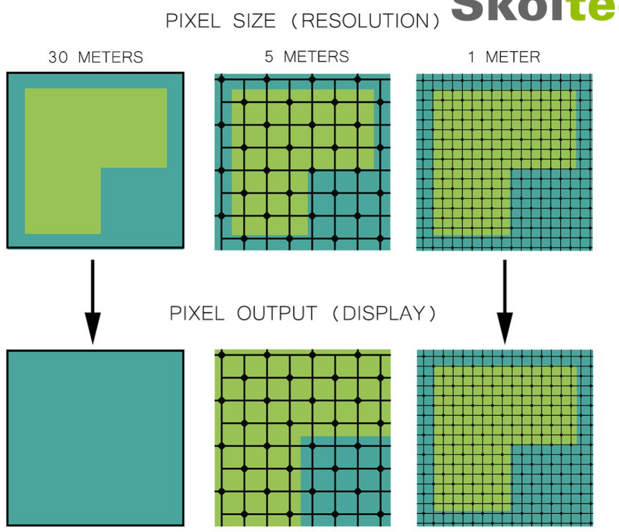
- **Spatial Resolution** : smallest size an object or detail can be represented in an image
- **Temporal Resolution** : period of measurement
- **Spectral Resolution** : number of independent channels

Accuracy – the distance between the actual geographic location of an object or detail compared to the position of the object in the image.
Accuracy depends on:

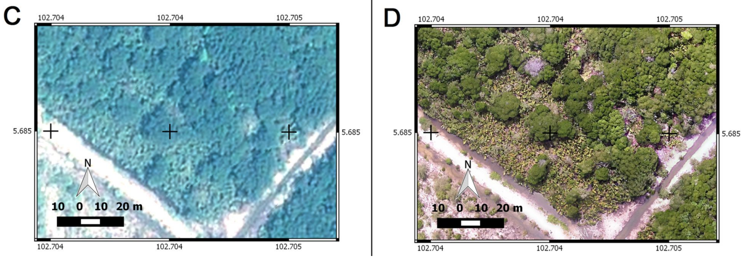
- satellite positioning technology and sensor viewing angle ;
- terrain relief.

Resolution does not affect accuracy.

Basic assumptions for accuracy: 1) the sensor on the satellite is looking straight down at the earth; 2) topography is flat.



The more pixels an image has, the more detailed it is.



Satellite resolution

UAV resolution

Spectral resolution of RSD, bands

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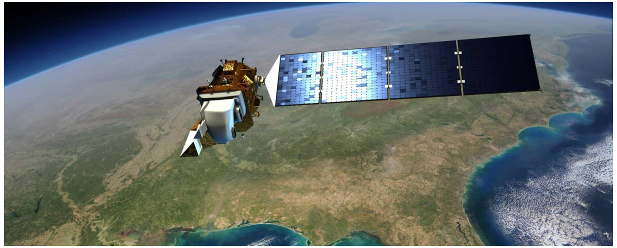
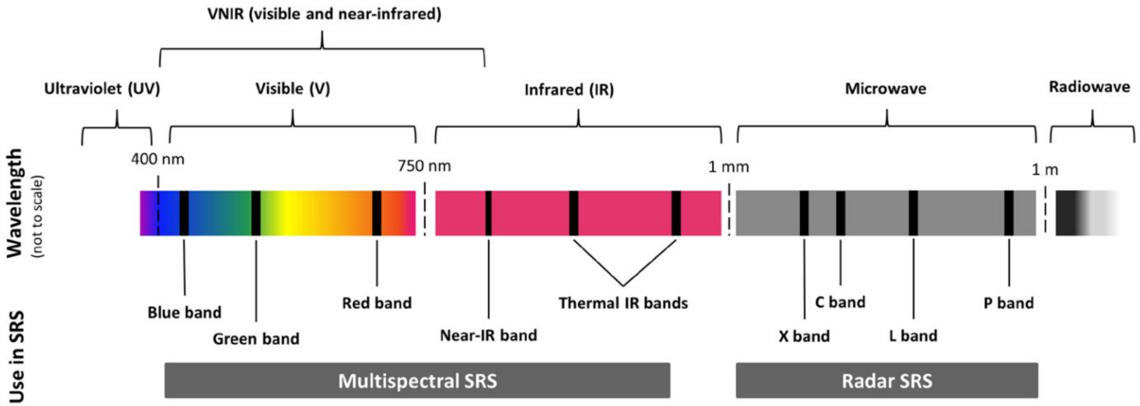
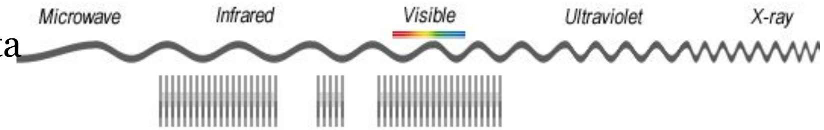
Each and every object has its own chemical composition. This is the equivalent to saying that each composition has its own spectral signature. RS captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or detected via the use of instruments that are sensitive to particular wavelengths. A **band** represents a segment of the electromagnetic spectrum.



Sensor	Spectral Band	Use Area	Wavelength
OLI	Band 1	Coastal/Aerosol	0.433 – 0.453 µm
OLI	Band 2	Blue	0.450 – 0.515 µm
OLI	Band 3	Green	0.525 – 0.600 µm
OLI	Band 4	Red	0.630 – 0.680 µm
OLI	Band 5	Near Infrared	0.845 – 0.885 µm
OLI	Band 6	Short Wavelength Infrared (SWIR 1)	1.560 – 1.660 µm
OLI	Band 7	Short Wavelength Infrared (SWIR 2)	2.100 – 2.300 µm
OLI	Band 8	Panchromatic	0.500 – 0.680 µm
OLI	Band 9	Cirrus (SWIR)	1.360 – 1.390 µm
TIRS	Band 10	Long Wavelength Infrared	10.30 – 11.30 µm
TIRS	Band 11	Long Wavelength Infrared	11.50 – 12.50 µm



Hyperspectral data



Most popular satellites' platforms

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Name of system or mission	Launched	Type of sensor	Spatial resolution	Grounding Track Repeat Cycle	Type of data
MODIS (Moderate Resolution Imaging Spectroradiometer)	1999	Passive	2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km	1-2 days	Provide measurements in large-scale global dynamics including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere.
ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	1999	Passive	15, 30, 90 m	16 days	14 bands of information of VNIR (Visible Near Infrared), SWIR (ShortWave Infrared), TIR(Thermal Infrared) to measures surface radiance, reflectance, emissivity, and temperature.
SRTM (Shuttle Radar Topography Mission)	2000	Radar (Active Sensor)	30 m	-	High-resolution digital elevation model (DEM) topographic data.
Landsat missions	1972 (!!)	Passive (Radiometer)	15 to 60 m	16 days	Multispectral high-resolution imaging information of the Earth's surface. It detects spectrally-filtered radiation in VNIR, SWIR, LWIR and panchromatic bands.
Sentinel	**2015**	**Both**	**10, 20 or 60 m**	**5 days**	**Sea-level change & sea-surface temperature, sea-ice extent and thickness mapping, land-cover, Earth's thermal radiation for atmospheric applications; water resource; wildfire detection; numerical weather prediction**

Band combinations and indices

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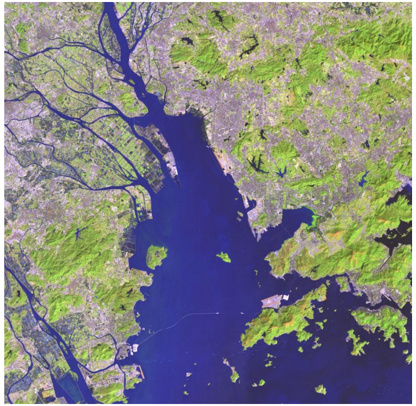
Name/Index	Interpretation	Bands combination
True Color	Colours of the resulting colour composite image resemble closely what would be observed by the human eyes	Red, Green, Blue
False color (urban)	False colour composite scheme allows vegetation to be detected readily in the image. In this type of false colour composite images, vegetation appears in different shades of red depending on the types and conditions of the vegetation, since it has a high reflectance in the NIR band	NIR, Red, Green/ SWIR, NIR, Red
NDVI	NDVI is highly associated with vegetation content. High NDVI values correspond to areas that reflect more in the near-infrared spectrum. Higher reflectance in the near-infrared correspond to denser and healthier vegetation.	(NIR - Red)/(NIR + Red)

Band combinations (to highlight)

True color

False color
(Urban)

Vegetation



Agriculture

http://www.geocarto.com.hk/edu/PJ-BCMBLSAT/main_BCLS.html

Band combinations and indices

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Name/Index	Interpretation	Bands combination
Agriculture	Commonly used for crop monitoring because of the use of short-wave and near infrared. Healthy vegetation appears dark green. Bare earth is red.	SWIR, NIR, Blue
Bare Soil Index	Identification of bare soil areas / fallow lands	(Green + NIR)/(Green - NIR)
Moisture index	Index shows the "amount" of moisture content. Water appears as blue with lighter shades containing less moisture. Finally, bright orange and red have significantly lower moisture content.	(NIR-SWIR1)/(NIR+SWIR1)
Normalized Difference Water Index	For surface water mapping	(SWIR1+Red) +(NIR+Blue)/(SWIR1+Red) - (NIR+Blue)

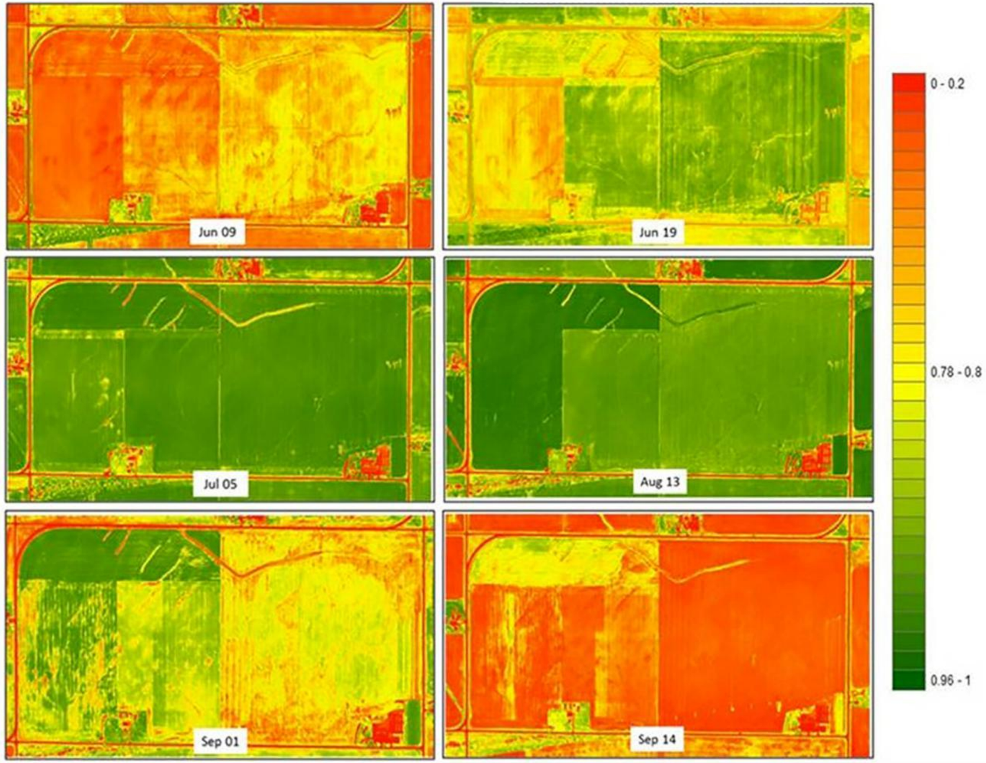
NDVI example (stages of plant growth <u>or not</u>)

<u>Option 1</u>

or

<u>Option 2</u>

No plant



Remote sensing and environmental issues

Overall usefulness

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Remote sensing applications

Atmospheric

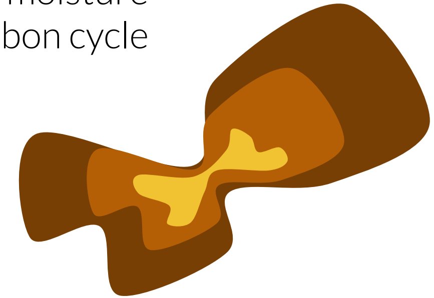
Temperature and water vapor
Aerosols and clouds Atmospheric constituents Greenhouse gases

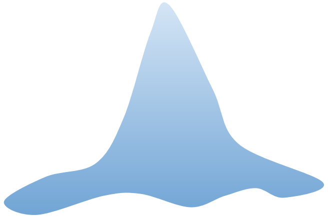
Oceanic/water

Surface temperature
Surface salinity/chemical composition
Surface wind
Surface height
Color

Land Applications

Topography
Geometric corrections and map Projection
Land cover and land use Geological applications
Soil moisture
Carbon cycle





Cryospheric

Sea Ice
Snow and glaciers

J.N. Pelton, S. Madry, S. Camacho-Lara (eds.), Handbook of Satellite Applications

Remote sensing applications in natural resources management

Land cover analysis: distribution of land-use types, detection of land-use change
Determination of carbon stock
Stratification of productivity zones

Land management

Forest monitoring, tree detection for inventory purposes
Distribution of timber resources
Detection of human-caused disturbances of nature
Determination of areas with plant stress due to abiotic and biotic factors
Fire threat, detection and observation

Forest management

Surface water quantity
Surface water quality

Water management

Fire! Fire!

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Each year around 340 million hectares of the Earth's vegetated surface burns

"NASA provides data that can be used to detect active fires and thermal anomalies, such as volcanoes, and gas flares.
These data are useful for studying the spatial and temporal distribution of fire, to locate persistent hot spots such as volcanoes and gas flares, and to locate the source of air pollution from smoke that may have adverse human health impacts"

FIRMS


FIRMS
Fire Information for Resource Management System
Feedback
Fires: Aug 06 2019
Arctic Ocean
EUROPE
ASIA
North Atlantic Ocean
AFRICA
SOUTH AMERICA
South Atlantic Ocean
Indian Ocean
AUSTRALIA
Quick View
Advanced
Burned Area
Aug 06 2019
1 day
Combined (NRT + SP)
VIIRS 375m / NOAA-20
VIIRS 375m / Suomi NPP
MODIS / Aqua
MODIS / Terra
Near Real-Time (NRT)
VIIRS 375m / NOAA-20
VIIRS 375m / Suomi NPP
MODIS / Aqua
MODIS / Terra
Standard Processing (SP)
VIIRS 375m / Suomi NPP
MODIS / Aqua
MODIS / Terra
Gridded Fire Hotspots
VIIRS 375m / S-NPP
Orbit Tracks and Overpass Times
ИЮЛЬ 2019
АВГУСТ 2019
AUG 06 2019
1 day
PAN
IDENTIFY
MEASURE
LAYERS
TIMELINE
MAXIMIZE
SHARE
SCREENSHOT
HELP
NASA Official: Ed Masuoka
Web Privacy Policy
Data & Information Policy
Communications Policy
Freedom of Information Act
USA.gov

Remote sensing applications in natural resources management: examples. Forest and fire.

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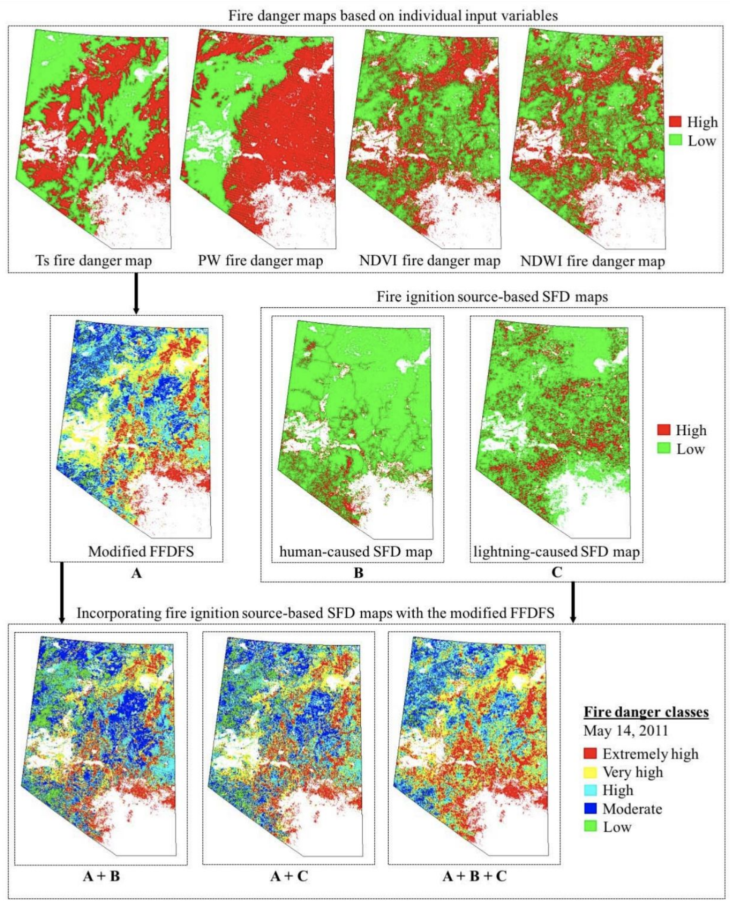
Objective: to enhance the existing forest fire danger forecasting system (FFDFS), and its implementation over the northern region of the Canadian province of Alberta.

Tools:

- Modification of FFDFS by Moderate Resolution Imaging Spectroradiometer (MODIS)-derived daily surface temperature (Ts) and precipitable water (PW), and 8-day composite of normalized difference vegetation index (NDVI) and normalized difference water index (NDWI).
- Generation ignition (appearance) cause-specific static fire danger (SFD) maps derived using the historical human- and lightning-caused fires during the period 1961–2014.
- Performance of these maps was evaluated against actual fire spots during the 2009–2011 fire seasons.



Results:

- Improved capture of fires, derived by classes of danger

Abdollahi M. et al., An advanced forest fire danger forecasting system: Integration of remote sensing and historical sources of ignition data. Remote Sensing. 2018 Jun;10(6):923.

Remote sensing applications in natural resources management: examples. Forest/climate change.

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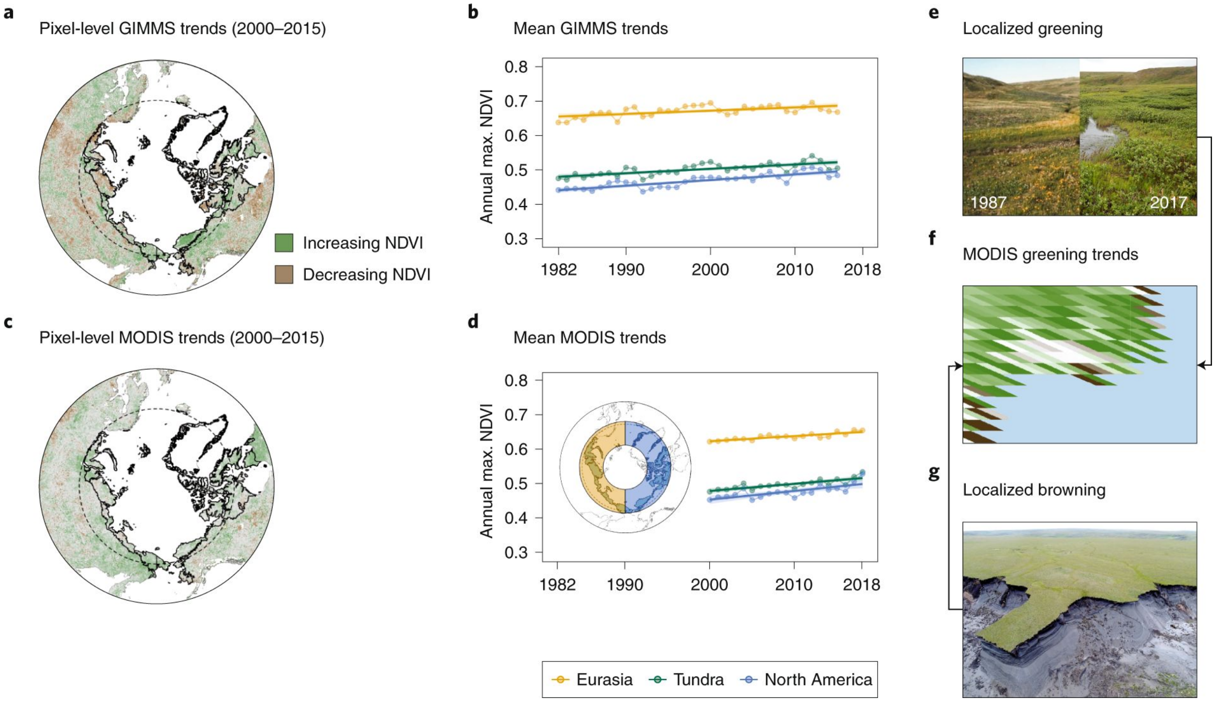
- Satellite measures indicate widespread greening at high latitudes.
- ‘Greening of the Arctic’ is among the world’s most important large-scale ecological responses to global climate change.
- Consensus is emerging that the underlying causes and future dynamics of so-called Arctic greening and browning trends are complex.



Myers-Smith, I.H., Kerby, J.T., Phoenix, G.K. et al. Complexity revealed in the greening of the Arctic. Nat. Clim. Chang. 10, 106–117 (2020).

Remote sensing applications in natural resources management: examples. Water.

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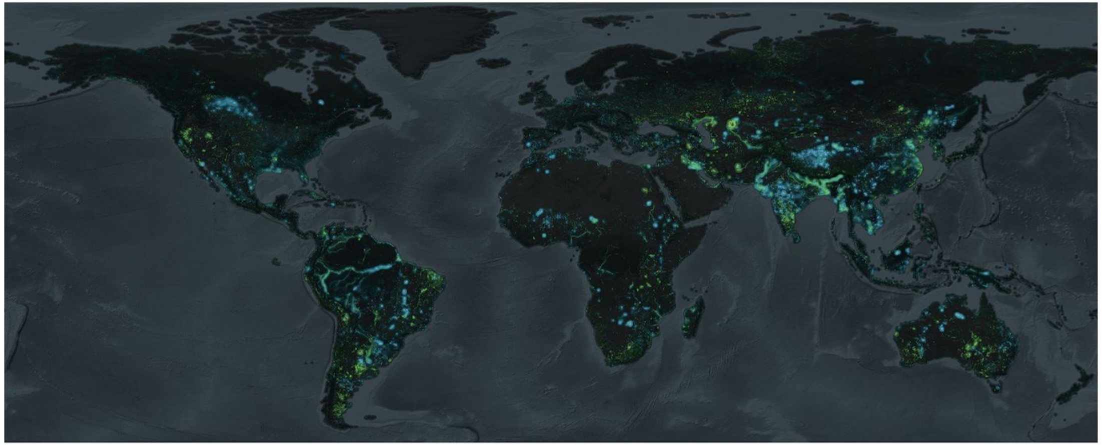
Objective: to demonstrate the planetary-scale ability of the Aqua Monitor by showing some significant and contrasting water–land conversions.

Tools:

- The Deltares Aqua Monitor (http://aqua-monitor.deltares.nl) is the first global-scale tool that shows at 30-m resolution where water is converted to land and vice versa.
- With assistance from Google Earth Engine, it analyses satellite imagery from multiple Landsat missions, which observed Earth for more than three decades on the fly.

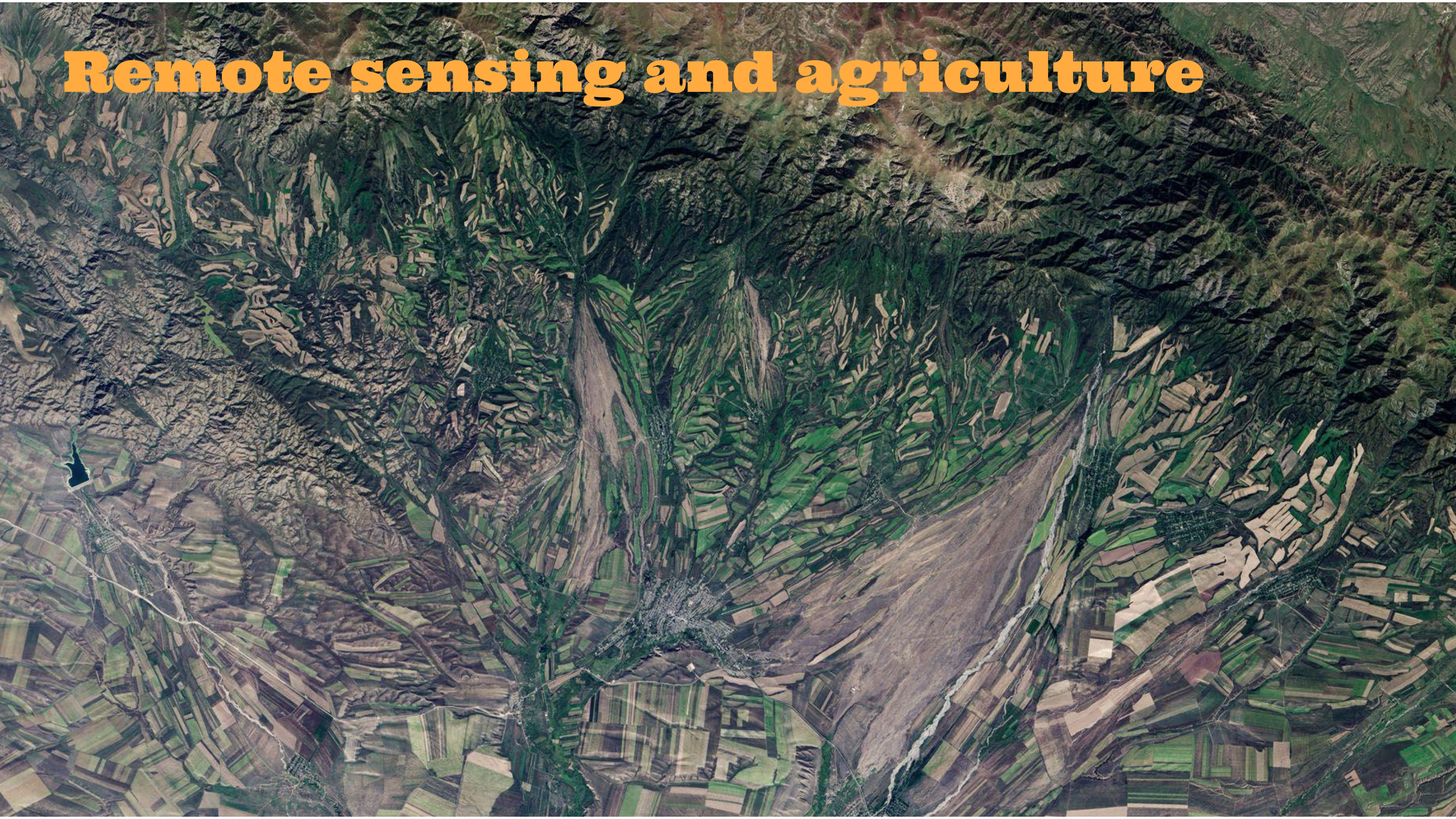
Results:
Big satellite data analytics at anyone's fingertips, may have strong implications on monitoring capacities and associated actions.



Blue lighting shows where land was converted into water over the period 1985–2015. Green lighting shows where water was converted into land over the same period. The intensity of the colours highlights the spatial magnitude of the change.

Donchyts, G., Baart, F., Winsemius, H. et al. Earth's surface water change over the past 30 years. Nature Clim Change 6, 810–813 (2016). https://doi.org/10.1038/nclimate3111

Remote sensing and agriculture



Remote sensing most common tasks: agriculture

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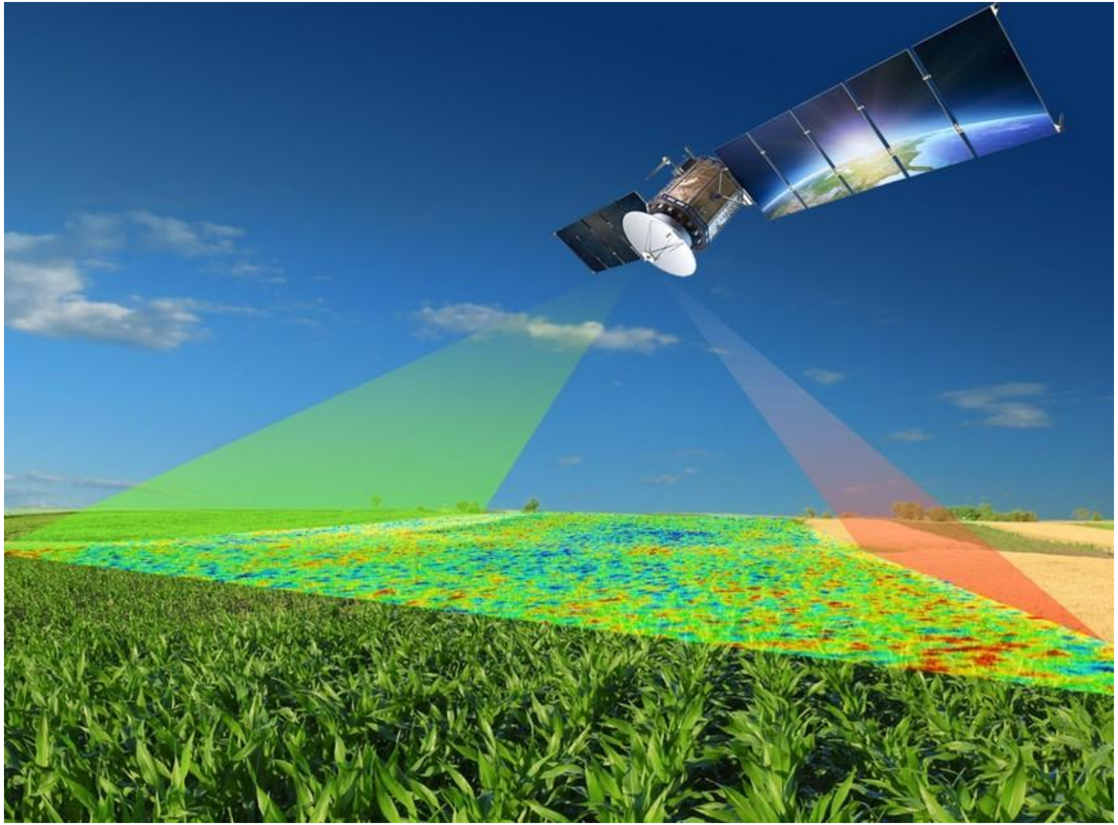
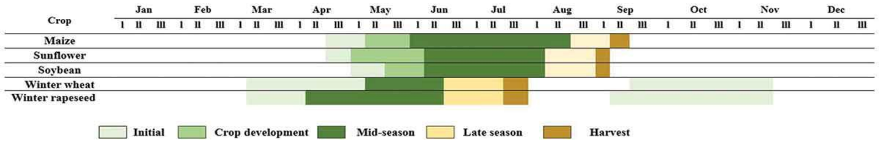
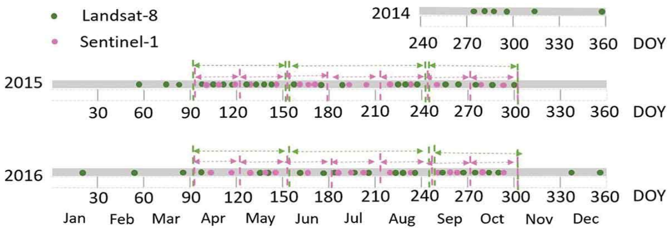
1. Phenotyping:
   - Identifying crops;
   - crop damage and crop progress;
   - stress detection;
   - disease detection.
2. Land use monitoring and ecosystem services
3. **Forecasting crop production*
4. Precision in farming;
5. Inventory tasks.



Remote sensing applications in agriculture: examples. Crop recognition.





Objective:

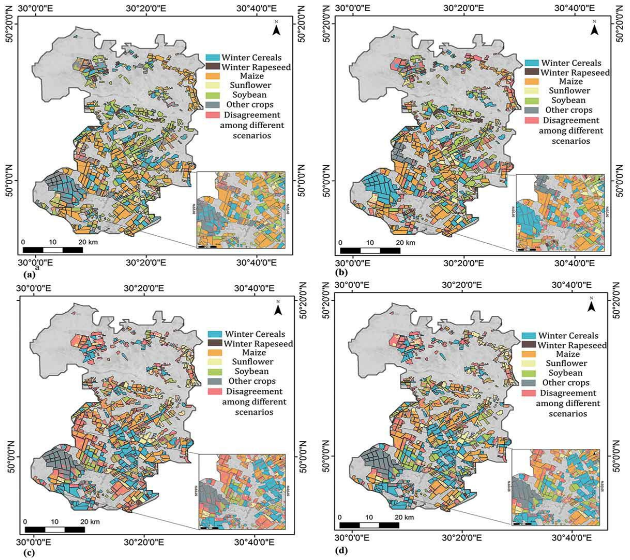
- To develop a two-step processing chain for crop classification

Data:

- Intra-annual variation of temporal signatures of remotely sensed observations (As input data for crop classification, composites based on Sentinel-1 and Landsat images were were preprocessed and analyzed using Google Earth Engine cloud computing platform)
- prior knowledge of crop calendars
- The developmental stage of each crop was modeled by fitting harmonic function. The model's output was further used for the automatic generation of training samples.
- Several classification methods (support vector machines, random forest, decision fusion) were tested.

Results:

- Overall classification accuracies exceeded 80% when the seasonal composites were used. Winter cereals were the most accurately classified, while we observed misclassifications among summer crops.



Gohar Ghazaryan, Olena Dubovyk, Fabian Löw, Mykola Lavreniuk, Andrii Kolotii, Jürgen Schellberg, Nataliia Kussul. (2018) A rule-based approach for crop identification using multi-temporal and multi-sensor phenological metrics. European Journal of Remote Sensing 51:1, pages 511-524.

Remote sensing applications in agriculture: examples. Yield.

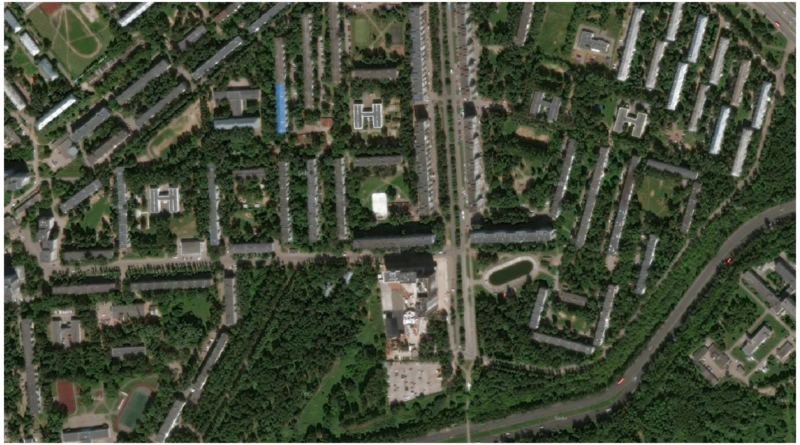
- Nevertheless RSD provides a large opportunity to monitor almost all processes occurring on the Earth, it is still does not allow to evaluate yield without field cross-measurements;
- Collecting the ground data is needed to calibrate and validate remote sensing algorithms at large spatial and temporal scales.
- This is particularly challenging for continuous variables, such as yield and biomass, which typically require on-the-ground estimation compared to categorical variables, which can sometimes be identified remotely through visual inspection of higher-resolution imagery, such as Google Earth.
- Identifying ways to easily collect such ground data could further revolutionize the ability to use satellite data to map agricultural characteristics at large spatial and temporal scales.

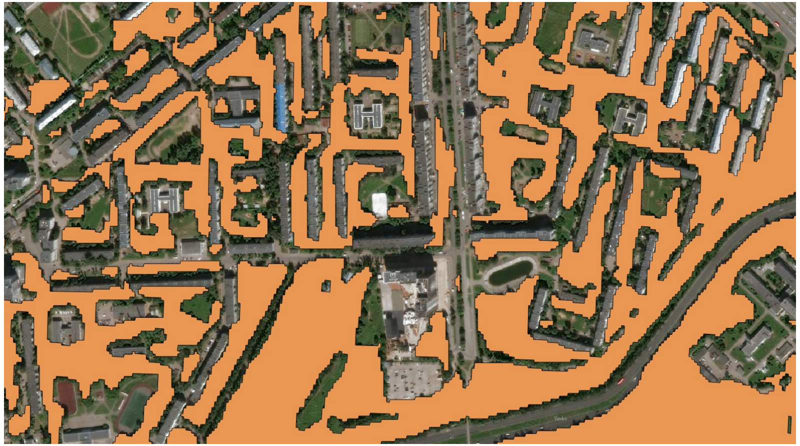
Collecting large training sets for modeling

Investments into development of more physiological indices, such as leaf area index (LEA) in high temporal resolution

Remote sensing and forestry

Forest segmentation

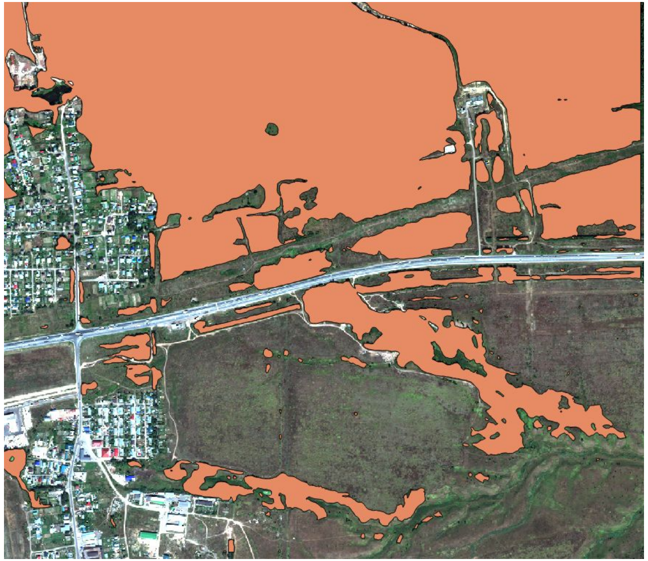




The goal:

- Robustness to different satellites and months
- Robustness to small details

- Different architectures
- broaden dataset
- fine-tune for small details
- merge different models prediction
- experiments with loss functions



Forest segmentation

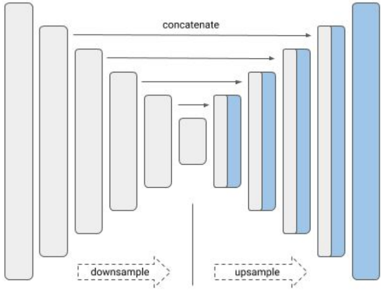
- One of the goals: create more robust to satellite change approach, to get a model that can generalize to any satellite sensor of high spatial resolution.
    - Gathered dataset containing imagery from SPOT-6, PlanetScope, WorldView
    - Color and scale augmentation at the training stage

Forest Inventory

Can we estimate the timber stock by species looking at satellite data?

What is the goal?

Satellite imagery



AI algorithms

Stock of timber

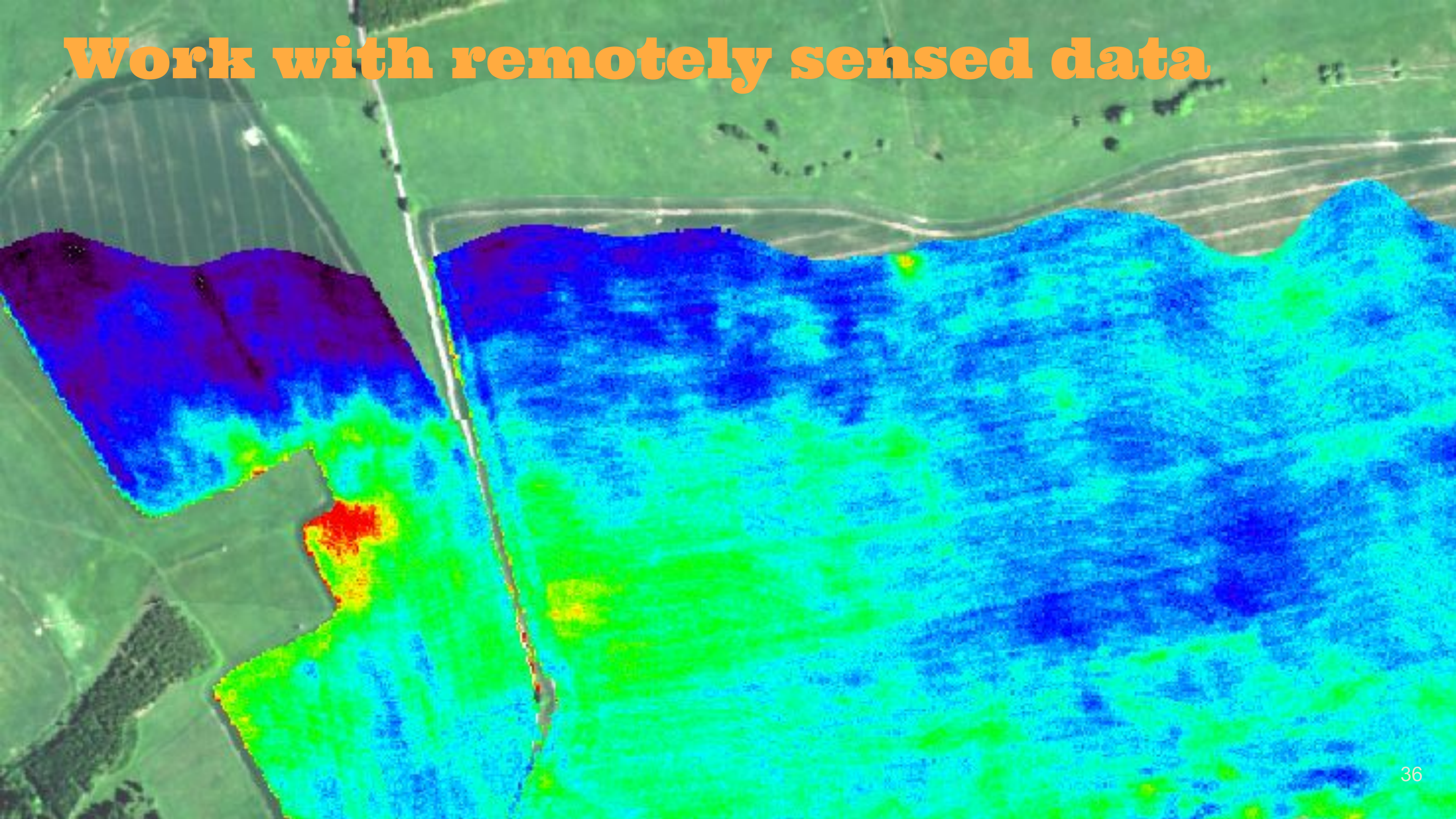
Who is the target user?

- **foresters**
- **silvicultural users**

To calculate timber stock:

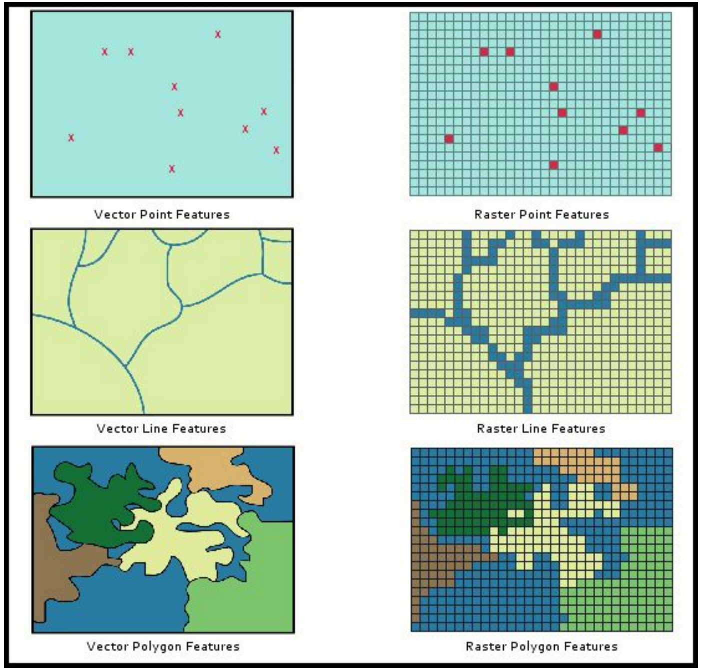
TS = ∑constants[specie] * square[i] * age[specie] * height[specie]

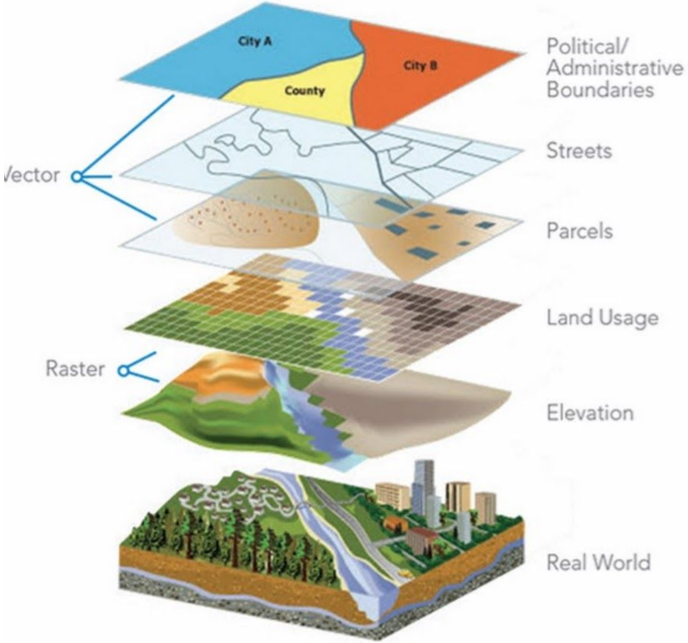
Work with remotely sensed data



How to prepare ground truth data?

(ascribe labels)





Ground based observations → Text files → Vectors → Raster