

Remote sensing tools and methods for natural resource mapping

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Course outline

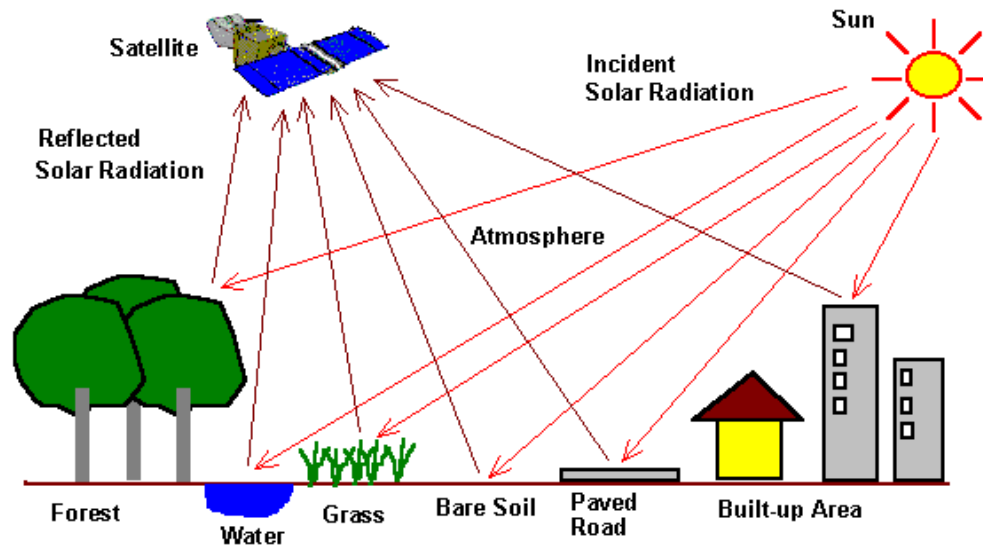
- Lesson objectives
- Basic remote sensing concepts
- Remote sensing of natural resources
- Practical applications of remote sensing in natural resource mapping
- Current and future research directions

Lesson objectives

- To introduce the learners to basic concepts of remote sensing
- To introduce the learners to the potential applications of remote sensing in natural resource assessment and monitoring

Basic concepts of remote sensing

- **Remote sensing** is the science and technology of acquiring information about an object or phenomena without being in physical contact with it.
- Remote sensing makes it possible to collect data over vast, dangerous or inaccessible areas



Source: <http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm>

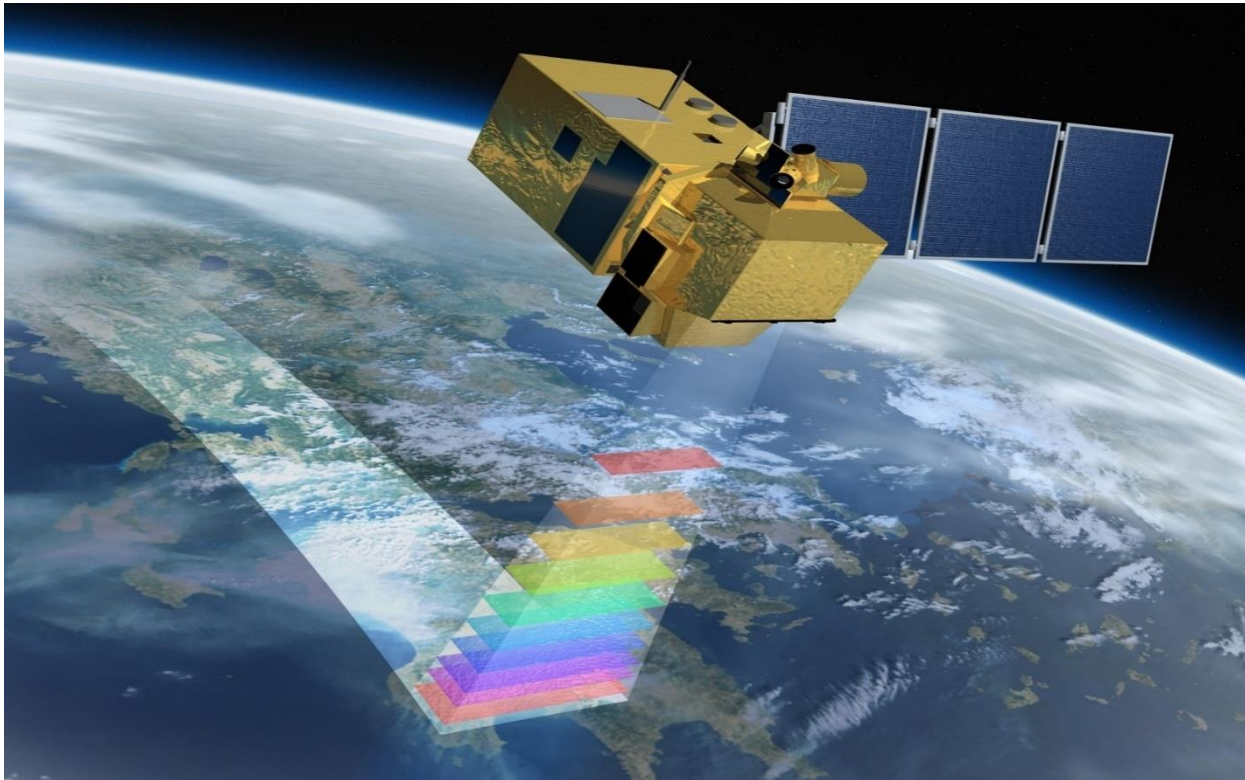
Remote sensing of natural resources

- Natural resources such as land, forests, water bodies, minerals etc. cover expansive, inaccessible and dangerous areas.
- Remote sensing is safe, cost-effective and accurate method for monitoring, mapping and studying such natural resources.



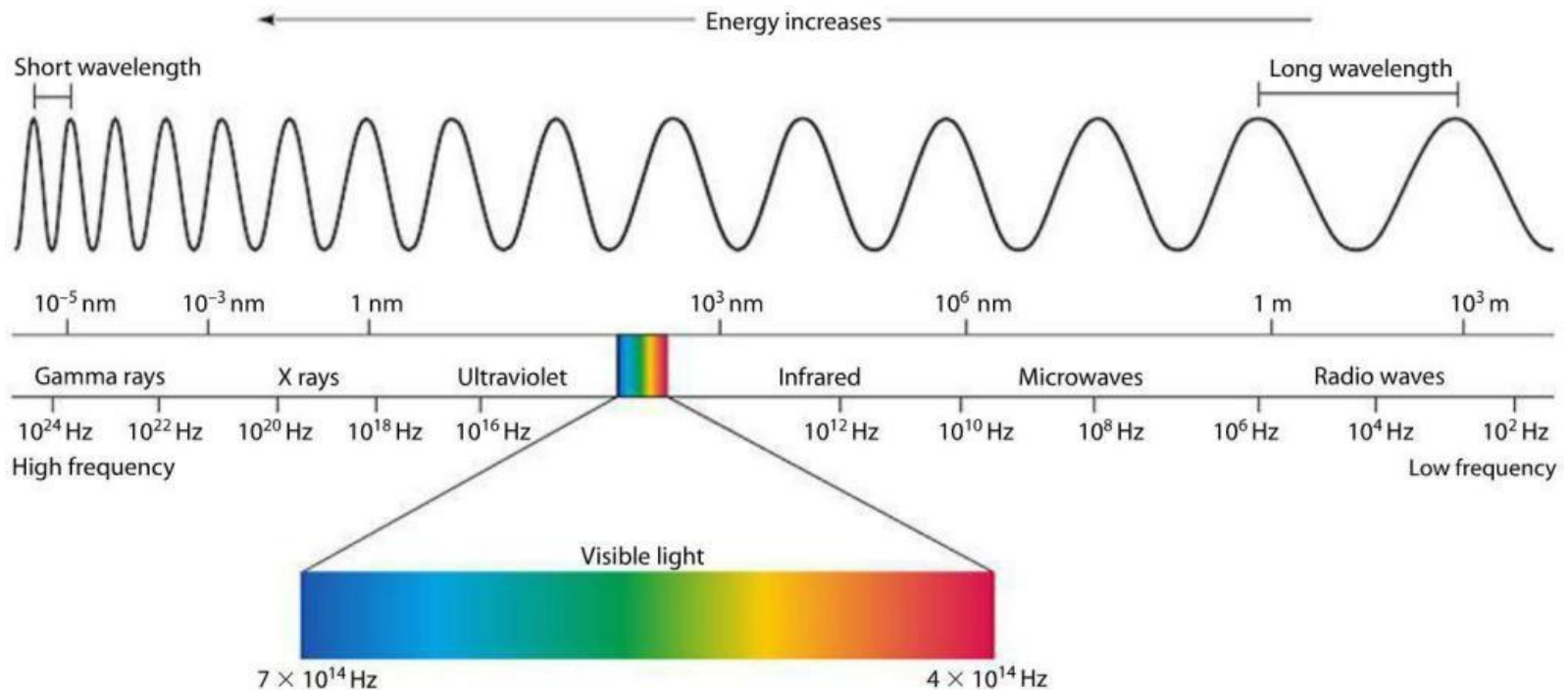
RS Image capture

- Most remote sensing devices make use of electromagnetic energy.
- Electromagnetic radiations absorbed, transmitted and reflected by objects on the earth surface either from the sun or active sensors is measured and recorded to produce an image of the surface sensed.



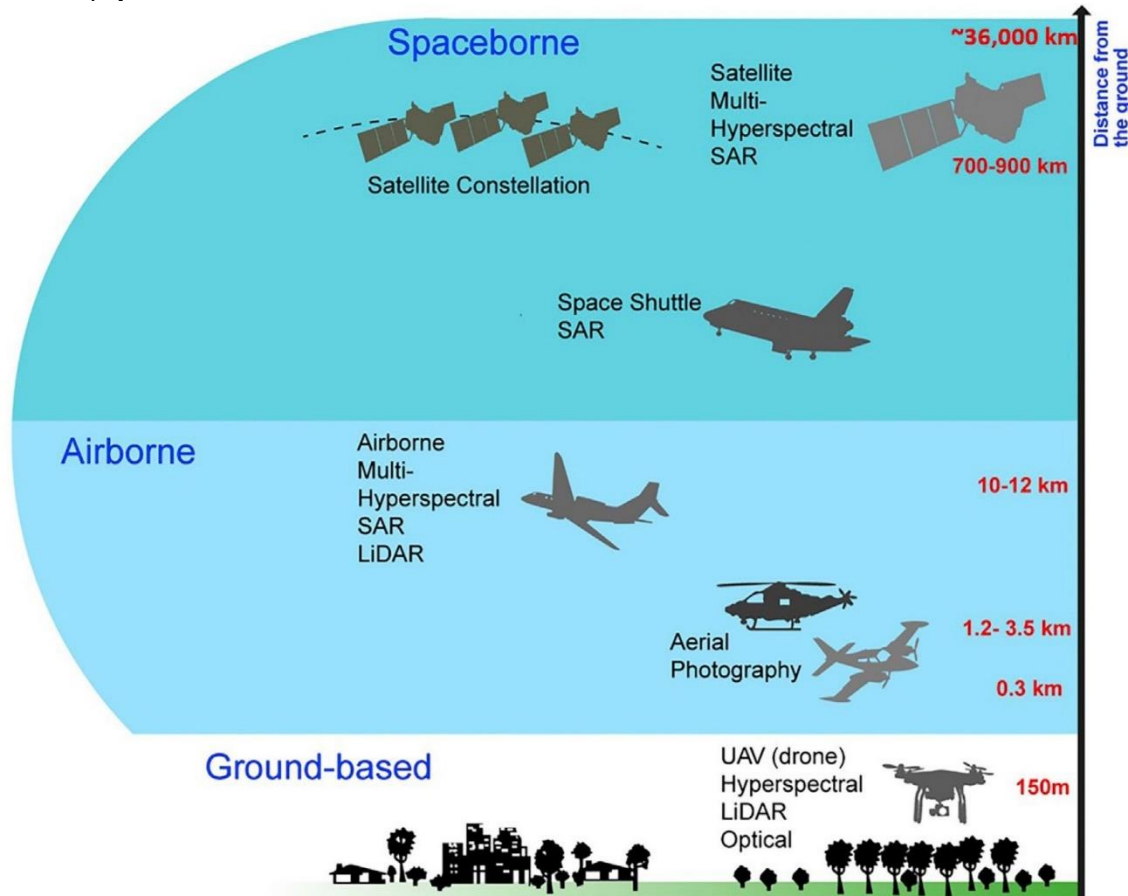
Electromagnetic Spectrum

- This is the entire range of electro magnetic energy that is transmitted in the atmosphere
- Portions of EM spectrum from visible light, infra-red and microwaves can be used for remote sensing of different materials
- Microwaves (because of their long wavelengths) are particularly used for mapping of material beneath the ground and under the sea



Remote sensing platforms

- The sensors for remote sensing can be onboard airborne, space-borne or terrestrial (ground-based) platforms

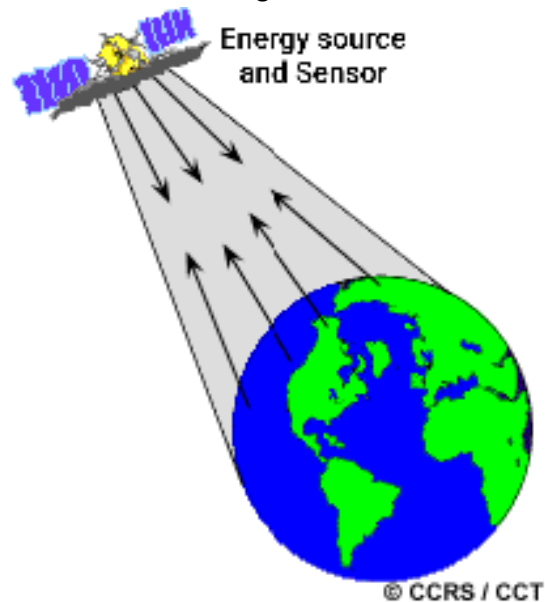


Source: Lechner et al 2020 <https://doi.org/10.1016/j.oneear.2020.05.001>

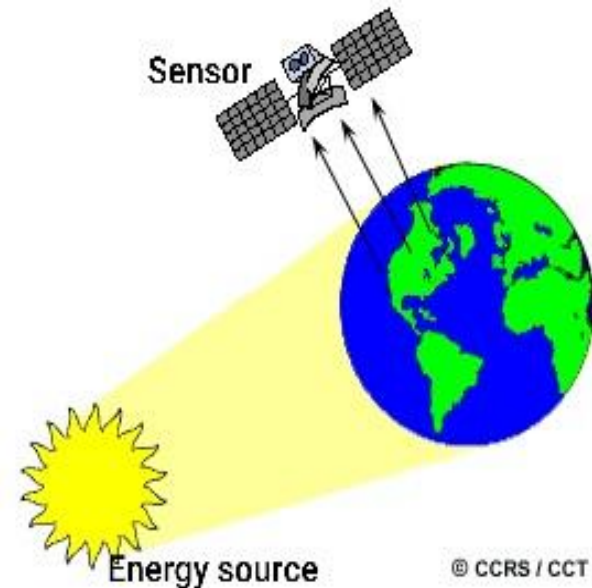
Active and Passive remote sensing

- **Passive remote sensing** entails use of sensors that measure ambient levels of existing energy sources such as the Sun.
- **Active remote sensing.** Active remote sensing involves use of sensors which emit their own energy and record the amount of energy reflected (back scatter) by objects.
- Light Detection and Ranging (LIDAR) and Synthetic Aperture Radar (SAR) are examples of active RS systems

(a) Active remote Sensing



(b) Passive remote Sensing



Example of Passive RS Data



Landsat 8 - True color composite

Source: <https://medium.com/google-earth/otsus-method-for-image-segmentation-f5c48f405e>

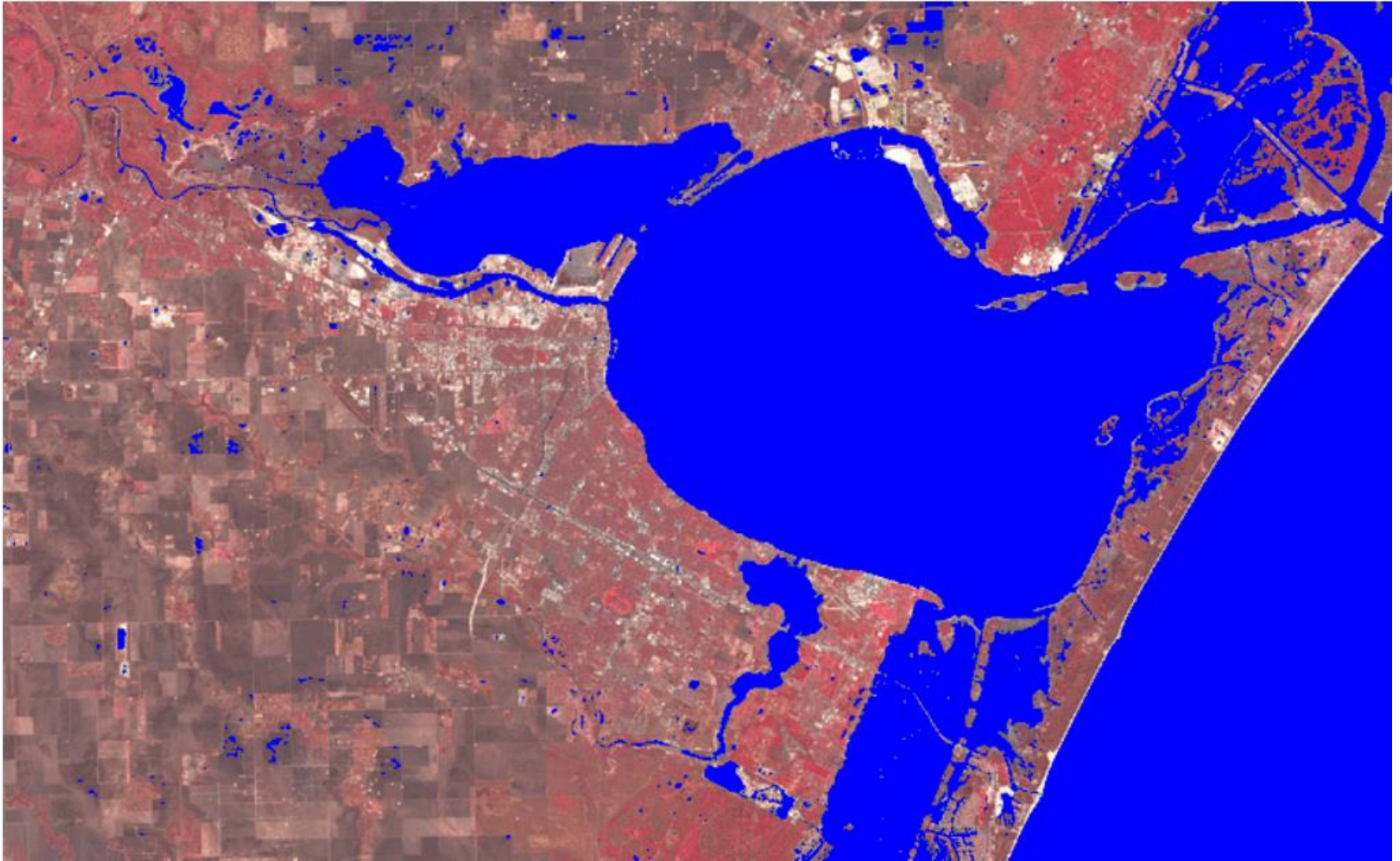
Example of Passive RS Data



Landsat 8 - False color composite

Source: <https://medium.com/google-earth/otsus-method-for-image-segmentation-f5c48f405e>

Example of Passive RS Data

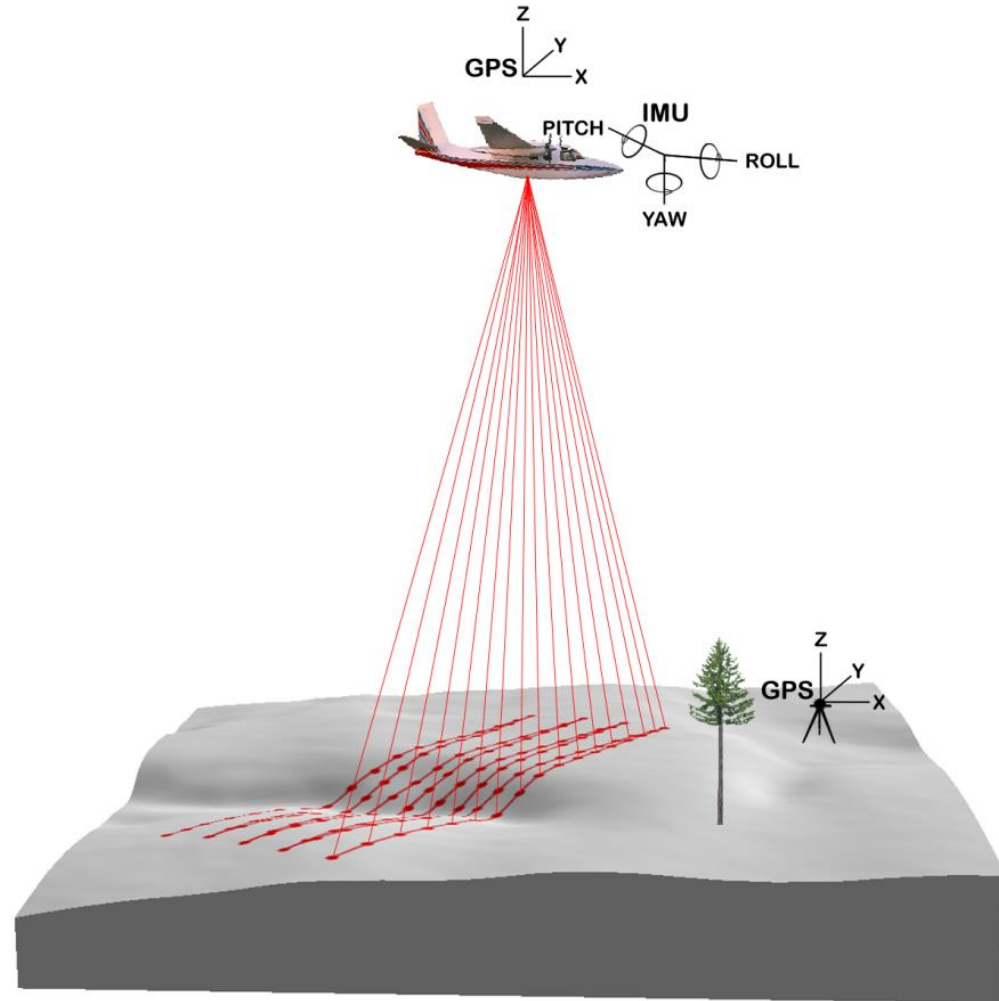


Landsat 8 – Feature extraction

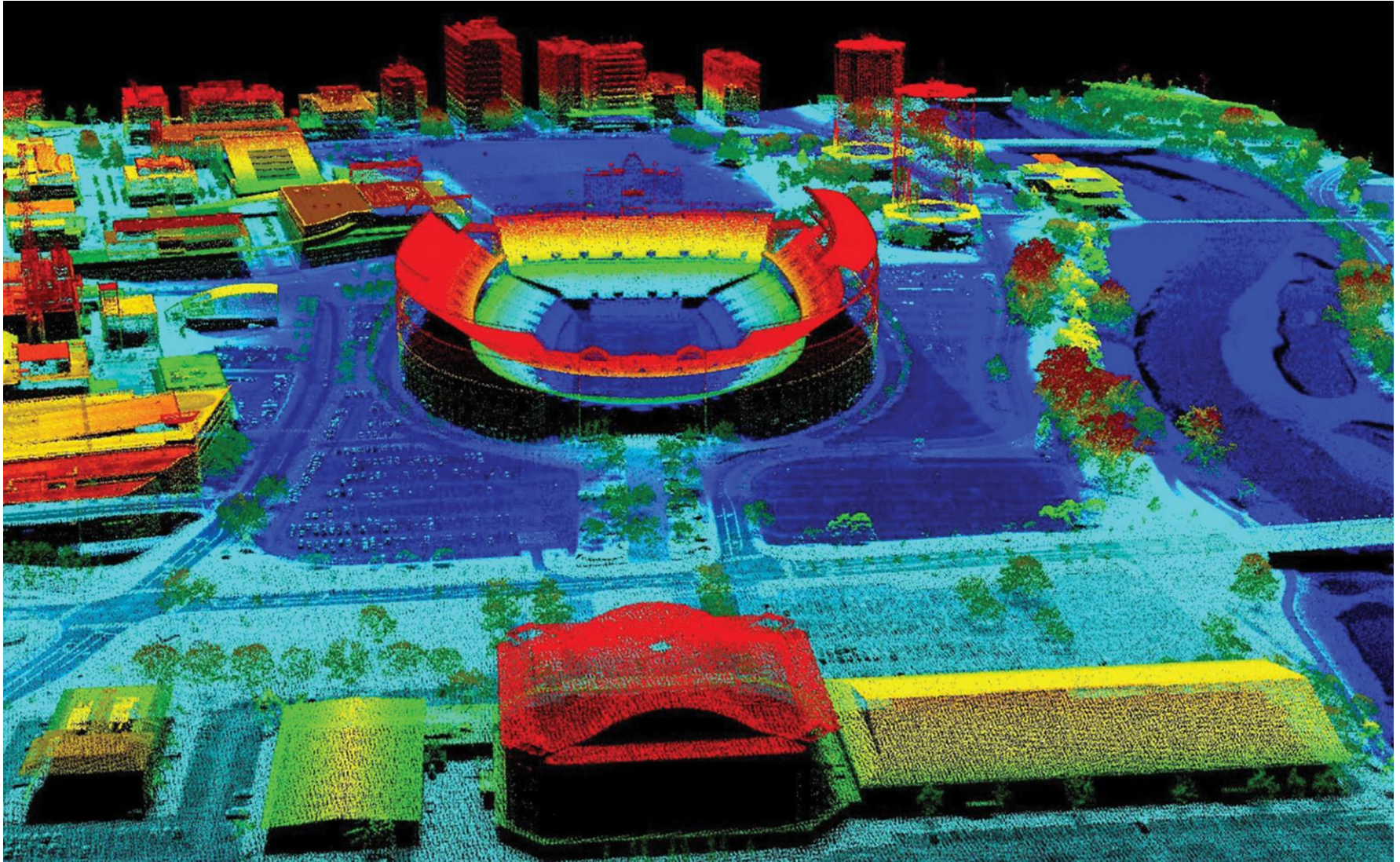
Source: <https://medium.com/google-earth/otsus-method-for-image-segmentation-f5c48f405e>

Example of Active Sensor: LiDAR System

- LIDAR – **L**ight **D**etection and **R**anging
- Light is emitted rapidly by Laser
- The light hits objects of interest and is reflected back
- Reflected light is recorded, time and distance traveled is calculated
- Recorded distance is used to calculate coordinates (X,Y,Z) of the reflecting object
- Differentially corrected GPS ensures accuracy of the coordinates
- Multiple returns and density of emitted light supports in mapping tree canopy structures in other 3D objects



Example of Active RS Data

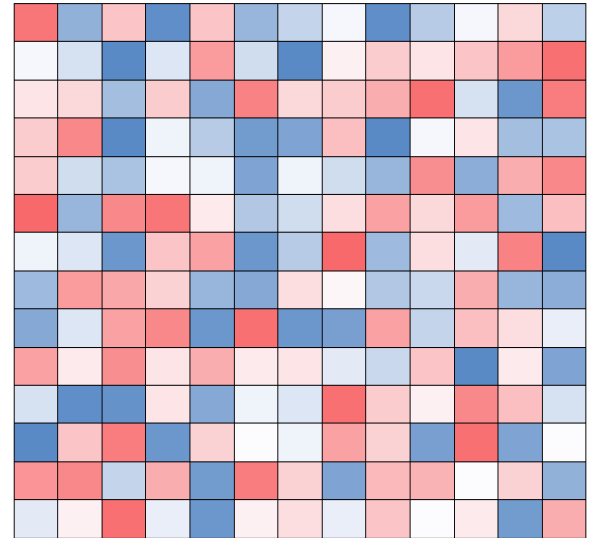


LIDAR– Point Clouds

Source: <https://lidarmag.com/2020/01/14/ql0-lidar-data-provides-highly-accurate-roadmap-for-blueprint-columbus/>

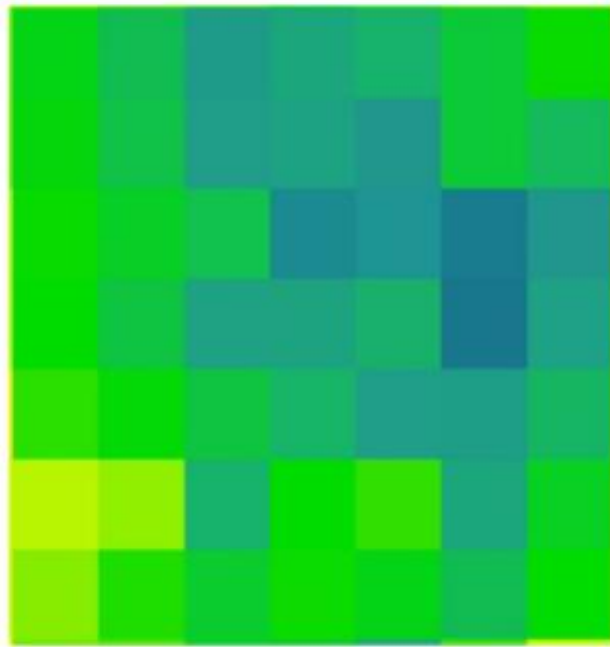
Basic concepts: Resolution

- The degree of fineness or detail with which information is captured
- Determines whether the information is fit for the intended purpose
- In remote sensing there are types of resolution including spatial, temporal, spectral and radiometric resolution

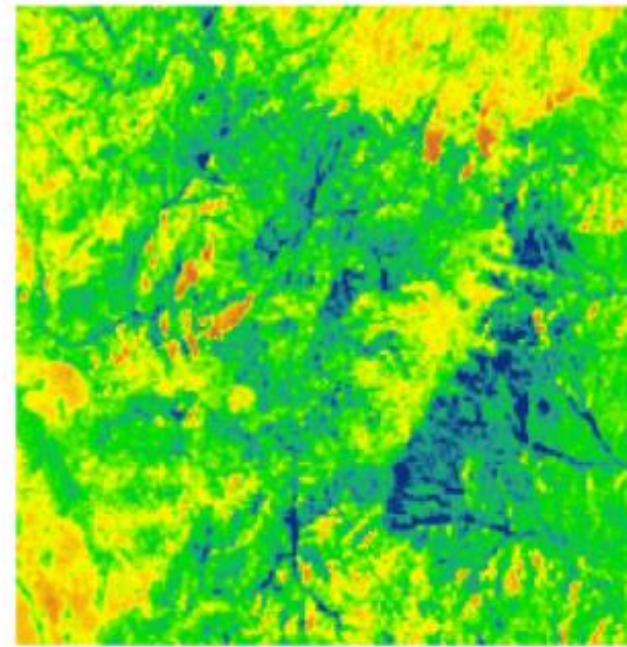


Spatial Resolution

- A measure of the finest distinguishable detail in an image
- Commonly considered as the size/width of a unit picture element (pixel) of an image
- The finer the pixel size, the more the detail hence the higher the resolution



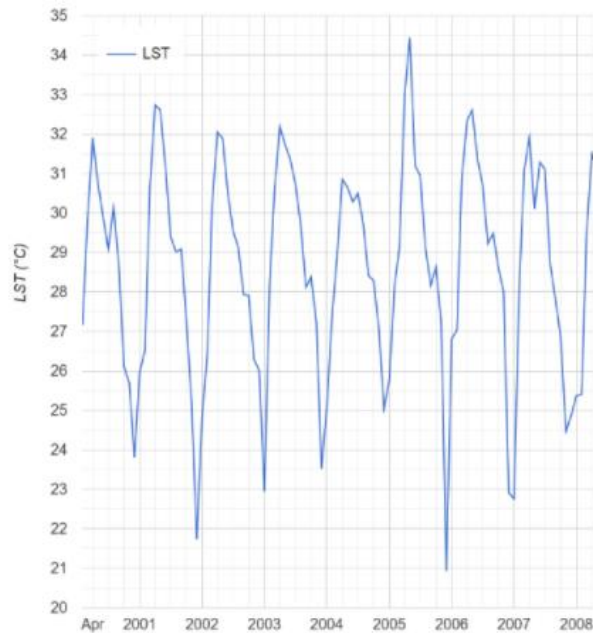
Low resolution



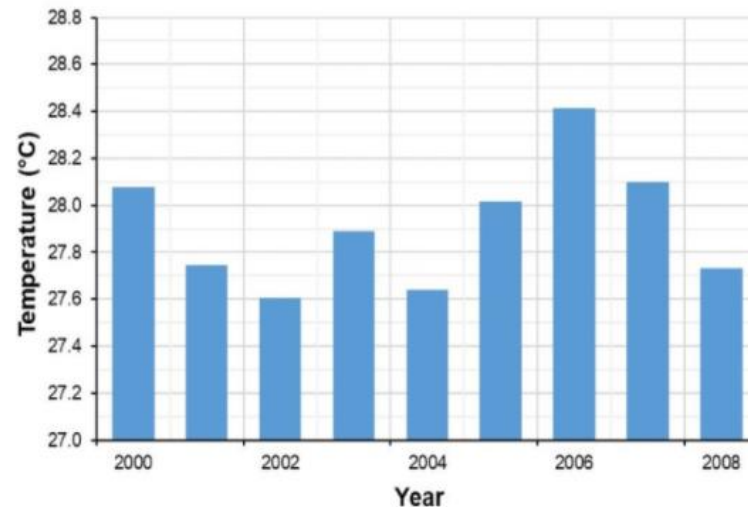
High resolution

Temporal Resolution

- A measure of the frequency at which information is captured
- In remote sensing, this is the amount of time required to revisit and capture data in the same location.
- Faster revisit times result in high temporal resolution data
- The revisit time depends on the orbital characteristics of the sensor



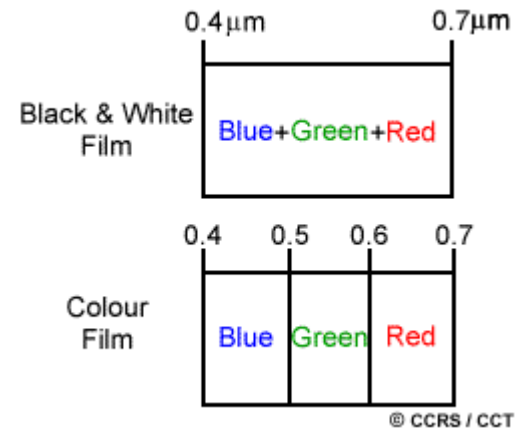
Low resolution



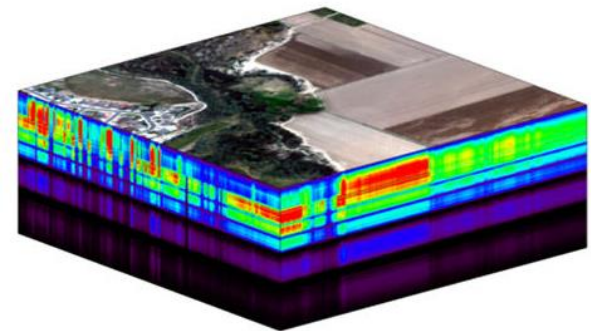
High resolution

Spectral Resolution

- The ability to define fine wavelength intervals
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band
- Hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum
- High spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.



Source: Canadian Centre for Remote Sensing (CCRS)



Radiometric Resolution

- The ability to detect small differences in electromagnetic energy
- The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.
- The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded
- If a sensor used 8 bits to record the data, there would be $2^8=256$ digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only $2^4=16$ values ranging from 0 to 15 would be available.



Source: Canadian Centre for Remote Sensing (CCRS)

Common remote sensing satellites

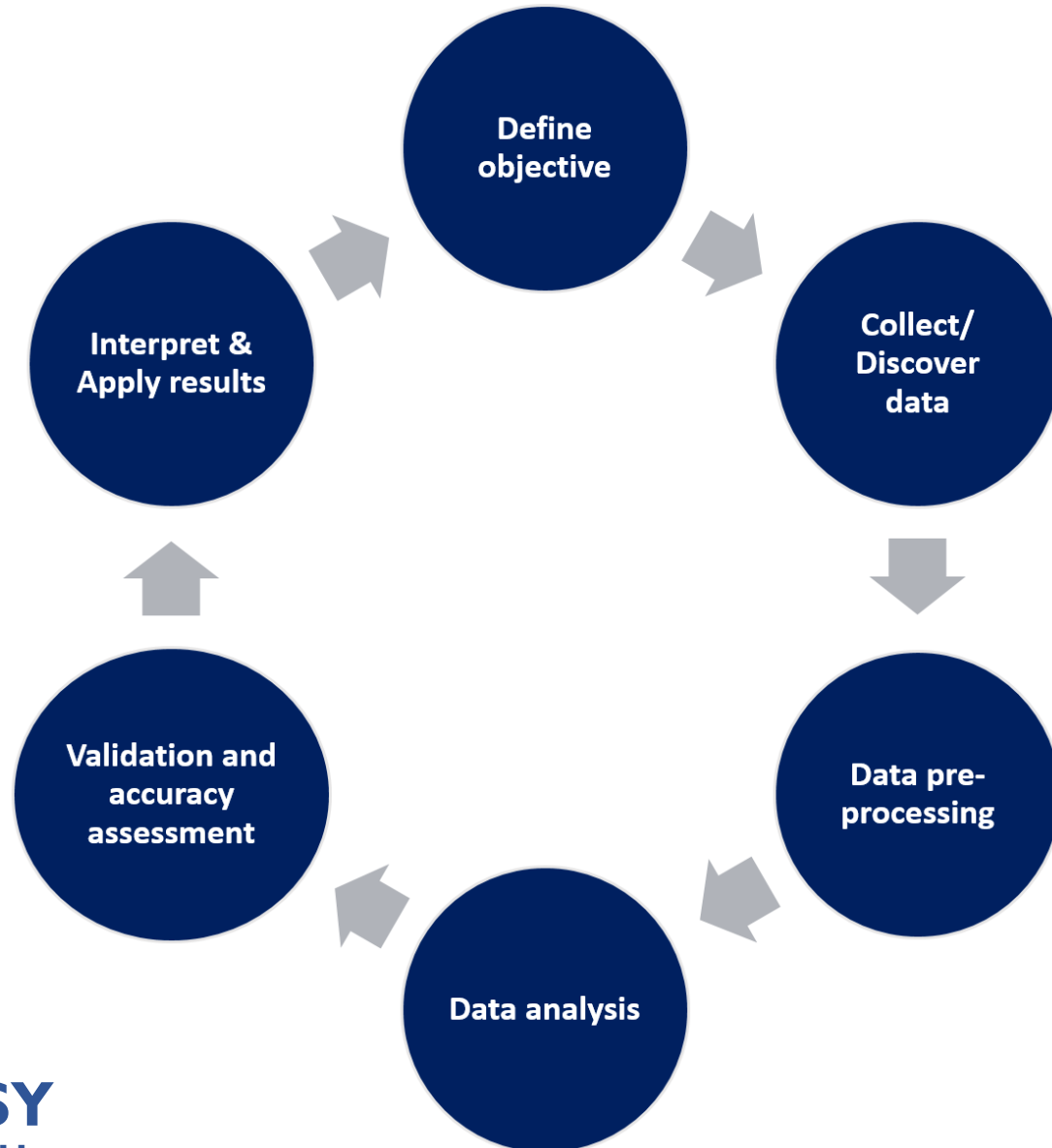
Satellites	Spatial resolution	Temporal resolution	Spectral resolution
AVHRR	1 km	1 day	2 bands
GOES	700 m	15 minutes	1 band
MODIS	1 km/500 m/250 m	1 day	36 bands
Landsat ETM	30-60 m	16 days	8 bands
Sentinel-1	5-20m	12days	4 bands
Sentinel-2	10-60 m	5 days	13 bands
SPOT-5	2.5-5 m	2-3 days	5 bands
WorldView-2	0.46 m	1-3 days	8 bands

Source: Adopted from Xie, 2020 ([doi:10.25334/CPFG-B331](https://doi.org/10.25334/CPFG-B331))

Sources remote sensing data

- NASA Earth Observations <https://neo.sci.gsfc.nasa.gov/>
- NASA's Land Processes Distributed Active Archive Center <https://lpdaac.usgs.gov>
- Landsat satellite data <https://landsat.gsfc.nasa.gov/>
- MODIS satellite data <https://modis.gsfc.nasa.gov/>
- USGS Earth Explorer <https://earthexplorer.usgs.gov/>
- **Google Earth Engine** <https://developers.google.com/earth-engine/datasets/catalog>
- Copernicus/ESA <https://www.copernicus.eu/en/access-data>
- **Free LIDAR Data** <https://grindgis.com/data/free-lidar-data-download>

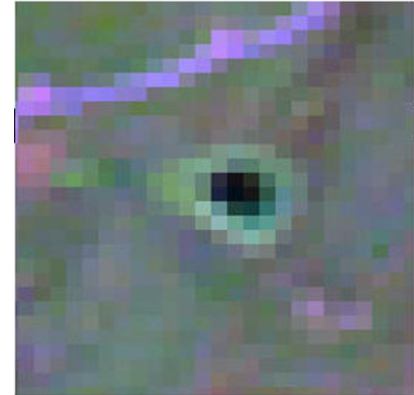
Satellite Image Analysis Steps



Pixel-based & Object-based Image Analysis

- **Pixel-based analysis**

- The pixel is the unit of analysis
- Procedures rely on the spectral characteristics of each individual pixel
- Contextual information of neighboring cells is not considered



- **Object-based image analysis**

- Unit of analysis is the object, which is derived from a collection of neighboring pixels meeting a certain similarity criteria
- Objects are characterized based on their spectral characteristics, shape, texture and spatial relationships among surrounding pixels
- The use of contextual information of the neighboring cells adds on the information that is available for analysis

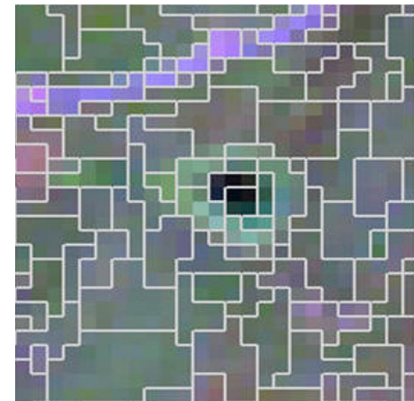
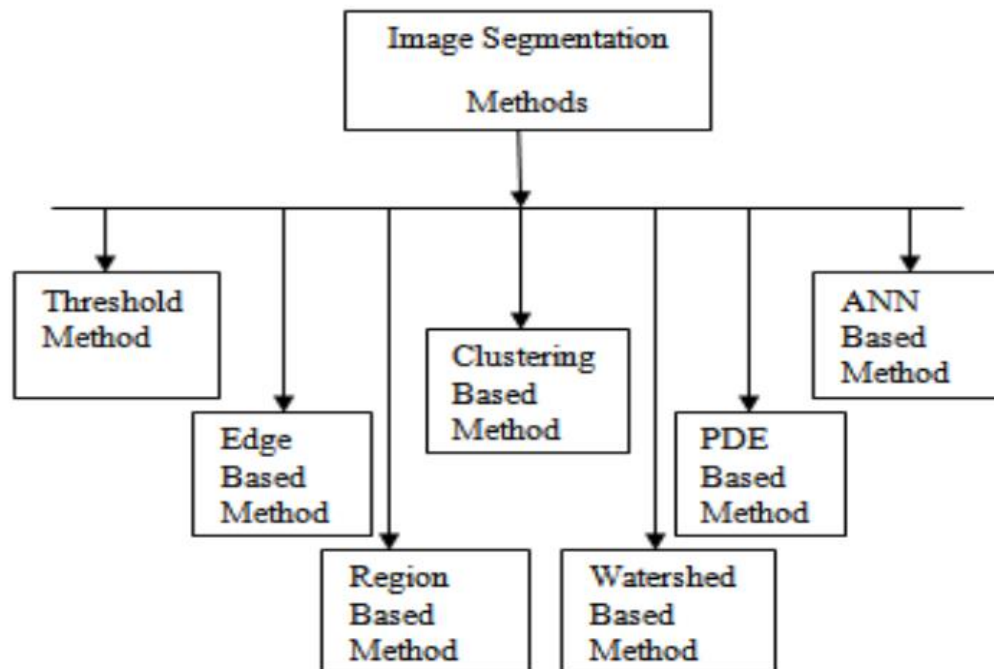


Image processing methods

• Segmentation

- Is the process of partitioning an image into meaningful objects
- Segmentation simplifies the image into objects with reasonable contextual information to support analysis
- Each of the pixels in a segment have similar characteristics including color, intensity, texture
- Neighboring objects should be significantly dissimilar to each other
- The objects then become the units for further analysis



Source: Kaur & Kaur

<https://ijcsmc.com/docs/papers/May2014/V3I5201499a84.pdf>

Image processing methods

- **Classification**

- Is the process of creating meaning thematic objects/categories from satellite imagery
- Specific steps of image classification include
 1. Determination of a suitable classification system
 2. Selection of training samples
 3. Image preprocessing
 4. Feature extraction
 5. Selection of suitable classification approaches
 6. Post-classification processing
 7. Accuracy assessment

Taxonomy of classification methods

Criteria	Categories	Characteristics	Example of classifiers
Whether training samples are used or not	Supervised classification approaches	Land cover classes are defined. Sufficient reference data are available and used as training samples. The signatures generated from the training samples are then used to train the classifier to classify the spectral data into a thematic map.	Maximum likelihood, minimum distance, artificial neural network, decision tree classifier.
	Unsupervised classification approaches	Clustering-based algorithms are used to partition the spectral image into a number of spectral classes based on the statistical information inherent in the image. No prior definitions of the classes are used. The analyst is responsible for labelling and merging the spectral classes into meaningful classes.	ISODATA, K-means clustering algorithm.
Whether parameters such as mean vector and covariance matrix are used or not	Parametric classifiers	Gaussian distribution is assumed. The parameters (e.g. mean vector and covariance matrix) are often generated from training samples. When landscape is complex, parametric classifiers often produce 'noisy' results. Another major drawback is that it is difficult to integrate ancillary data, spatial and contextual attributes, and non-statistical information into a classification procedure.	Maximum likelihood, linear discriminant analysis.
	Non-parametric classifiers	No assumption about the data is required. Non-parametric classifiers do not employ statistical parameters to calculate class separation and are especially suitable for incorporation of non-remote-sensing data into a classification procedure.	Artificial neural network, decision tree classifier, evidential reasoning, support vector machine, expert system.
Which kind of pixel information is used	Per-pixel classifiers	Traditional classifiers typically develop a signature by combining the spectra of all training-set pixels from a given feature. The resulting signature contains the contributions of all materials present in the training-set pixels, ignoring the mixed pixel problems.	Most of the classifiers, such as maximum likelihood, minimum distance, artificial neural network, decision tree, and support vector machine.
	Subpixel classifiers	The spectral value of each pixel is assumed to be a linear or non-linear combination of defined pure materials (or endmembers), providing proportional membership of each pixel to each endmember.	Fuzzy-set classifiers, subpixel classifier, spectral mixture analysis.

Source: Lu & Weng

<https://doi.org/10.1080/01431160600746456>

Taxonomy of classification methods

Criteria	Categories	Characteristics	Example of classifiers
Which kind of pixel information is used	Object-oriented classifiers	Image segmentation merges pixels into objects and classification is conducted based on the objects, instead of an individual pixel. No GIS vector data are used.	eCognition.
	Per-field classifiers	GIS plays an important role in per-field classification, integrating raster and vector data in a classification. The vector data are often used to subdivide an image into parcels, and classification is based on the parcels, avoiding the spectral variation inherent in the same class.	GIS-based classification approaches.
Whether output is a definitive decision about land cover class or not	Hard classification	Making a definitive decision about the land cover class that each pixel is allocated to a single class. The area estimation by hard classification may produce large errors, especially from coarse spatial resolution data due to the mixed pixel problem.	Most of the classifiers, such as maximum likelihood, minimum distance, artificial neural network, decision tree, and support vector machine.
	Soft (fuzzy) classification	Providing for each pixel a measure of the degree of similarity for every class. Soft classification provides more information and potentially a more accurate result, especially for coarse spatial resolution data classification.	Fuzzy-set classifiers, subpixel classifier, spectral mixture analysis.
Whether spatial information is used or not	Spectral classifiers	Pure spectral information is used in image classification. A 'noisy' classification result is often produced due to the high variation in the spatial distribution of the same class.	Maximum likelihood, minimum distance, artificial neural network.
	Contextual classifiers	The spatially neighbouring pixel information is used in image classification.	Iterated conditional modes, point-to-point contextual correction, frequency-based contextual classifier.
	Spectral-contextual classifiers	Spectral and spatial information is used in classification. Parametric or non-parametric classifiers are used to generate initial classification images and then contextual classifiers are implemented in the classified images.	ECHO, combination of parametric or non-parametric and contextual algorithms.

Source: Lu & Weng

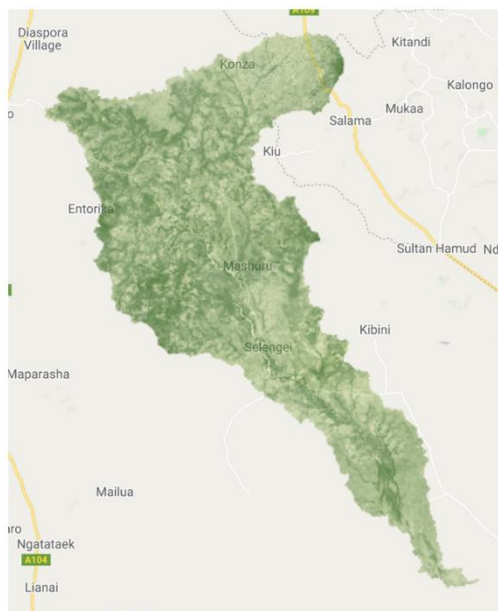
<https://doi.org/10.1080/01431160600746456>

Image processing methods

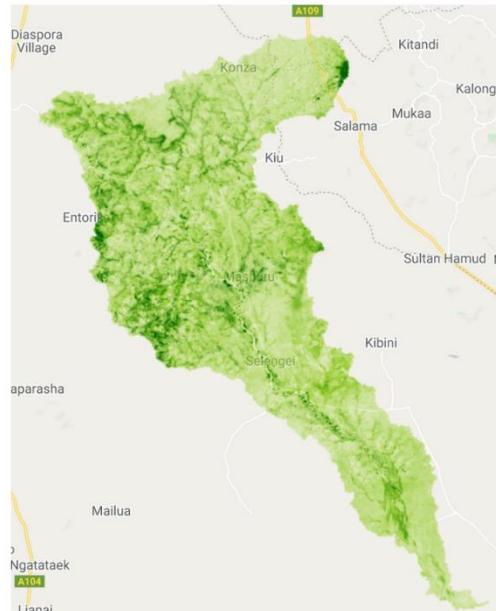
- Spectral indices based analysis**

- Spectral indices are combinations of spectral reflectance from two or more wavelengths that indicate the relative abundance of features of interest
- Vegetation indices are the most popular type e.g NDVI, MSAVI, EVI
- Other indices are available for burned areas, man-made (built-up) features, water, and geologic features

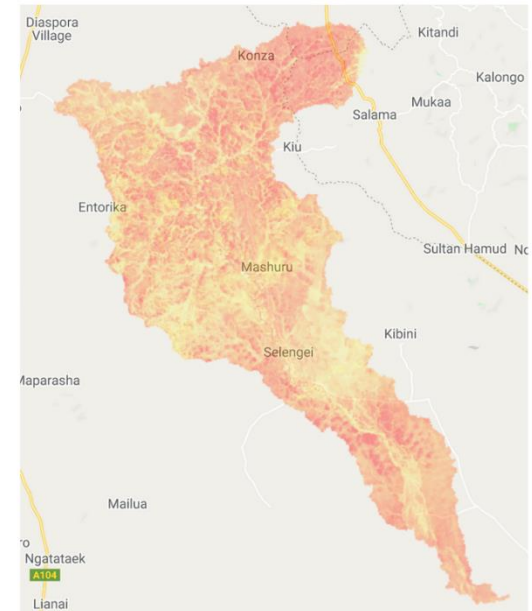
Modified Soil Adjusted Vegetation Index (MSAVI)



Enhanced Vegetation Index (EVI)



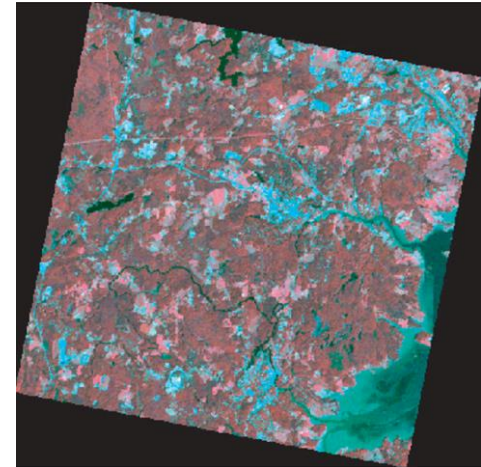
Bare Soil Index (BSI)



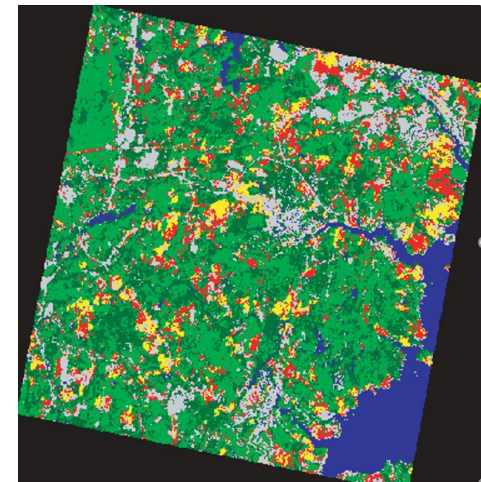
Accuracy Assessment

- Is a measure of the agreement between a map created from remote sensing and some other reference information from another source.
- Accuracy assessment is important for the following reasons:
 - a. To calibrate and improve an analysis method
 - b. To quantitatively compare methods
 - c. To provide the basis for using results and image analysis in decision making
- Accuracy analysis methods include
 - Visual inspection
 - Non-site specific analysis
 - Difference image creation
 - Error budgeting
 - Quantitative accuracy assessment

Reference image



Classified data



Accuracy Assessment

- Commonly evaluated using **Confusion matrix**
- Confusion matrix compares the relationship between known reference data and the results of the classification, based on the classes

a. Errors of omission (exclusion) and commission (inclusion)

- Number of elements that are wrongly excluded or included to a certain category

b. Overall accuracy

- Indicates the quality of the map classification

c. Producer's accuracy

- Indicates the quality of the classification of training set pixels

d. User's accuracy

- Indicates the probability that prediction represent reality

		Reference Data				
		A	B	C	D	Total row
Classified data	A	83	12	6	3	104
	B	15	95	16	6	132
	C	3	5	63	19	90
	D	6	12	15	85	118
Total column		107	124	100	113	444

$$\text{Overall accuracy} = (83+95+63+85)/444 \\ = 73.4\%$$

Producer's Accuracy

$$A: 83/107 = 77.6\%$$

$$B: 95/124 = 76.7\%$$

$$C: 63/100 = 63\%$$

$$D: 85/113 = 75.2\%$$

Users's Accuracy

$$A: 83/104 = 79.8\%$$

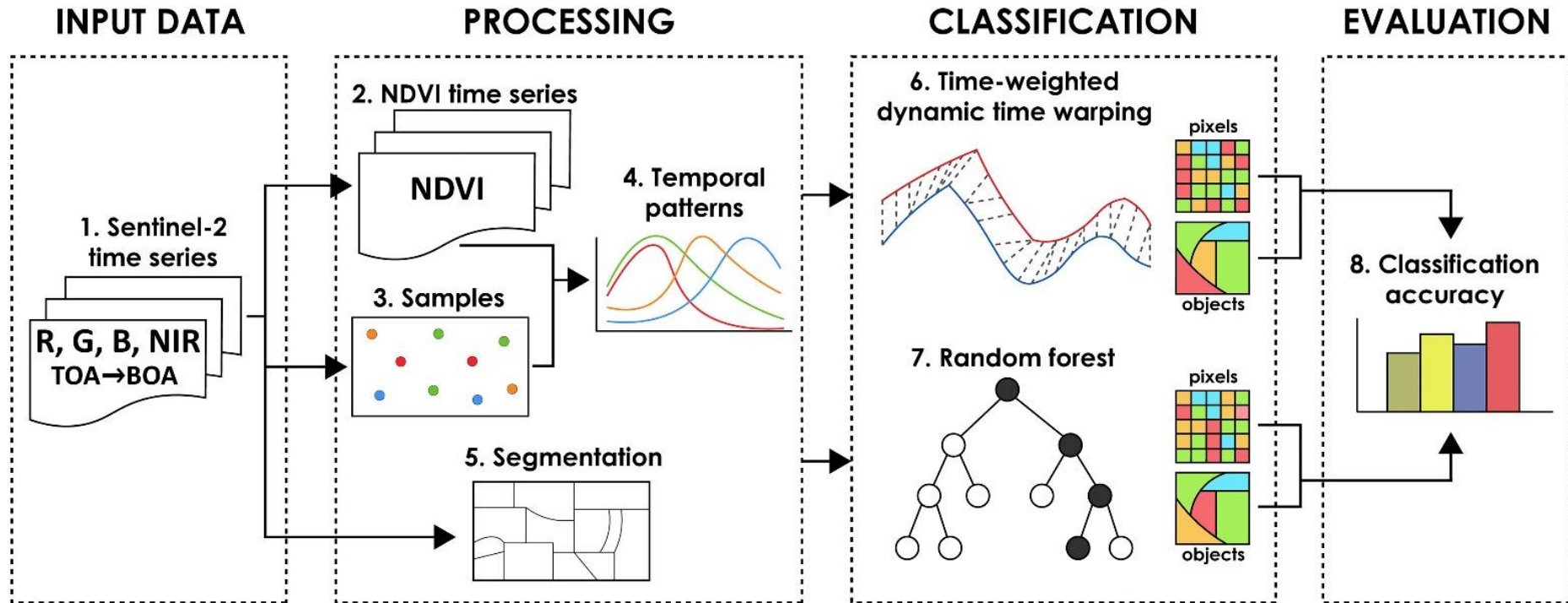
$$B: 95/132 = 72\%$$

$$C: 63/90 = 70\%$$

$$D: 85/118 = 72\%$$

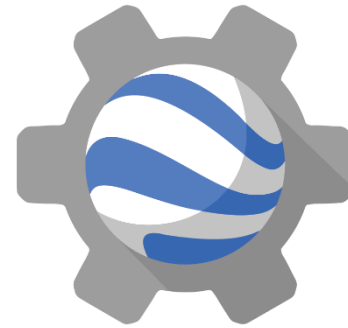
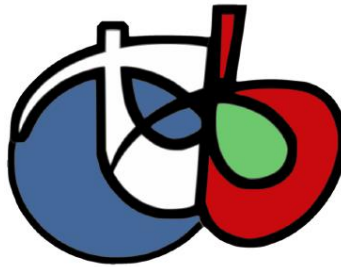
Mixed-method approaches

- Robust methods of analysis are those that combine raw data with indices, and also pixel and object-based methods



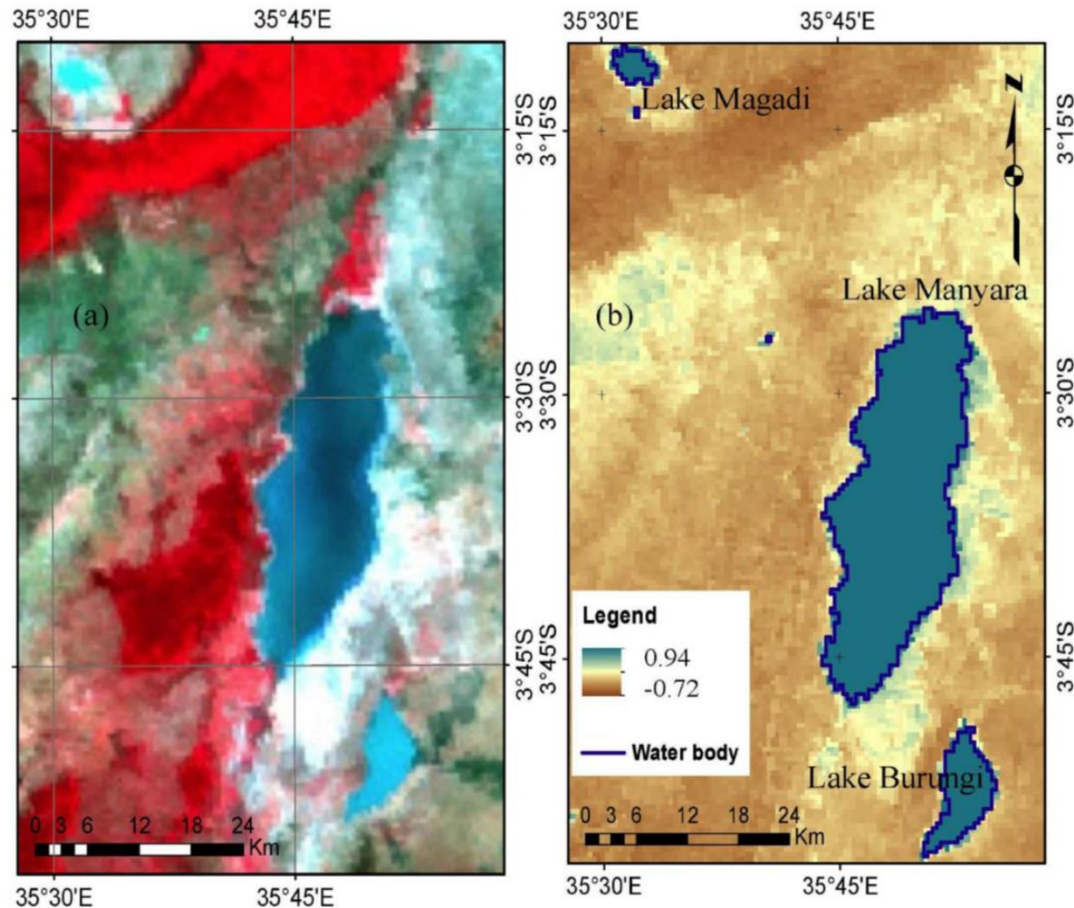
Source: Belgiu & Csillik <https://doi.org/10.1016/j.rse.2017.10.005>

Open Source tools for remote sensing of natural resources



Water resource mapping

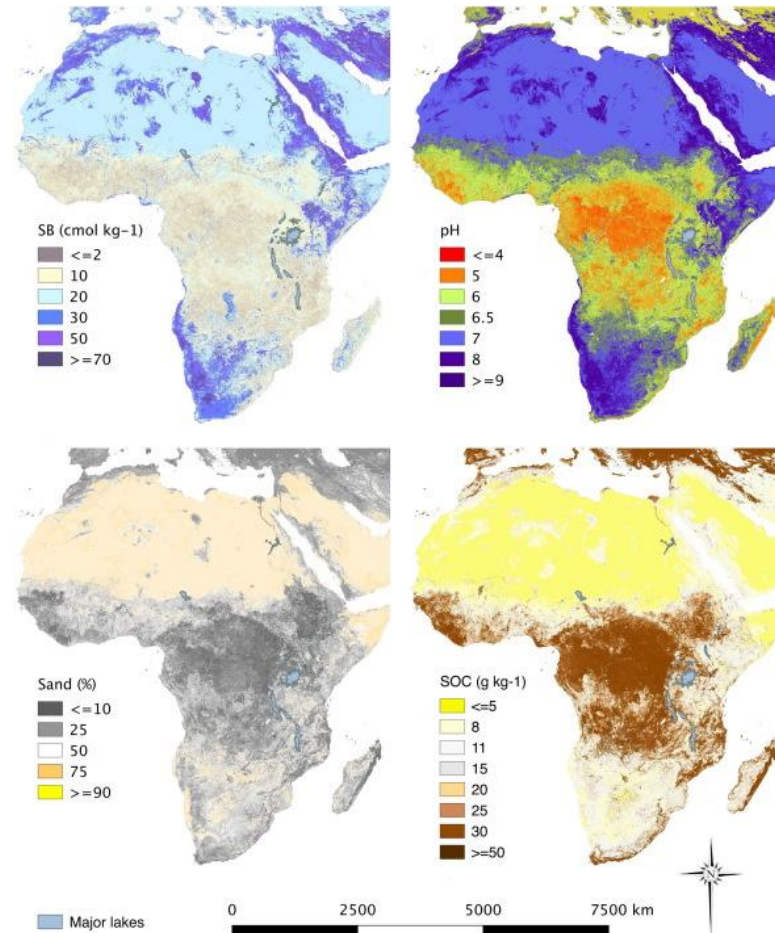
- Notable applications of Remote Sensing in water resource mapping include determination of surface water quantity and quality, ground water quantity and quality as well as water project management.



Source: Deus & Gloaguen, 2013 <https://doi.org/10.3390/w5020698>

Land health and land degradation

- Land health is a topic of global interest
- Remote sensing plays key roles in mapping, assessment and monitoring of land and soil characteristics at different spatial, temporal and spectral resolutions.
- In particular, remote sensing has been applied to map soil characteristics including soil moisture and biochemical characteristics
- Remote sensing is also commonly used for land degradation mapping at large spatial scales

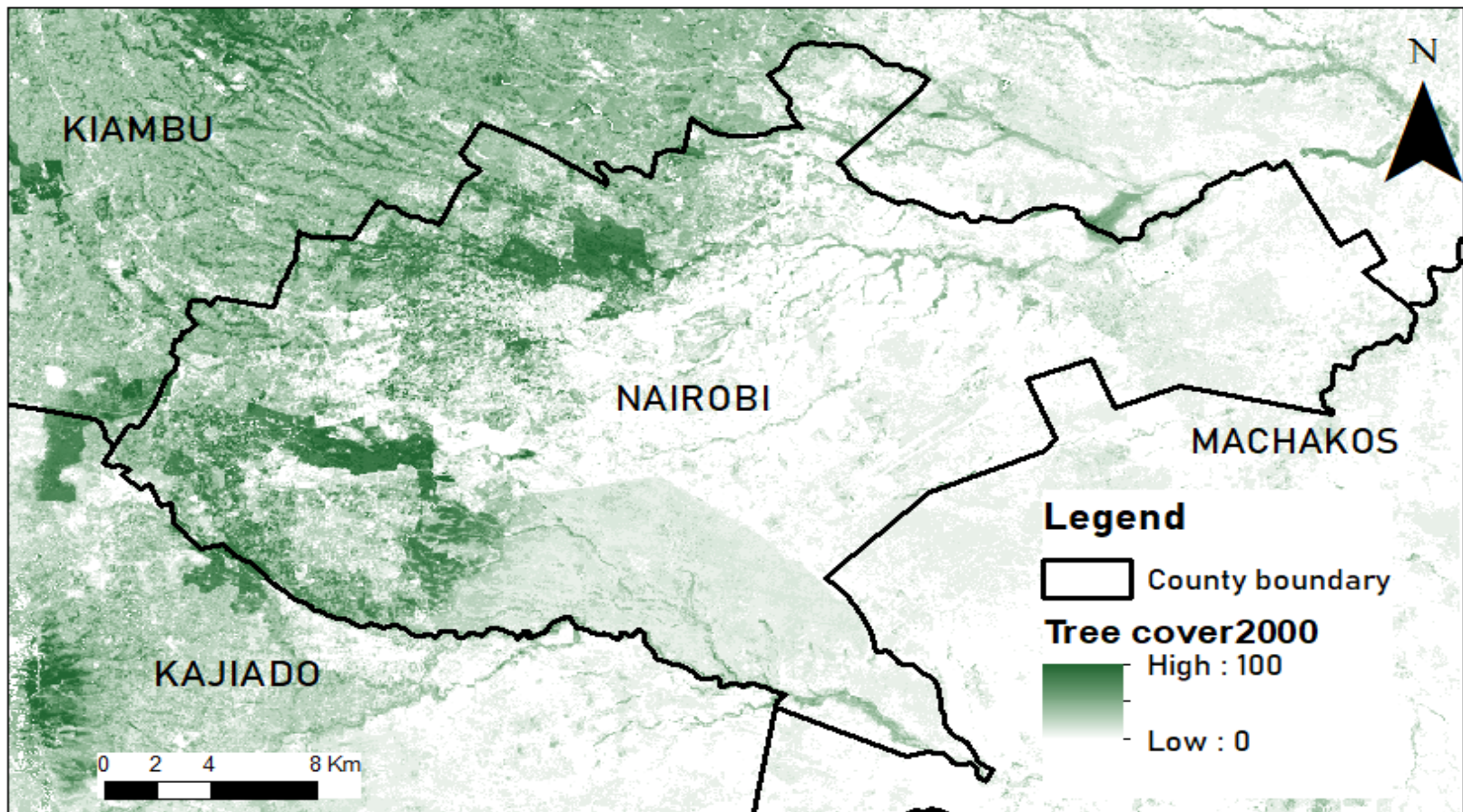


Source: Vågen et al, 2015

<https://doi.org/10.1016/j.geoderma.2015.06.023>

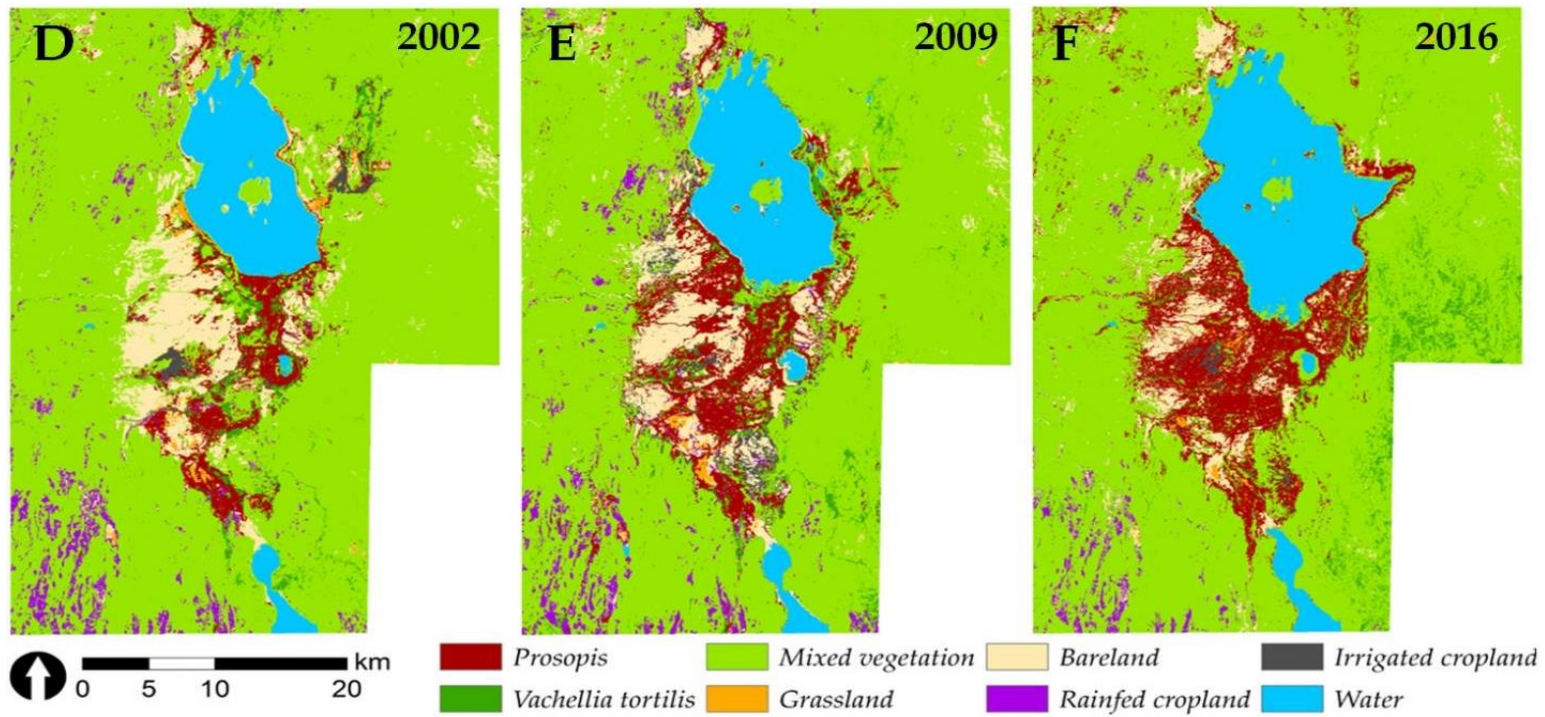
Forest mapping/ forest fires/forest degradation

- Applications of remote sensing in Forestry include terrain analysis, forest management, re-cultivation, updating of existing forest inventories, forest cover type discrimination, the delineation of burned areas, and mapping of cleared areas.



Invasive species mapping

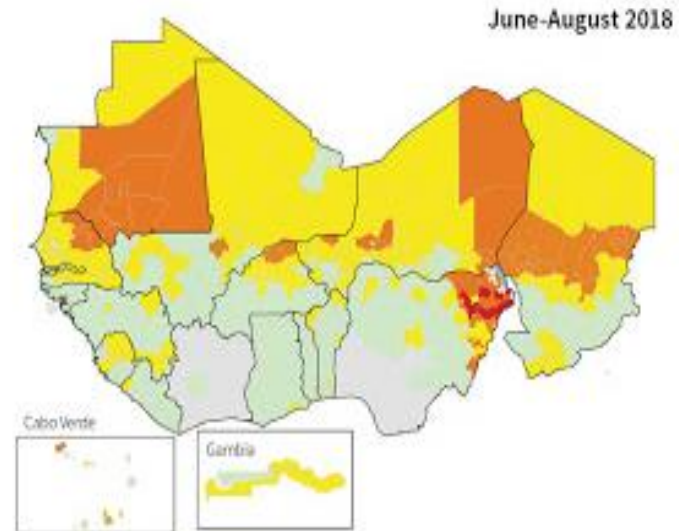
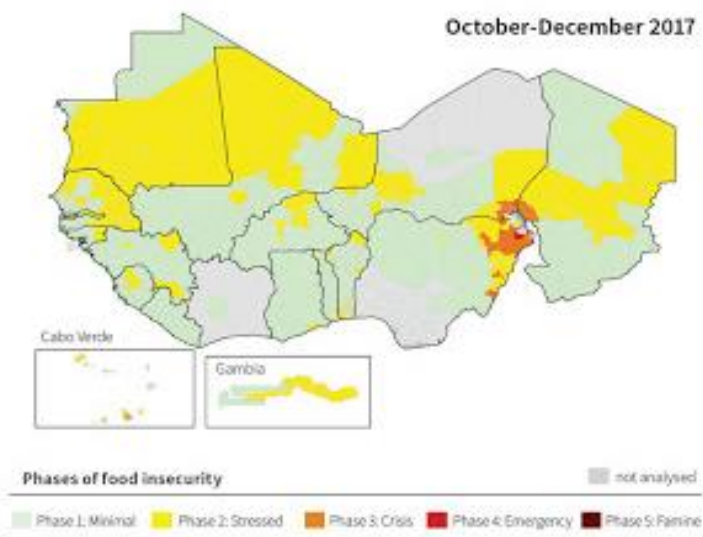
- Mapping and monitoring invasive plants and animals is possible using optical imagery when the species have unique characteristics.
- By using phenometric trends it is possible to identify and map specific invasive species and their distribution in regions of occurrence.
- Vegetation indices such as NDVI and spectral signatures are used.



Source: Mbaabu et al, 2019 <https://doi.org/10.3390/rs11101217>

Crop modelling and food security

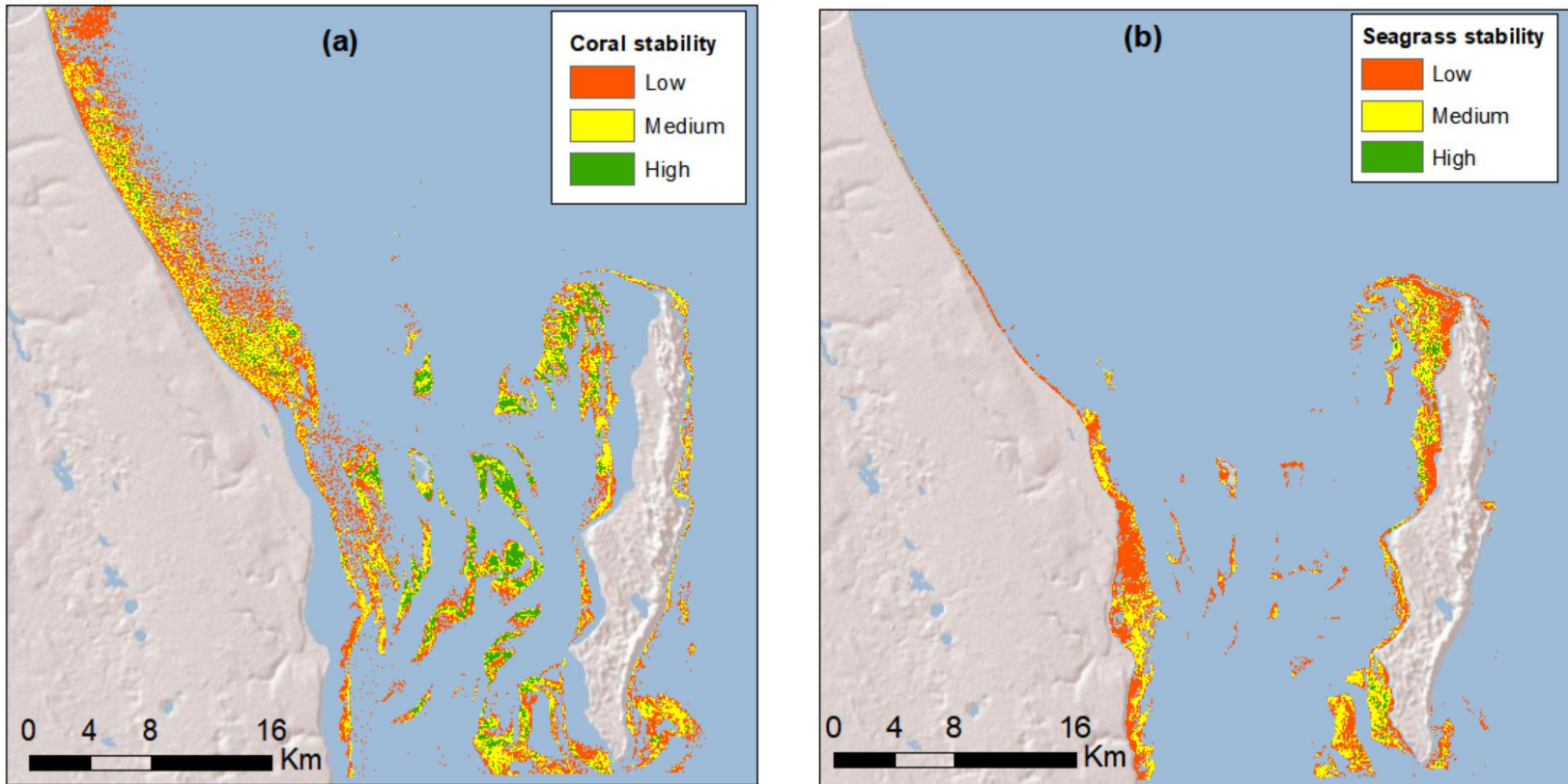
- Remote sensing fills data gaps thereby enabling crop modelling and food security.
- Remote sensed datasets such as Satellite imagery, Drone images make it possible to understand when and where certain crops are grown.
- It also helps to predict crop yields and spread of pest diseases.
- Remote sensed data is used for crop suitability analysis



Source: <http://www.west-africa-brief.org/content/en/critical-food-and-nutrition-situation-sahelian-belt>

Wetland/Coastal mapping

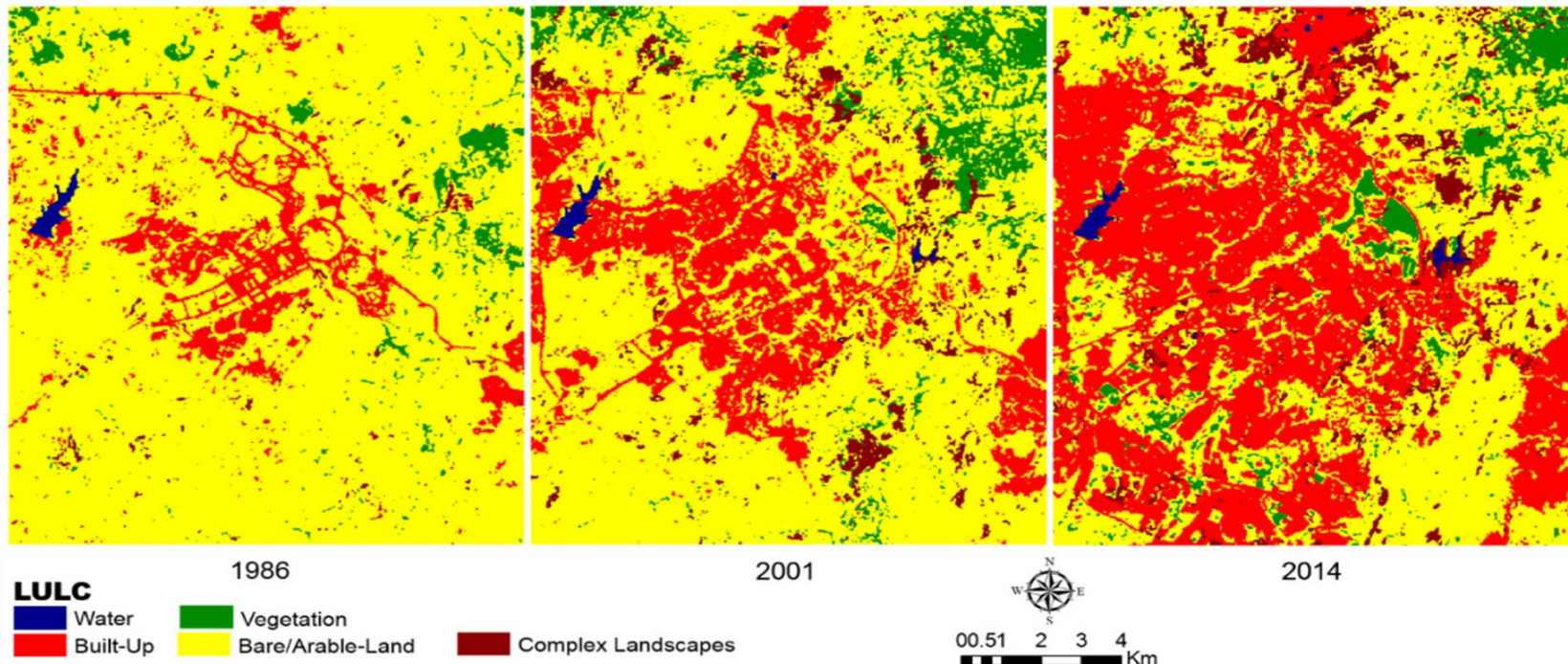
- RS has enabled availability of data at finer spatial, temporal and spectral resolution.
- Coupled with digital image analysis and processing techniques it is now possible to map and monitor wetlands and coastal ecosystems more accurately.



Source: MIMIAP-Mozambique. 2019; https://infoflr.org/sites/default/files/2020-04/coastal_and_marine_restoration_baseline_report_-_mozambique.pdf

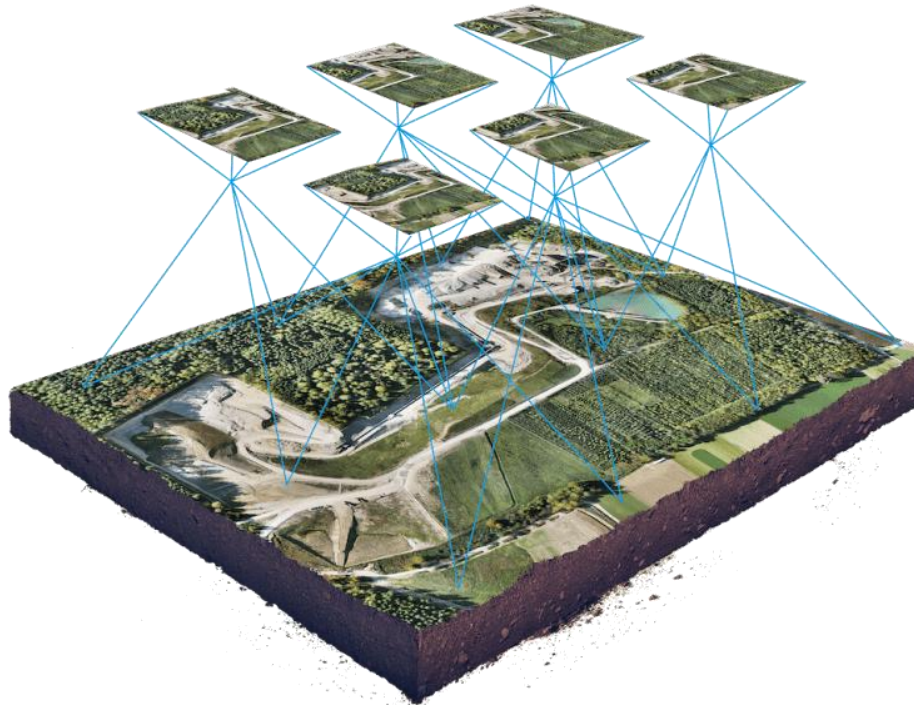
Land use land cover mapping

- Refers to the purpose the land serves, such as agriculture, settlement, recreation etc.
- Remote sensing has eased the process of land use mapping by filling the data gap.
- Land use mapping is carried out through classification which is easily carried out



Drone surveying

- Refers to the use of drones, or unmanned aerial vehicles (UAV), to capture aerial data with downward-facing sensors
- The sensors may include RGB or multispectral cameras, and LIDAR payloads
- The ground is photographed several times from different angles, and each image is tagged with coordinates.
- Results can be orthomosaics, elevation models or 3D models for extracting information such as highly-accurate distances or volumetric measurements.



Sample drone data



DRONE

WHY WINGTRA

APPLICATIONS

LEARN

JOIN ONLINE DEMO

TALK TO SALES



High accuracy tests with PPK

Camera: Sony RX1RII

Coverage: 8 ha (22 acres)

GSD: 1 cm/px (0.4 in/px)

Raw data 

White paper 



Village mapping

Camera: Sony QX1/15mm

Coverage: 20 ha (50 acres)

GSD: 3.5 cm/px (1.4 in/px)

Open 

Raw data 



Urban river and island mapping

Camera: Sony QX1/20mm

Coverage: 116 ha (287 acres)

GSD: 2.8 cm/px (1.1 in/px)

Open 

Raw data 

Source: <https://wingtra.com/mapping-drone-wingtraone/aerial-map-types/>

Questions & Comments

oloo@geopsy-research.org

The preparation of these material is supported by European Geoscience Union (EGU) Higher Education (HE) Teaching Award

