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Titles of pre-course Sentinel-2

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Introduction: Remote sensing, different applications and a short history

Introduction

Remote sensing:

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from a satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth (USGS).

A Short History:

The history of remote sensing begins with photography. The origin of other types of remote sensing can be traced to World War II, with the development of radar, sonar, and thermal infrared detection systems. Since the 1960s, sensors have been designed to operate across nearly the entire electromagnetic spectrum. Today a wide variety of remote sensing instruments are available for use in different studies (Moore, 1979). The first Earth Resources Technology Satellite, Landsat-1, was launched in 1972. Satellite platforms have evolved from a single satellite to multi-satellite constellations (Zhu et. al, 2017). Remote sensors are divided into two groups: passive sensors and active sensors (see Fig.1).

Active sensors have their own source of light. In particular, they actively send a wave and measure the backscatter reflected back to them (RADAR, LIDAR, Sonar, Sodar; etc.). On the contrary, passive sensors measure reflected sunlight emitted from the sun. When the sun shines, passive sensors measure this energy (Landsat, ASTER, Sentinel, etc.).

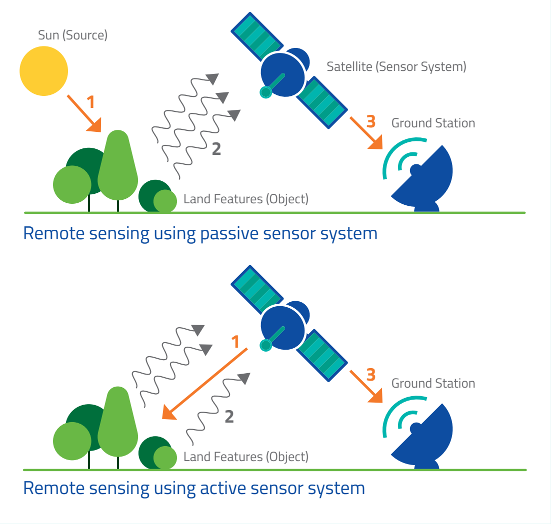


Fig.1. Remote sensing illustration: passive v. active sensors (Donev et al., 2019)

Remote sensing major application areas

Find below different uses of remotely sensed images of the Earth (USGS):

- Agriculture: Crop mapping and yield prediction; assessment of crop damages due to storms, droughts, diseases and insect outbreaks
- Forestry inventory: mapping of deforestation, logging and wildfires
- Geological mapping: Mapping of faults, folds, lineaments, rock types, alterations, etc.
- Climate: Tracking clouds to help predict the weather, erupting volcanoes, dust storms, etc.
- Urban management: Tracking the growth of a city and changes in farmland or forests over several years or decades
- Oceans: Discovery and mapping of the rugged topography of the ocean floor (e.g., huge mountain ranges, deep canyons and the "magnetic striping" on the ocean floor)

2

Source, radiation and the interaction of electromagnetic radiation with the atmosphere and natural surfaces

The Sun as an energy source

For remote sensing, it is necessary to have an energy source to illuminate the target. Similar to our eyes that need light in order to see an object, sensors also require a source of energy to illuminate the earth's surface. The sun, in the form of electromagnetic radiation (EMR), is this natural source of energy (Lillesand et al., 2002). Electromagnetic energy from the Sun reaches Earth after a journey of 150 million km. This is accomplished in eight minutes. The Sun produces a continuous spectrum of electromagnetic radiation varying in wavelength, from the very short gamma and cosmic waves (with very high frequency) up to large waves (= very low frequency) such as radio waves (see Fig.2).

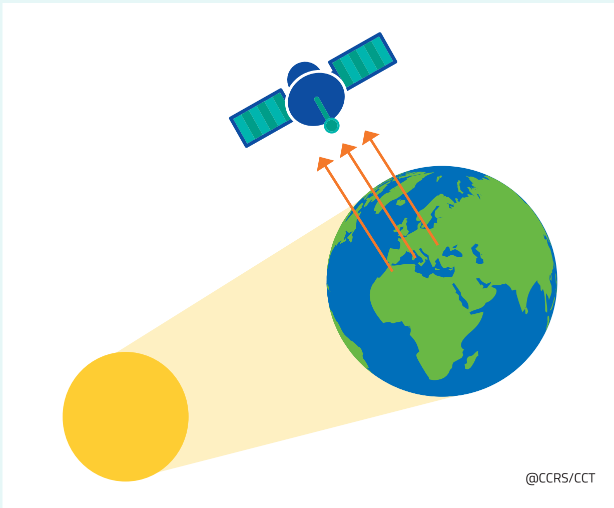


Fig.2. Sun as the source of energy (www.nrcan.gc.ca)

Electromagnetic radiation

Electromagnetic radiation is a form of energy that is all around us and takes many forms, such as radio waves, microwaves, X-rays and gamma rays. Sunlight is also a form of electromagnetic energy. However, visible light is only a small portion of the electromagnetic spectrum, which contains a broad range of electromagnetic wavelengths (see Fig.3). The set of all possible wavelengths constitutes the electromagnetic spectrum, of which we usually consider subsets depending on the application we are interested in (Lillesand et al., 2002). For example, water and vegetation reflect similarly in the visible wavelengths, however they are usually separable in the infrared.

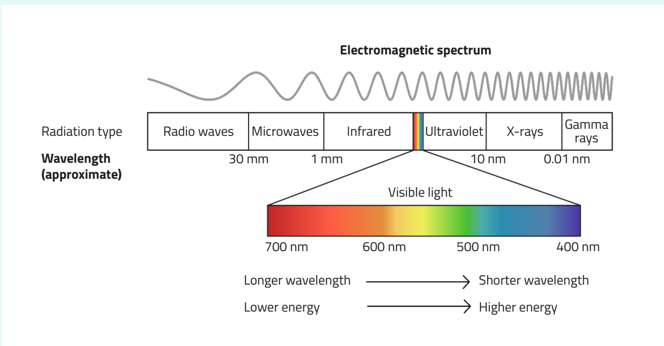


Fig.3. Electromagnetic spectrum of light classified according to the wavelength (Venier, 2016)

Remote sensing reflection and spectral reflectance curves

Three fundamental energy interactions happen when electromagnetic energy hits a given earth surface feature. This is illustrated in Fig.4. Incoming electromagnetic energy from the Sun, or incident energy, can interact with the Earth in three ways: reflection, absorption and transmission.

Applying the principle of conservation of energy, the interrelationship between these three energy interactions can be expressed as:

$E1(\lambda) = ER(\lambda) + EA(\lambda) + ET(\lambda)$

where,

E1 = incident energy

ER = reflected energy

EA = absorbed energy

ET = transmitted energy

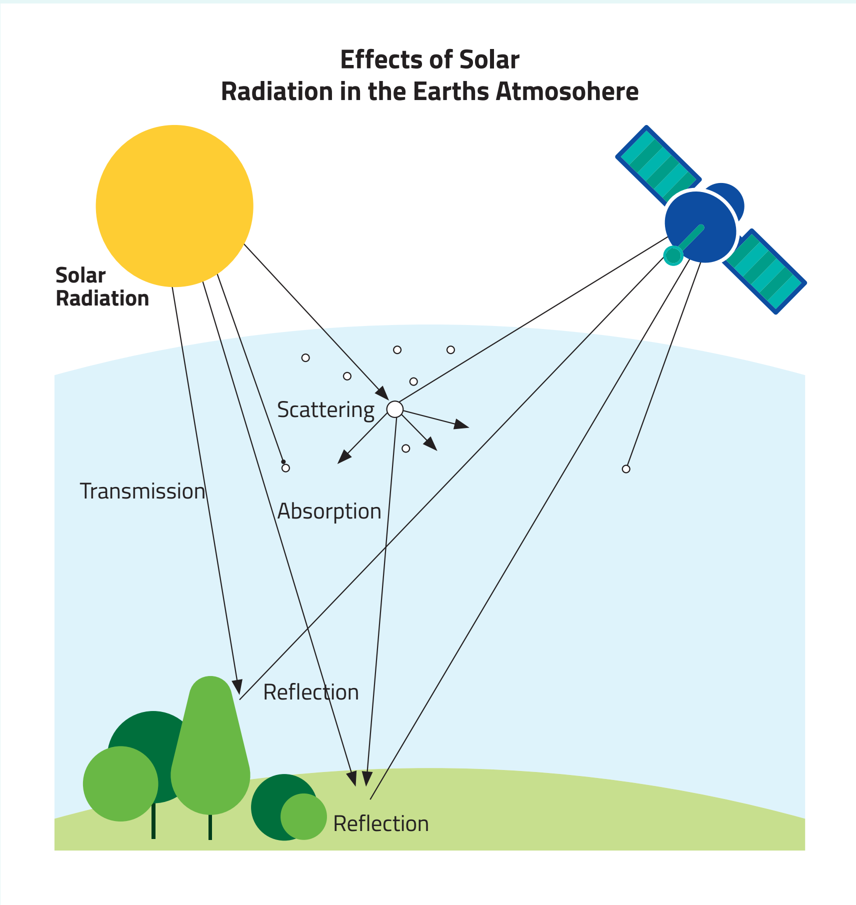


Fig.4. Remote sensing illustration, active and passive sensors (USGS)

Two main points concerning the described relationship should be considered. First, the proportions of energy reflected, absorbed, and transmitted varies for different Earth features. This depends on material type and conditions of Earth features (e.g. water, soil, snow, vegetation, etc.). These differences make it possible to distinguish different features on an image. Secondly, even within specific feature types, there is a wavelength dependency, which means that the proportion of reflected, absorbed, and transmitted energy will vary at different wavelengths. Therefore, it's possible to distinguish two features within a specific wavelength band, which were not distinguishable in another spectral range. This helps us build the spectral signature of a given feature.

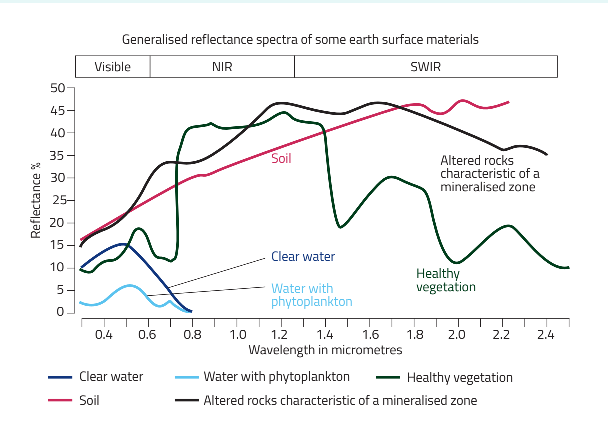
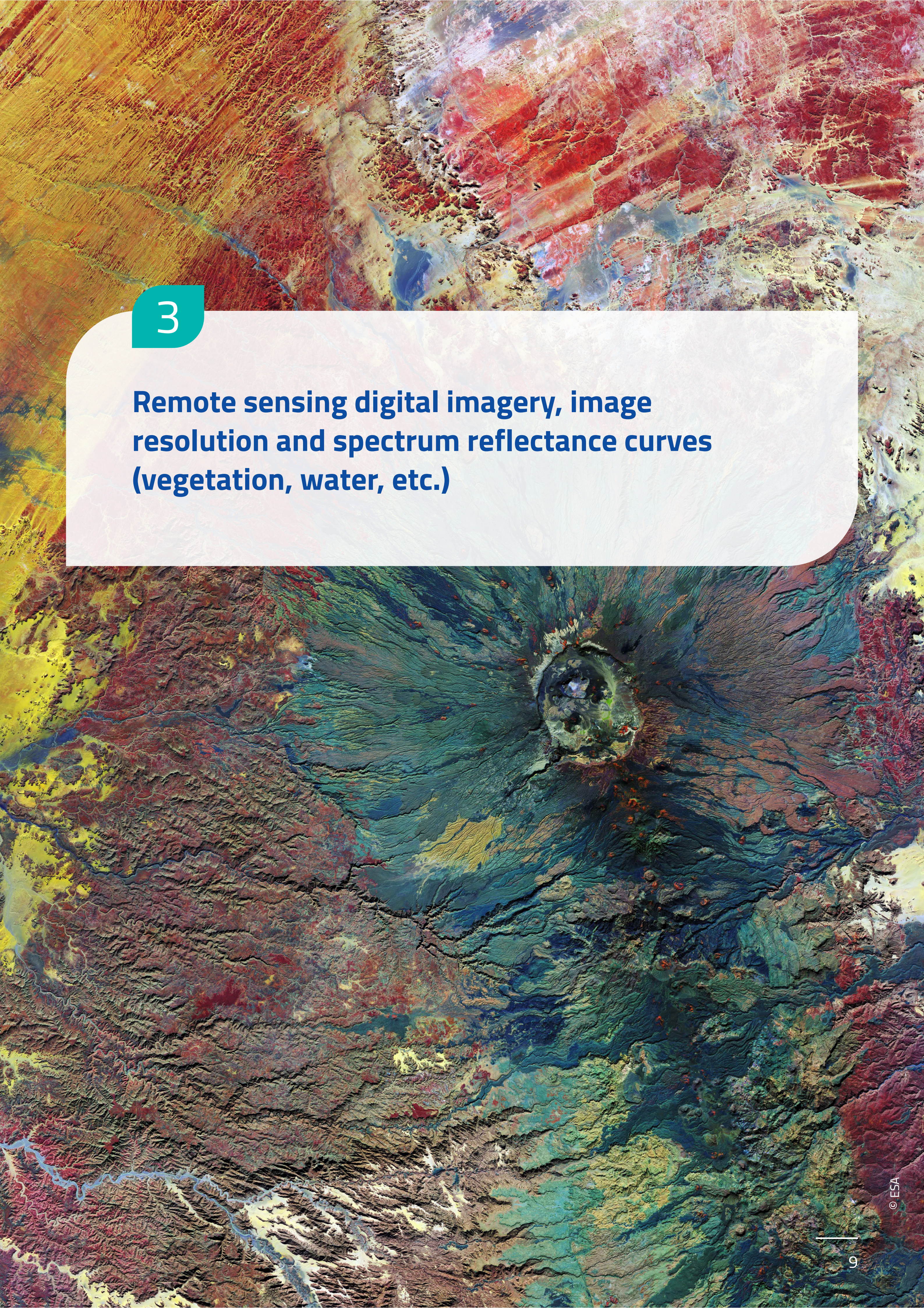


Fig.5. Reflectance spectra for five surface materials (clear water, water with phytoplankton, soil, vegetation and altered rocks) (USGS)

To illustrate the spectral response of materials (spectral signature), the measured reflected energy for different wavelengths can be represented graphically as a Spectral Reflectance Curve (see Fig.5).

To distinguish different surface features, their spectral reflectance curves can be studied and compared (in the graph of spectrum view, see Fig.5). For example, for vegetation and water, a large reflectance difference can be appreciated between the red and Near Infrared (NIR) bands. Vegetation has a low reflectance in the visible wavelength, but some reflectance in the green wavelength, and then strong reflectance in the NIR. While water shows a low reflectance in the visible wavelength, but no reflectance in the NIR (USGS).

Spectral reflectance curves indicate how much incident energy, would be reflected from the surface and subsequently recorded by a remote sensing instrument. At a given wavelength, the higher the reflectance, the brighter the object appears in an image.



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Remote sensing digital imagery, image resolution and spectrum reflectance curves (vegetation, water, etc.)

Remote sensing digital imagery

For a given image, a pictorial representation of the different wavelengths and the type of remote sensing device used to detect and record the electromagnetic energy can be produced. (www.nrcan.gc.ca). This allows an image to be represented and displayed in a digital format (called picture pixels) and the brightness of each area can be translated to numeric values or digital numbers (DN) (see Fig.6).

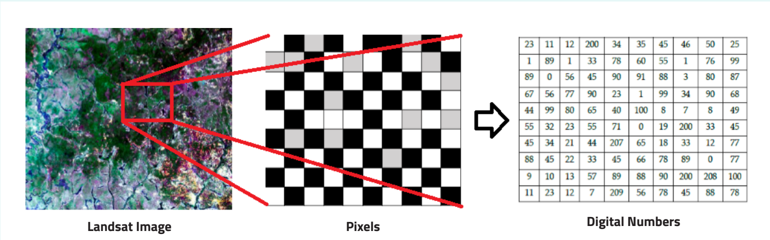

Fig.6. The remote sensing image and its pixels relating to the specified area and digital numbers extracted from the defined pixels (Phiri and Morgenroth, 2017)

With the lower DN values, the radiance of a pixel is lower. Different radiance values in different pixels show the differences of land cover surfaces. Generally, the DN values show the radiance values of pixels composing an image. However, in multispectral images, each pixel presents several bands of the electromagnetic spectrum simultaneously (Phiri and Morgenroth, 2017).

The resolution of an image refers to the potential detail provided by the imagery (https://cimss.ssec.wisc.edu). There are four types of resolution defined for each imaging system:

1. Spatial resolution (what area and how detailed)
Spatial resolution refers to how much detail in a photographic image is visible to the human eye. The ability to "resolve," or separate, small details is one way of describing spatial resolution (see Fig.7).

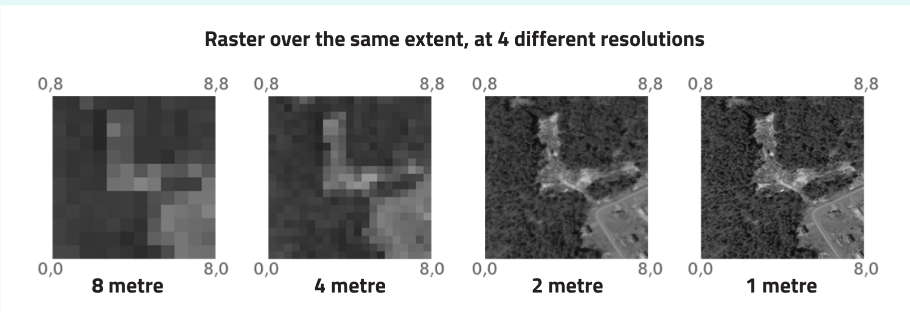

Fig.7. Raster over the same area at four different spatial resolution

2. Spectral resolution (what colors –bands)

The spectral resolution refers to the number of bands shown in an image and the spectral width of each band in the dataset. The ability of a sensor to record and define different wavelength intervals is called spectral resolution. The finer the spectral resolution, the narrower the wavelength range for a particular band (see Fig.8), allowing us to characterise more subtle spectral features.

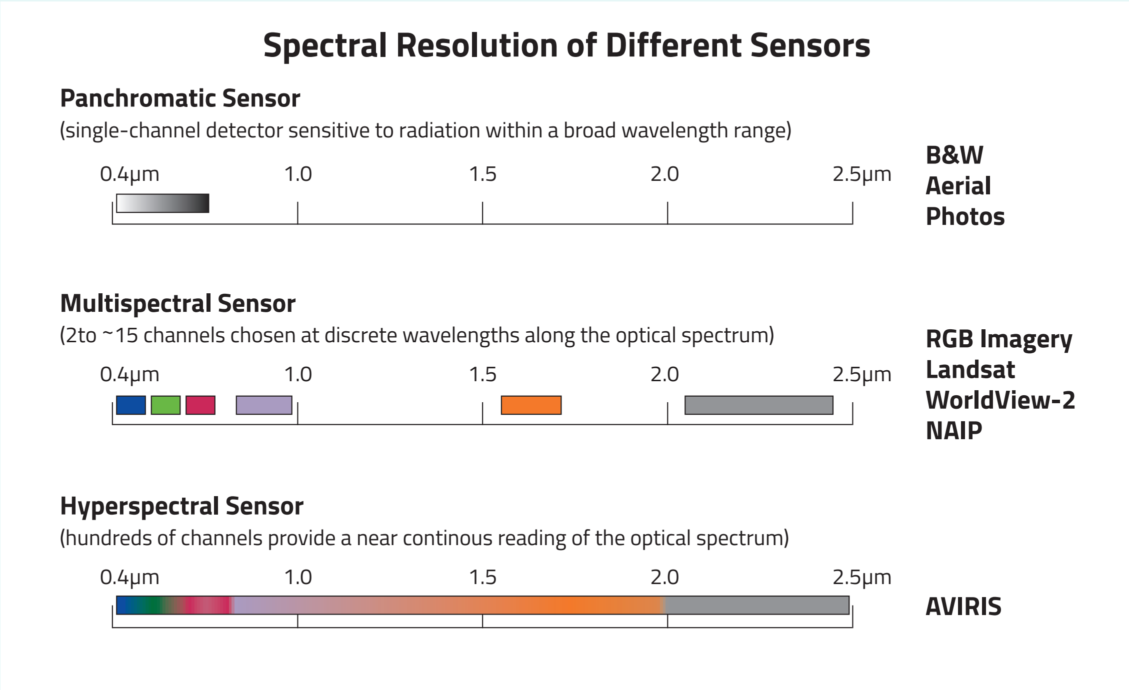

Fig.8. Spectral resolution of different sensors (https://www.harrisgeospatial.com)

3. Temporal resolution (time of day/season/year)

The repetition cycle for consecutive acquisitions of the same area by a sensor is called the temporal resolution. Some satellite systems are able to capture a specific area every one to five days (see Fig.9).

Collecting and comparing multi-temporal imagery is important to detect changes over time in the spectral characteristics of surface features (www.nrcan.gc.ca).

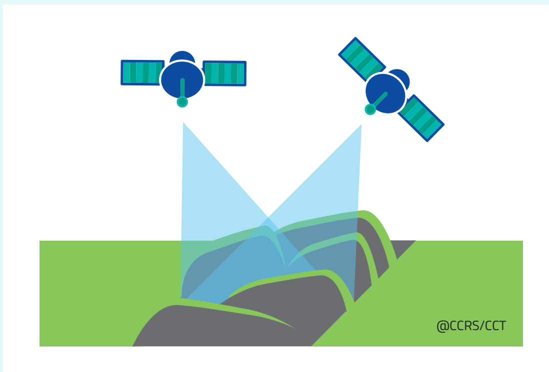

Fig.9. Temporal resolution of a sensor for a specific area (www.nrcan.gc.ca)

4. Radiometric resolution (color depth)

The capacity of a remote sensing instrument to distinguish differences in the light intensity or reflectance of a surface feature is called radiometric resolution. Generally, the radiometric resolution is presented by a bit number (see Fig. 10). These images show an area with different radiometric resolution in grey scale. The illustration on the left shows the image presented in four bits, or 16 shades of grey, which provides more details. The illustration on the right is the same but presented in 1 bits or 2 shades of grey (only black and white), therefore there are fewer details. This shows the difference in the level of detail between the two radiometric resolutions (www.nrcan.gc.ca).

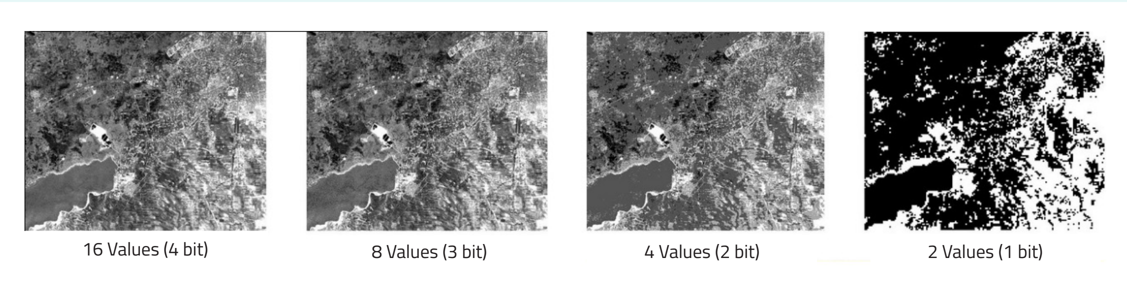

Fig.10. Radiometric resolution of four different images (www.dartproject.info)

Viewing and image processing: pre-processing (atmosphere and radiometric corrections, resampling), statistical parameters, single and multiple bands, visualisation, band operations, spatial filters, etc.

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Viewing and image processing: pre-processing (atmosphere and radiometric corrections, resampling), statistical parameters, single and multiple bands, visualisation, band operations, spatial filters, etc.

To obtain useful information on land cover types, a mathematical transformation of digital values called digital image processing is needed. Image processing involves three major stages:

1. pre-processing
2. image enhancement and transformation
3. image classification (Phiri and Morgenroth, 2017)

1. Pre-processing:

The operations generally required prior to the main data processing, analysis and extraction of information is called the pre-processing function. The two main pre-processing procedures are radiometric and geometric corrections.

Radiometric correction: This procedure involves correcting the data because of sensor irregularities and unwanted sensor or atmospheric noises. After radiometric corrections, the data accurately represents the reflected or emitted radiation measured by the sensor.

Radiometric corrections will be necessary to account for variations in scene illumination, viewing geometry, atmospheric conditions, and sensor noise and response. Each of these parameters depends on the specific sensor and platform used to acquire the data and on the conditions present during the acquisition of the data. Moreover, radiometric corrections should be performed to convert and/or calibrate the data to known (absolute) radiation or reflectance units, which will facilitate comparison between different data. The images used in the optical section of this course have already undergone radiometric corrections.

Geometric correction: This procedure requires correcting for geometric distortions due to sensor-Earth geometry variations, and results in the conversion of the data to real world coordinates (e.g. latitude and longitude) on the Earth's surface (www.nrcan.gc.ca).

The procedure to geometrically correct the original distorted image is called resampling. When there are some changes in the cell size due to change of resolution (e.g. from a 5-metre cell size to a 10-metre cell size), cell size will be different in the output raster grid of the image. The output raster of an image is the output format for the raster dataset of an image (e.g. GRID, GPEG, TIFF, etc.).

When converting raster data between different coordinate systems, cell centers don't match. In both situations, a resampling approach must be taken to specify how the output grid will take shape (see Fig.11). Mainly, there are three methods for resampling: nearest neighbour, bilinear interpolation, and cubic convolution. Nearest neighbour resampling uses the digital value from the pixel in the original image, which is nearest to the new pixel location in the corrected image. This is the simplest method and does not alter the original values, but may result in some pixel values being duplicated while others are lost (www.nrcan.gc.ca).

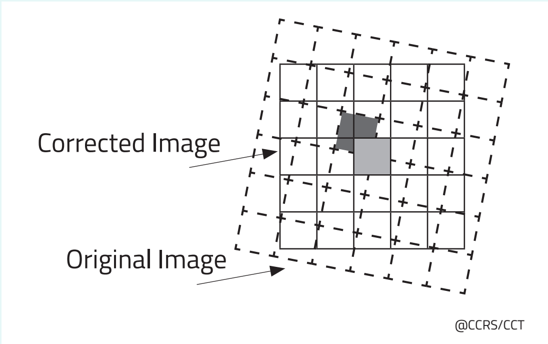

Fig.11. Resampling using the Nearest neighbor method (www.nrcan.gc.ca)

2. Image enhancement and transformation

The image enhancement process allows us to improve the appearance of an image and perform procedures assisting the visual interpretation and analysis of an image. The image enhancement procedure includes contrast stretching to increase the tonal distinction between various features in a scene and spatial filtering to enhance (or suppress) specific spatial patterns of an image.

Usually processing data from multiple spectral bands is considered an image transformation. Arithmetic operations such as subtraction, addition, multiplication and division of image bands are some examples of combining and transforming the original bands into "new" images, which better display or highlight certain features in the scene. Some relevant transformations such as band ratioing and principal components analysis, a procedure used to more efficiently represent the information in multichannel imagery, are presented in this course (www.nrcan.gc.ca).

Spatial filtering

Spatial filtering consists in selecting a small window of a few pixels in a specific dimension (e.g. 3x3 or 5x5), applying a mathematical calculation to the pixel values within the selected window (e.g. calculating the average), and replacing the central pixel with the new value. The window is then moved along both in the row and column dimensions one pixel at a time, until the entire image has been covered (Fig.12). By calculating the average of a small window around each pixel, a smoothing effect is achieved, and the visual appearance of the speckle is reduced (www.nrcan.gc.ca)

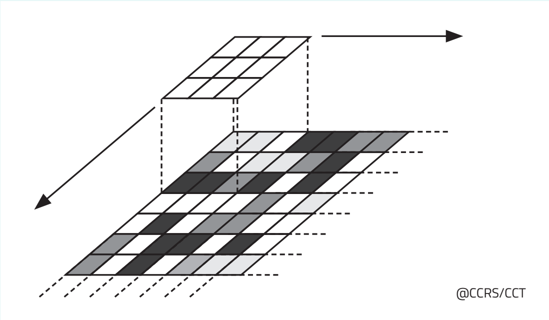

Fig.12. Spatial filtering using a 9x9 window (www.nrcan.gc.ca)

Normalised Difference Vegetation Index (NDVI)

One of the widely used image transformations is the Normalised Difference Vegetation Index (NDVI), which has been used to monitor vegetation conditions on continental and global scales (www.nrcan.gc.ca). The NVDI can be derived using the following formula:

$$NVDI = \frac{NIR-R}{NIR+R}$$

Where NIR is the spectral reflectance measured in near infrared and R is the spectral reflectance measured in red wavebands. This index is widely used for monitoring ecosystems because it allows researchers to create images due to different vegetation type and the condition of the land surfaces. Moreover, by NDVI index, it is possible to monitor changing conditions such as vegetation density, soil colors, deforestation and natural disturbances (USGS).

Principal Component Analysis (PCA)

The objective of Principal Component Analysis (PCA) is to reduce the dimensionality (e.g. the number of bands) in the data and compress the information in the original bands into fewer bands. The result of this statistical procedure is “new” bands that are called components (see Fig.13).

For more information on PCA, please read:

https://builtin.com/data-science/step-step-explanation-principal-component-analysis

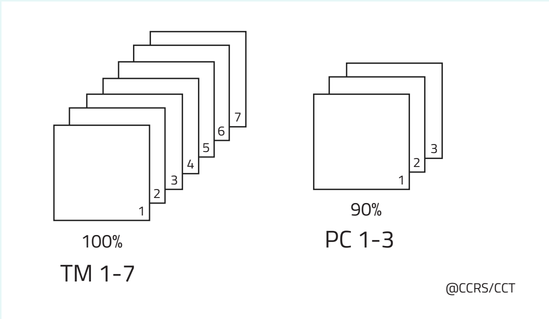

Fig.13. Thematic mapper (TM) transformation into principle component (PC) (www.nrcan.gc.ca)

Statistical Parameters

Different statistical parameters are used in remote sensing analysis. Statistical parameters are useful in analysis of remote sensing data. A commonly used tool to study the statistical parameter is the image histogram, a key tool to represent the brightness values that comprise an image. The brightness values (i.e. 0-255) are displayed along the x-axis of the graph. The frequency of occurrence of each of these values in the image is shown on the y-axis. The brightness values can be used for classification studies. Therefore, before performing any kind of classifications, it is necessary to examine its histogram to check the range of useful data and its distribution (www.nrcan.gc.ca).

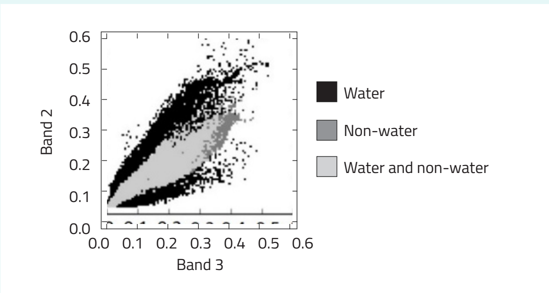

Fig.14. An example of a scatter plot between Band 2 and Band 3

Scatter plots are diagrams to define the correlation between different bands (see Fig.14). Scatter plots consist of a geometric pattern. If the pattern is a narrow ellipse (means that all bands' values are in the middle, between two axes with about a 45° angle from both axes), the two bands are strongly correlated. If a shape other than to an ellipse occurs, this usually denotes a bimodal or polymodal distribution (Short et al., 1999).

Band Ratios

Band ratios refer to combinations of selected bands using mathematical operations to identify specific targets. One of the main uses of band-ratio images is geological mapping, especially for the identification of rock and hydrothermal alteration types (Yamaguchi et al., 1998, 2001). As an example, Table 1 shows band combinations that fall in the wavelength range of Sentinel-2A MSI (Van der Werff and Van der Meer, 2016). The expressions in the right column show the mathematical operations between selected bands defined for highlighting the relative feature on the surface (for example ratio 4/2: band 4 of Sentinel-2 divided by band 2, to detect all iron oxide features).

Feature	Sentinel-2A MSI
All iron oxides	4/2
Ferrous iron oxides	4/11
Ferric Iron, Fe3+	4/3
Ferrous Iron, Fe2+	12/8 + 3/4
Laterite	11/12
Ferrous silicates	12/11
Ferric oxides	11/8

3. Image classification

Image classification is a procedure to classify pixels. Usually classification operations are performed on multi-channel data sets (A) and based on statistical characteristics of the pixel brightness values. This process assigns each pixel

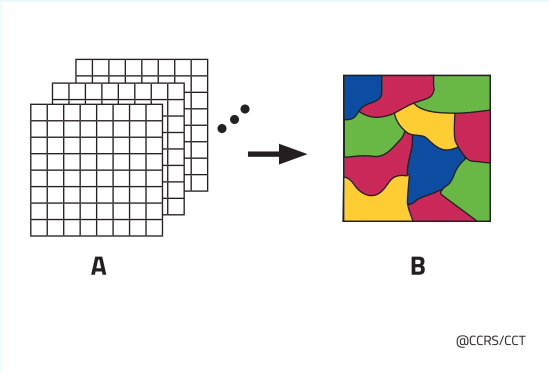

Fig.15. Classification of data from multiple image (www.nrcan.gc.ca)

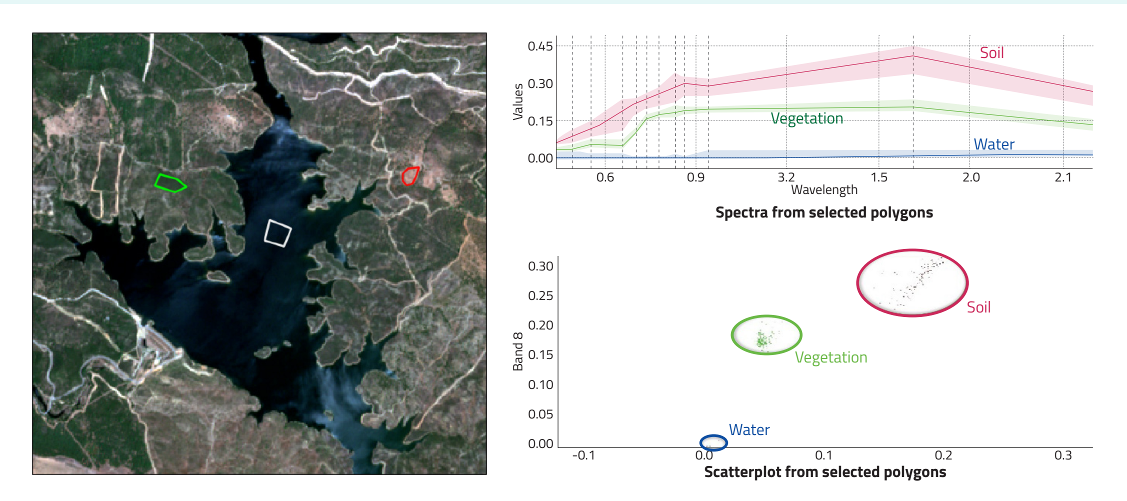

Fig.16. Classification of data from spectral signatures

in an image to a particular class or theme (B) (see Fig.15). The resulting raster from image classification can be used to create thematic maps.
There are different approaches to perform digital classification. In this course, the two generic approaches are briefly presented, namely supervised and unsupervised classification. In fact, different surface features have different spectral signatures, which can be characterised or classified from a statistical point of view (see Fig. 16).

Unsupervised classification

The unsupervised classification process is used when there is a need to classify spectral groups of an image, based on the numerical information in the data. It means assigning pixels of an image to spectral classes without the knowledge of their existence and names. Different clustering algorithms are used to define the statistical groupings in the data. To perform the unsupervised classification, one needs to specify the desired number of classes, the separation distance among the clusters and the

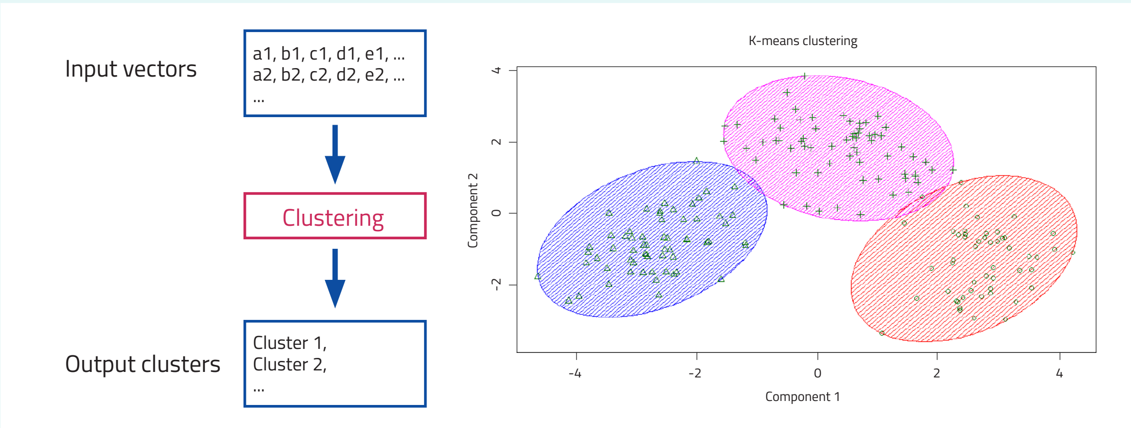

Fig.17. Unsupervised classification of data using K-mean clustering

variation within each cluster (www.nrcan.gc.ca). The most used clustering algorithm is K-mean clustering (see Fig.17).

The K-Mean is an unsupervised classification method, which interactively classifies pixels into clusters in space in the nearest class with the minimum distance. Within each iteration, there is a recalculation of the class means and pixels will be reclassified according to the new means. Hence, the majority of pixels can be classified into the nearest class, however, some pixels may be unclassified due to selected criteria (e.g. a specified standard deviation or distance threshold). This process continues until the number of pixels in each class reaches a value lower than the imposed threshold or until it reaches to the selected maximum number of iterations (www.nrcan.gc.ca).

Supervised classification

Supervised classification can be performed when there are some representative and homogeneous samples from different types of surface features. These representative samples are used as training data. In order to create a training data sample, target areas with different surface features, known geographical area and known real surface types are selected. Then, samples from these known areas can be employed as training data and used in the classification procedures. This process is known as supervised classification (www.nrcan.gc.ca).

In this course, the Random Forest method is used. The Random Forest method is an approach employing "random forests of classifiers" (RFC). The RFC method involves developing multiple trees from randomly sampled subspaces of input features, then combining the resulting outputs via voting or a maximum a posteriori rule. This is done

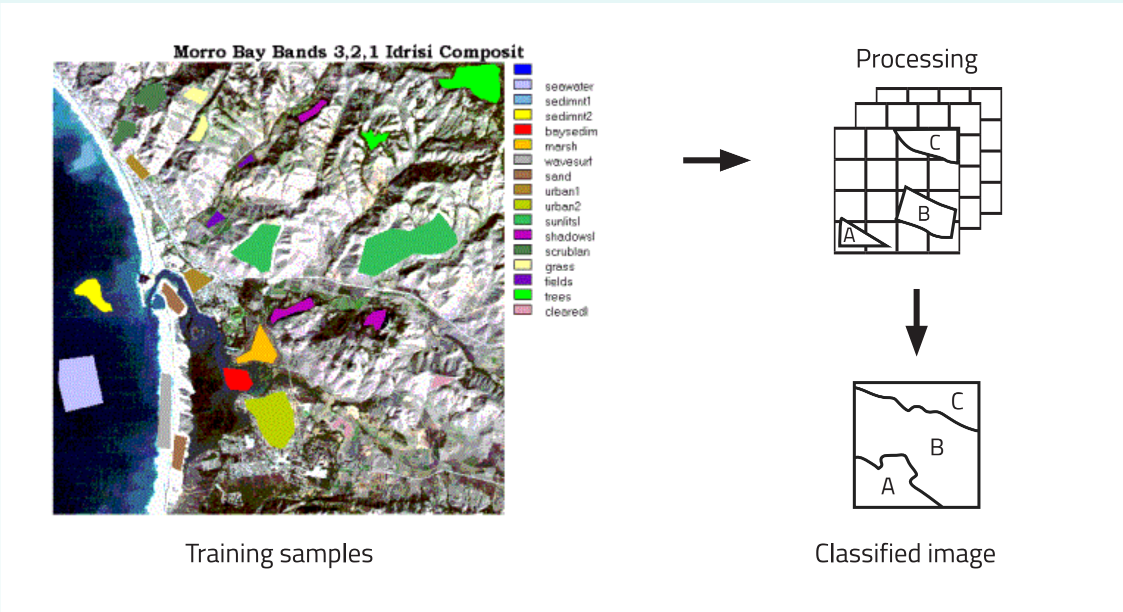

Fig.18. Supervised classification of data using training samples (redraw from image source: Short, N. 2009. The Remote Sensing Tutorial, Section 1, www.nrcan.gc.ca)

with an algorithm that trains several classifiers and combines their results through a voting process. The classifier uses a large number of individual decision trees and performs classification by majority voting on these trees to find the most popular class (Breiman, 2001).

Spectral Angle Mapper (SAM)

The Spectral Angle Mapper (SAM) is a tangible spectral classification that uses the minimum angle to match pixels with a set of reference spectra (endmembers, e.g. spectral library or training data). In an n-dimensional multispectral space, a pixel vector x has both magnitude (length) and an angle measured with respect to the axes that define the coordinate system of the space.

The spectral angle mapping approach considers only the angular information, reducing the dimensionality of the problem by not considering the magnitude. The algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands. SAM compares the angle between the endmember spectrum vector and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified (Kruse et al., 1993).

5

Introduction to remote sensing platforms and sensors, Copernicus programme, satellites, acquisition systems, introduction of sentinels

Remote sensing platforms and sensors

For remote sensors, there are different platforms situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere. Satellites belong to space-borne platforms.

In general, for remote sensing satellites, three types of orbits are used: geostationary, equatorial, and sun-synchronous orbits. Geostationary satellites rotate around the earth in 24 hours, and therefore the satellite remains over the same location on Earth (common examples are communication and weather satellites). Equatorial orbit satellites circle the Earth at a low inclination (the inclination is the angle between the orbital plane and the Earth's equatorial plane). Equatorial orbits can be useful for satellites observing tropical weather patterns because they can monitor cloud conditions around the globe (galactics@spacesim.org).

Finally, sun-synchronous satellites have orbits with high inclination angles, passing nearly over the Earth's poles. Many of these sun-synchronous satellites cover each area of the world at a constant local time of day called local sun time. Radarsat is an example of a satellite in a low sun-synchronous orbit. Regarding the timing of orbits, they are timed according to the local time at which the satellite passes over the equator (Zhu et. Al, 2017).

As previously mentioned, there are two types of sensors, active and passive, which can be used to actuire remote sensing images. Given their different combination of frequency bands and polarisation modes, sensors can be categorised into four classes:

- Single frequency (L-band, C-band, or X-band)
- Multiple frequency (a combination of two or more frequency bands)
- Single polarisation (VV, HH, or HV)
- Multiple polarisation (a combination of two or more polarisation modes) (Zhu et. Al, 2017)

Copernicus Programme

Copernicus is the European Union's Earth Observation (EO) and monitoring programme. Copernicus is managed by the European Commission in partnership with the European Space Agency (ESA), EU Member States and EU Agencies.

The aim of this programme is to achieve a global, continuous, autonomous, high quality and wide range EO capacity (Copernicus.eu). This is done by collecting large amounts of data and aggregating it with ground-based measurement systems, airborne and seaborne measurements to create timely and quality information, services and knowledge. Copernicus provides information on the environmental and security domains on a global scale to support the work of service providers, public authorities and other international organisations as well as improve the quality of life for European citizens. The Copernicus programme offers a wealth of information comprising satellite, air and ground sensor data to allow users to form a comprehensive picture of the "health" of Earth.

Copernicus and its satellites generate over 12 TB of publicly-available, open-access and free Earth Observation data daily via the Copernicus services. These services are data platforms providing information across six service themes: atmosphere, marine, land, climate, emergency and security (Copernicus.eu). There are three components contributing to Copernicus' data provision (Copernicus.eu.):

- Space component, which includes observation satellites and associated ground segments with missions observing land, atmospheric and oceanographic parameters. This component comprises two types of satellite missions: ESA's five families of dedicated Sentinels (space missions) and missions from other space agencies, called Contributing Missions.
- In-situ measurements which include ground-based and airborne data-gathering networks providing information on oceans, continental surface and atmosphere
- Services developed and managed by Copernicus and offered to its users and public in general (like data access portals)

Introduction to Sentinels

ESA's Sentinel programme comprises five satellite families – part of Copernicus' space component (https://sentinel.esa.int/web/sentinel/missions). The objective of the Sentinel programme is to develop a series of EO missions on behalf of the joint ESA/European Commission initiative Global Monitoring for Environment and Security (GMES). The programme is composed of five Sentinel missions, each one focusing on a specific aspect of EO including atmospheric, oceanic, and land monitoring. The Sentinels provide a unique set of observation data. For example, Sentinel-1A and -1B, launched in April 2014 and April 2016 respectively, offer all-weather, day and night radar images. Sentinel-2A, launched in June 2015, was designed to deliver high-resolution optical images for land services. The second satellite, Sentinel-2B, joined its twin in orbit in March 2017.

The two Sentinel-3 satellites were launched next in February 2016 and 25 April 2018, respectively. Sentinel-3 provides data for services relevant to the ocean and land. Sentinel-4 and -5 offer data for atmospheric composition monitoring from geostationary and polar orbits, respectively. Finally, Sentinel-6 will carry a radar altimeter to measure global sea-surface height primarily for operational oceanography and for climate studies (planned to be launched in 2020) (https://sentinel.esa.int/web/sentinel/missions). The summary of Sentinel missions is shown in Fig.19 (Jutz, 2015).

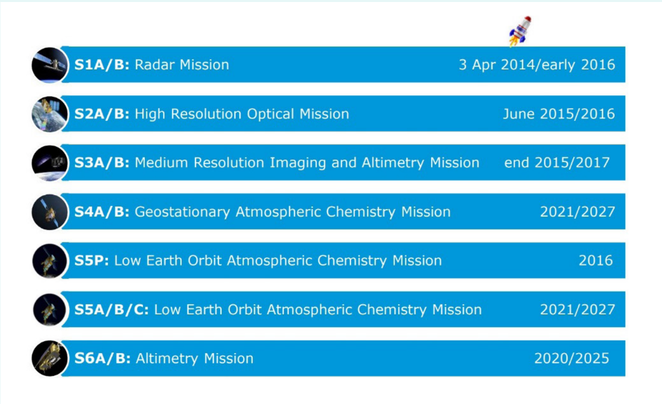

Fig.19. Copernicus Space Component: the dedicated Sentinels (Jutz, 2015)

This course's focus on mining and environmental applications will allow for the employment of Sentinel 1 and 2 data in selected case studies.

Sentinel-1 Mission:

The Copernicus Sentinel-1 mission, as the first ESA mission and operates day and night performing C-band synthetic aperture radar imaging. The mission comprises a constellation of two polar-orbiting satellites and produces a consistent long-term data archive built for applications based on a long time series. The Sentinel-1 mission covers the entire world's land masses on a bi-weekly basis; sea-ice zones, Europe's coastal zones and shipping routes on a daily basis and open ocean continuously by wave images (https://sentinel.esa.int/web/sentinel/missions). More information is in the Sentinel-1 section of the pre-course materials.

Sentinel-2 Mission:

The Copernicus Sentinel-2 mission aims to monitor variability in land surface. The orbital swath width is about 290 km and its high revisit time (10 days at the equator

Sentinel-2 bands	Sentinel-2A		Sentinel-2b		
	Central wavelength (nm)	Bandwith (nm)	Central wavelength (nm)	Bandwith (nm)	Spatial resolution (m)
Band 1 - Coastal aerosol	442.7	21	442.2	21	60
Band 2 - Blue	442.4	66	492.1	66	10
Band 3 - Green	559.8	36	559.0	36	10
Band 4 - Red	664.6	31	664.9	31	10
Band 5 - Vegetation red edge	704.1	15	703.8	16	20
Band 6 - Vegetation red edge	740.5	15	739.1	15	20
Band 7 - Vegetation red edge	782.8	20	779.7	20	20
Band 8 - NIR	832.8	106	832.9	106	10
Band 8A - Narrow NIR	864.7	21	864.0	22	20
Band 9 - Water vapour	945.1	20	943.2	21	60
Band 10 - SWIR - Cirrus	1373.5	31	1376.9	30	60
Band 11 - SWIR	1613.7	91	1610.4	94	20
Band 12 - SWIR	2202.4	175	2185.7	185	20

Table.2. Sentinel-2 Bands (Multi-Spectral Instrument (MSI) Overview, Sentinel Online. European Space Agency. Retrieved 3 December 2018)

with one satellite, and 5 days with 2 satellites under cloud-free conditions, which results in 2-3 days revisit time at mid-latitudes) supports the monitoring of terrestrial surface changes. The offered coverage is from latitude 56° south to 84° north.

Sentinel-2 carries an optical instrument with 13 spectral bands: four bands at 10 metres, six bands at 20 metres and three bands at 60 metres spatial resolution (see Table.2).

The spectral bands of Sentinel-2 provide data for land cover / change classification, atmospheric correction and cloud / snow separation (https://sentinel.esa.int/web/sentinel/missions).

The main characteristics of Sentinel-2 data are (https://sentinel.esa.int/web/sentinel/missions):

- systematic global acquisitions of high-resolution, multispectral images allied to a high revisit frequency
- continuity of multi-spectral imagery provided by the SPOT series of satellites and the USGS LANDSAT Thematic Mapper instrument
- observation data for the next generation of operational products, such as land-cover maps, land-change detection maps and geophysical variables

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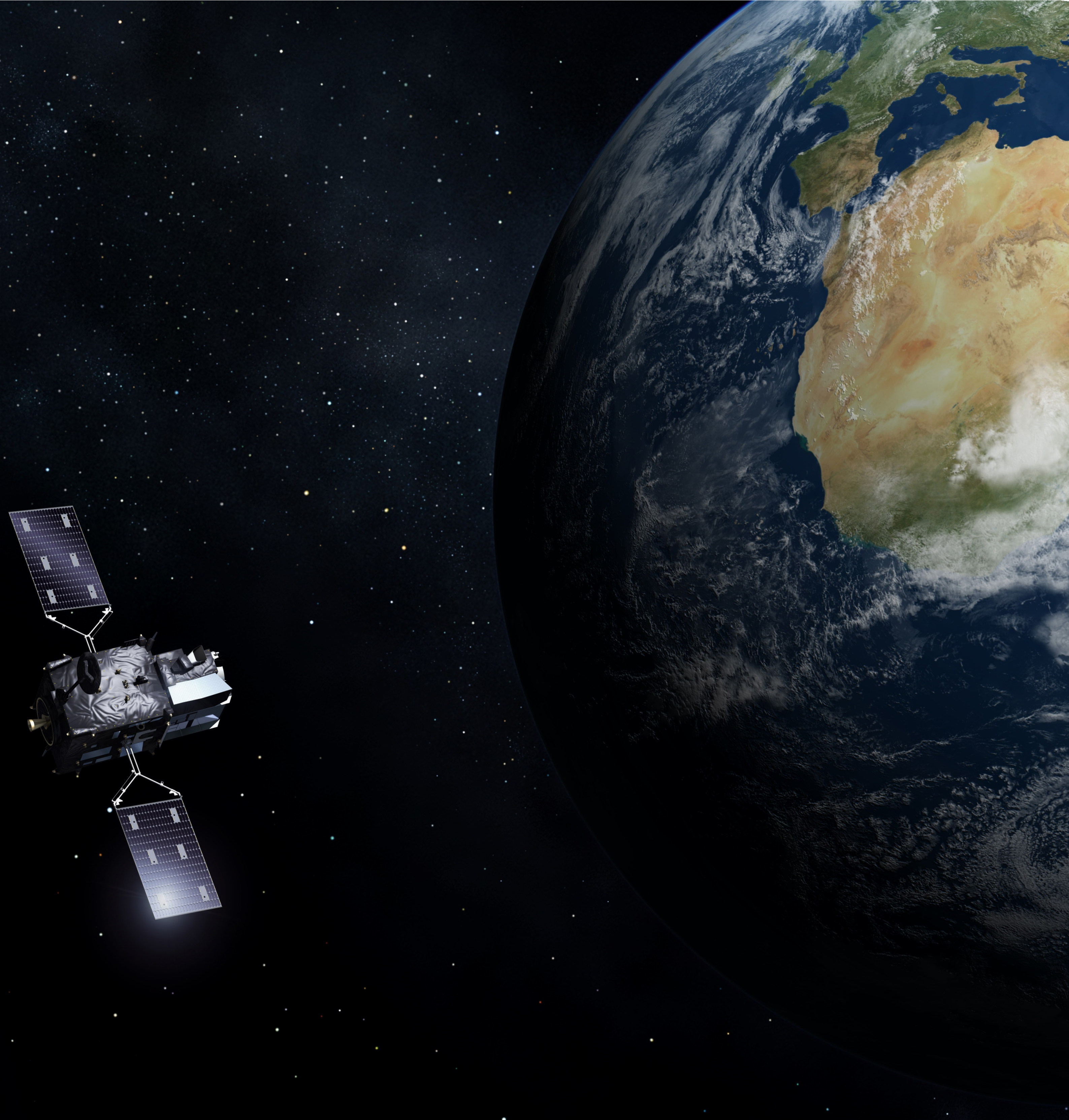
Notes



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