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ARCH Interreg Project

Assessing Regional Changes to natural Habitats – photo-interpretation, mapping and study of the potential of new remote sensing technologies for monitoring natural habitats and biodiversity in the Nord – Pas de Calais and Kent regions.

LOT N°2

STUDY INTO THE POTENTIAL OF NEW REMOTE SENSING TECHNOLGOIES FOR MONITORING NATURAL HABITATS AND BIODIVERSITY IN THE NORD – PAS DE CALAIS CROSS-BORDER REGION

Report on Mission 3

"Inventory of remote sensing technologies applicable to the ARCH Project"

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- Summary

Beyond the inventory of experiences produced during Mission 2, Mission 3 aims to produce technical documentation on remote sensing technology. Mission 2 consisted of producing an inventory of significant European experiences carried out in the fields of remote sensing, biodiversity and natural habitat monitoring in Europe.

This report will present an analysis of remote sensing technologies and methodologies. This documentation should help lay the foundations of the guiding principles of remote sensing in order to meet the future needs of users.

The following aspects have been looked at: the physical principles of remote sensing (the founding principles, as well as the notions of electromagnetic waves, spectrum, orbit and the resolutions of satellite images), the different types of sensors attached to satellites (both active and passive, and currently available or to be available in the future), the different types of data pre-processing, the remote sensing software available, as well as the methods for extracting information, the traditional and operational methods (e.g. CAPI, semi-automatic methods, etc.), and methods from “Research and Development”.

This presentation and analysis of remote sensing technologies has enabled recommendations to be made for the ARCH Project study. These recommendations are on aspects such as the nomenclature of the map, the geographical expanse, compromises between the different resolutions, the focus on one specific area of interest, costs, the choice of methodology and data, multi-temporality and on national and European remote sensing initiatives.

Taking into account the initial needs expressed by the different users (i.e. GIS and end users), and taking account of the different perspectives and potential uses of satellite technologies highlighted in this report, several large areas for development are suggested to the Nord-Pas de Calais and Kent regions in terms of implementing different updating scenarios. These areas for development concern detecting rapid changes, updating the whole (i.e. regional) of the ARCH database annually, a specific localised need or a need for possible occasional updating and the exploration and integration of new technologies.

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List of abbreviations

ARCH	Assessing Regional Changes to Habitats
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
LR	Low Resolution
CASI	Compact Airborne Spectrographic Imager
CCRS/CCT	Canada Center for Remote Sensing / Centre Canadien de Télédétection
Cemagref	French National Centre for Agriculture and Forestry, Engineering and Water Management
CIRAD	French Agricultural Research Centre for International Development
CORINE	Coordination of environmental information
DEM	Digital Elevation Model (see DTM)
DIREN	Regional Directorate for the Environment
DMC	Disaster Monitoring Constellation
EEOS	Epidemiology Earth Observation Services
ENGREF	French National College for Rural Engineering, Water and Forests
ENVISAT	Environmental Satellite
EOS	Earth Observing System
ERS	European Remote Sensing Satellite
ESA	European Spatial Agency
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetal Index
GEO	Group on Earth Observations
GEOSUD	GEOInformation for SUstainable Development
GMES	Global Monitoring for Environment and Security
GPS	Global Positioning System
HR	High Resolution
GHR	Geometric High Resolution
INBO	Instituut voor Natuur – en Bosonderzoek (Research Institute for Nature and Forests
IR	Infrared
IRD	Research Institute for Development
IRS-LISS	Indian Remote Sensing Satellite - Linear Imaging and Self Scanning Sensor
OJ	Official Journal
LIDAR	LIght Detection And Ranging
METEOSAT-VISSR	Meteo Satellite - Visible and Infrared Spin Scan Radiometer
DEM	Digital Elevation Model

DTM	Data Terrain Model
MODIS	Moderate Resolution Imaging Spectroradiometer
MR	Medium Resolution
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NOAA-AVHRR	National Oceanic and Atmospheric Administration's - Advanced Very High Resolution Radiometer
NPdC	Nord-Pas de Calais
CAPI	Computer Assisted Photo Interpretation
NIR	Near Infra-red
PNRZH	French National Wetlands Research Programme
RADAR	RAdio Detection And Ranging
RADARSAT	RADAR Satellite
RGB	Red-Green-Blue
SAR	Synthetic Aperture Radar
GIS	Geographical Information System
SIRS	Systèmes d'Information à Référence Spatiale (Spatial Reference Information Systems)
SONAR	SOund NAvigation and Ranging
SPOT	Satellite Probatoire pour l'observation de la Terre (Probationary System of Earth Observation – a satellite)
VHR	Very High Resolution
TM	Thematic Mapper
UTM	Universal Transverse Mercator
VITO	Institut Flamand de Recherche Technologique (Flemish Technological Research Institute
WGS	World Geodetic System

Remote Sensing Glossary

Glossary from the website of the Canada Centre for Remote Sensing:
(http://cct.rncan.gc.ca/glossary/index_f.php)

Active sensor: A sensing system which sends out radiation and measures the part of the radiation which is backscattered by the surface of the Earth. Radar is an example of an active system. It sends out pulses of microwaves and then receives the echo reflected (backscattered) from the target.

Aerial remote sensing: Remote sensing from an airborne platform (such an airplane).

Aerosol: A suspension of ultramicroscopic particles in a gas, smoke or fog.

Albedo: The ratio of the radiation reflected from an object to the total amount incident upon it, for a particular portion of the spectrum.

Atmospheric absorption: The process whereby some or all of the energy of sound waves or electromagnetic waves is transferred to the constituents of the atmosphere.

Atmospheric reflectance: Ratio of reflected radiation from the atmosphere to incident radiation.

Atmospheric scattering: The random dispersion of electromagnetic radiation by particles in the atmosphere.

Automatic classification: Process that groups data according to some criteria by automatic or semi-automatic as opposed to purely manual methods. During classification, each pixel is compared to each of the class signatures. The comparison is performed by computer using a predetermined classification algorithm. The most commonly used classifiers are: Minimum Distance (to Means) Classifier, Parallelepiped Classifier, and the (Gaussian) Maximum Likelihood Classifier. Once a pixel has been assigned to a class, it is given the class value in the corresponding cell of the 'classified' image.

Bidirectional reflectance: Bidirectional reflectance is an expression which relates the reflection by the surface of a target with the reflection by a lambertian surface that would be observed at the location of the target.

Colour composite: A colour image produced through optical combination of multiband images by projection through filters.

Contrast enhancement: A radiometric enhancement technique used to improve the visual contrast of an image. It matches the data's dynamic range to the dynamic range of the display medium (photographic or digital).

Data Base: An information store of related data usually in digital form organized in such a manner that retrieval and updating can be done on a selective basis and in an efficient manner.

Digital Terrain Model: A three-dimensional representation of the relief of a piece of land in a numerical format.

Electromagnetic spectrum: The total range of wavelengths or frequencies of electromagnetic radiation, extending from the longest radio waves to the shortest known cosmic rays.

Electromagnetic wave: A wave described by variations in electric and magnetic fields, elegantly described in a formulation by J. C. Maxwell in 1873.

Error matrix: A matrix or table that displays statistics for assessing image classification accuracy by showing the degree of misclassification among classes.

False colour composite: An image produced by displaying multiple spectral bands as colours different from the spectral range they were taken in.

Geographic Information System (GIS): A computer-based system designed to input, store, manipulate, and output geographically referenced data.

Georeferencing: An operation which involves attributing to a set of phenomena geographical coordinates to define their exact position in relation to a geographical reference system.

Geostationary orbit: An orbit around the Earth whereby a satellite travels in the same direction and completes the orbit in the same time as the Earth completes a revolution. Hence, the satellite maintains a fixed position relative to the surface of the Earth.

Geosynchronous orbit: An orbit around the Earth whereby a satellite travels in a general west-to-east direction and completes the orbit in the same time as the Earth completes a revolution.

Ground reflectance: The ratio of the intensity of reflected radiation from the ground surface to that of the radiation incident on the ground surface.

High pass filter: A type of spatial filter that uses a convolution filter to produce an image that emphasizes areas of fine spatial detail (e.g. edges).

Hyperspectral imaging: The simultaneous acquisition of images of the same area in many (usually 100 or more), narrow, contiguous, spectral bands. The preferred term is “imaging spectroscopy”.

Hyperspectral remote sensing: Data acquired using an airborne radiometer which detects electromagnetic radiation in several spectral bands simultaneously, ranging up to several hundreds (for example, the CASI hyperspectral sensor can make measurements in 288 bands and AVIRIS can make measurements in 224 bands).

Illumination: The luminous flux which a surface receives per unit area.

Image processing: Encompasses all the various operations which can be applied to photographic or image data. These include, but are not limited to image compression, image restoration, image enhancement, pre-processing, quantization, spatial filtering and other image pattern recognition techniques.

Image resampling: A technique for geometric correction in digital image processing.

Image restoration: Reconstruction of an image from digital or analogue data. A process by which a degraded image is restored to its original condition.

Image texture: The frequency of change and arrangement of image tones, or the pattern of spatial tone variations.

Kappa co-efficient: A statistical measure of the agreement, beyond chance, between two maps (e.g. output map of classification and ground-truthed map).

Low pass filter: A type of spatial filter that uses a convolution filter to produce an image that appears smoother in comparison to the original data.

Luminance: The quantitative attribute of light that correlates with the sensation of brightness and is the evaluation of radiance by means of the standard luminosity function.

Mie scatter: A form of atmospheric scatter that occurs when radiation interacts with atmospheric particles whose diameter is approximately equal to the wavelength of the radiation.

Mosaic: An assemblage of overlapping aerial or space photographs or images whose edges have been matched to form a continuous pictorial representation of a portion of the earth surface.

Multi-spectral remote sensing: Data acquired by a radiometer which detects electromagnetic radiation in several spectral bands simultaneously (for example, the multi-spectral SPOT 3 sensor measures a quantity of radiation in three spectral bands: green, red and near-infrared).

Non-selective scatter: A form of atmospheric scatter that occurs when radiation interacts with atmospheric particles whose diameter is much larger than the wavelength of the radiation.

Optical system: A collection of mirrors, lens, prisms, and other devices (placed in some specified configuration) which reflect, refract, disperse, absorb, polarize, or otherwise act on light.

Orbit: The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves.

Orthophotography: An aerial photograph which corrects distortions due to the shape of the Earth, the inclination of the view the photo is taken from and the relief of the terrain. The distortions are corrected by transforming, in small areas, the projection perspective of the photograph into an orthogonal projection by continuously adjusting the scale ratio to be in-line with the relief. It uses the same projection systems as for maps.

Passive sensor: A sensing system that detects or measures radiation emitted or reflected by the target. The signal received by the passive sensor may be composed of energy emitted by the atmosphere, reflected energy from the surface, energy emitted by the target, or energy transmitted then emitted by the surface.

Photo-interpretation: Interpreting the characteristics of photographed objects based on a qualitative and quantitative analysis of the photographs and on logical deductions which allow the interpreter to use their own personal experience and knowledge of the discipline.

Pixel: "Picture element" is the ground area corresponding to a single element of a digital image data set.

Platform: The vehicle which carries a sensor, i.e. satellite, aircraft, balloon, etc.

Polarisation: A property of an electromagnetic wave that describes the locus of the electric field vector as a function of time.

Post-processing: Steps that may be applied to digital image files to adjust selected attributes, such as geometric accuracy or radiometric corrections, including speckle reduction and contrast enhancement, or any other form of value-added processing.

Pre-processing: Initial stages of data processing where the image is corrected for various errors and degradation.

Radiometer: An instrument for quantitatively measuring the intensity of electromagnetic radiation in some band of wavelengths in any part of the electromagnetic spectrum. Usually used with a modifier, such as an infrared radiometer or a microwave radiometer.

Radiometric correction: Correcting the variations in data caused by a malfunction of the scanner or by atmospheric interferences.

Radiometric resolution: The expected spread of variation in each estimate of scene reflectivity as observed in an image. Smaller radiometric resolution is "better". Radiometric resolution for a given radar may be improved by averaging, but at the cost of spatial resolution.

Raster/Vectoral: These names refer to different types of map files. A Raster map or Bitmap is an image, a matrix of coloured points. There is therefore no information on the coordinates, the identifiers or the surfaces. These maps are used as a base map or in digitising vectoral maps. A vectoral map, on the other hand, is described by a set of polygons or other objects such as circles or curves, with all the details included such as the identifying position sizes, names, colours, etc., and even sometimes the projection system used, as well as the scale and unit of measure used.

Rayleigh scatter: A form of atmospheric scattering that is caused when radiation interacts with particles whose diameter is much smaller than its wavelength. It therefore affects shorter wavelengths.

Rectification: Applying pre-processing procedures to an image in order to reduce (in a defined order) geometric, or even radiometric, abnormalities. When the images are aerial and/or spatial photographs, the rectification, when it is done, is generally limited to recovery.

Reflectance: Ratio of the intensity of reflected radiation to that of the incident radiation on a surface. The suffix (-ance) implies a property of that particular specimen surface.

Remote sensing: Remote sensing is a collection of techniques for studying the Earth, the oceans and the atmosphere using sensors installed on board aircraft or satellites.

Satellite: A vehicle put into orbit around the earth or other body in space and used as a platform for data collection and transmission.

Scattering: The process in which a wave or beam of particles is diffused or deflected by collisions with particles of the medium which it traverses.

Sensor swath: The width of the track covered by a sensing system.

Spatial filter: An image enhancement method that modifies pixel values based on the values of the surrounding pixels, with the objective of enhancing areas of high or low spatial frequency.

Spatial remote sensing: Remote sensing from a satellite platform.

Spatial resolution: A measure of the smallest angular or linear separation between two objects usually expressed in radians or meters.

Speckle: Speckle refers to a noise-like characteristic produced by coherent systems, including synthetic aperture radars (SAR). It is evident as a random structure of picture elements caused by the interference of electromagnetic waves scattered from surfaces or objects.

Spectral resolution: The ability of a sensing system to resolve or differentiate electromagnetic radiations of different frequencies.

Spectral signature: The frequency distribution patterns of radiation reflected and/or emitted by an object.

Stereoscopy: The science or art which deals with three-dimensional effects and the methods by which these effects are produced.

Sun-synchronous orbit: The path of a satellite in which the orbital plane is near-polar and the altitude is such that the satellite passes over the same latitude at approximately the same local (sun) time each day.

Supervised classification: A procedure for identifying spectrally similar areas on an image by identifying 'training' sites of known targets and then extrapolating those spectral signatures for the rest of the image. Supervised classification relies on the *a priori* knowledge of the location and identity of land cover types that are in the image. This can be achieved through field work, study of aerial photographs or other independent sources of information. Training areas, usually small and discrete compared to the full image, are used to "train" the classification algorithm to recognize land cover classes based on their spectral signatures, as found in the image. The training areas for any one land cover class need to fully represent the variability of that class within the image. There are numerous factors that can affect the training signatures of the land cover classes. Environmental factors such as differences in soil type, varying soil moisture, and health of vegetation, can affect the signature and affect the accuracy of the final thematic map.

Temporal resolution: The frequency of temporal coverage of a sensor/platform system.

Vegetation index: The reduction of multispectral scanning measurements to a single value for predicting and assessing vegetative characteristics. Examples of such characteristics include plant leaf area, total biomass, fresh and dry above-ground phytomass, chlorophyll content, plant height, percent ground cover by vegetation, grain or forage yield and general plant stress and vigour.

Wavelength: Minimum distance between two events of a recurring feature in a periodic sequence, such as the crests in a wave. It is represented by the Greek letter lambda.

Introduction

Beyond the inventory of experiences produced during Mission 2, Mission 3 aims to produce technical documentation on remote sensing technology. Mission 2 consisted of producing an inventory of significant European experiences carried out in the fields of remote sensing, biodiversity and natural habitat monitoring in Europe. This involved:

- undertaking a survey of the current and future remote sensing technologies available;
- presenting their technical, organisational and financial characteristics;
- analysing new methods of data processing under development;
- analysing the current and future service provision available (in particular, under the GMES programme);
- assessing the potential use of these services for the needs of the cross-border Kent/NPdC region.

This report will present an analysis of remote sensing technologies and methodologies. This documentation should help lay the foundations of the guiding principles of remote sensing (technologies currently available or in the future, their technical characteristics, new data processing methods under development, etc.) in order to meet the future needs of users.

In terms of the working methodology and with the aim of producing this report, a number of steps were taken. The following is a non-exhaustive list:

- internal meetings in SIRS with different remote sensing experts;
- meetings with habitat monitoring stakeholders in France and Europe;
- participation in European workshops on habitat monitoring;
- contact with different service providers of satellite data and remote sensing software. As part of this activity, SIRS was constantly in contact with the different image producers, whether this was, for example, DigitalGlobe for QuickBird, Worldview and Ikonos images, Spot Image for SPOT data or Eurimage for GeoEye data. Furthermore, the technical specifications of the sensors and images are detailed on the website of each producer. In addition, for the remote sensing software (GIS), SIRS was also in contact with different software producers in order to find out about the latest developments and participate in presentations on new software versions, such as for example ENVI and ERDAS Imagine.
- internal bibliographic research within SIRS;
- bibliographical research and documentary studies of remote sensing courses and scientific articles published on the internet.

1. Remote sensing

1.1. The physical principles of remote sensing

1.1.1. The founding principles

Remote sensing is "the set of knowledge and techniques used to determine the physical and biological characteristics of objects through measurements carried out at a distance, without material contact with them" (OJ of 11 December 1980). It uses the properties of the electromagnetic waves emitted or radiated by the objects. The discipline brings together all of the knowledge and techniques used to observe, analyse, interpret and manage the environment using measurements and images obtained from airborne, spatial, terrestrial and maritime platforms. Among all of these platforms, this report is particularly interested in spatial remote sensing.

The founding principle of remote sensing involves measuring the energy reflected on to or emitted from the Earth's surface. This energy can come from different sources. It could be a natural source such as the sun which illuminates the Earth's surface. This is the most common example. The radiation reflected by the surface of the Earth is then captured and recorded by the sensor attached to the satellite. Furthermore, the surface of the Earth also acts a natural source by emitting its own radiance. This is the area known as passive remote sensing. Moreover, energy can also come from an artificial source such as the transmission antennae of the sensors. These antennae send radiation towards the surface of the Earth which is then backscattered and recorded by the satellite platform. This process is called active remote sensing in the microwave band.

The electromagnetic radiation interacts with the atmosphere and the surface of the Earth. The nature of the interactions depends on the radiation and the spectral properties of the surfaces.

Measuring and recording the reflected signal, emitted or backscattered by the surface of the Earth is carried out by the sensors on the satellite platform.

Finally, in order for the data collected by the satellite to be processed, it must be transmitted to the ground via a satellite station to undergo a series of pre-processing treatments. The data recorded onboard the satellite is in the form of raw data. It must therefore undergo a series of pre-processing treatments (i.e. radiometric and geometric corrections, etc.).

1.1.2. Electromagnetic waves

Energy is transported from one point to another in the form of a wave. There are two types of waves:

- mechanical waves which are propagated through the vibration of the material (e.g. a sound wave);
- electromagnetic waves which are propagated in a vacuum, with no contact with any other materials.

In remote sensing, the latter is studied.

The electromagnetic waves are made up of two fields which are perpendicular to each other, specifically an electric field and a magnetic field which oscillate at the same frequency. Its propagation speed depends on the environment in question. For example, in a vacuum, the propagation speed is equal to 3.10^8 m.s-1.

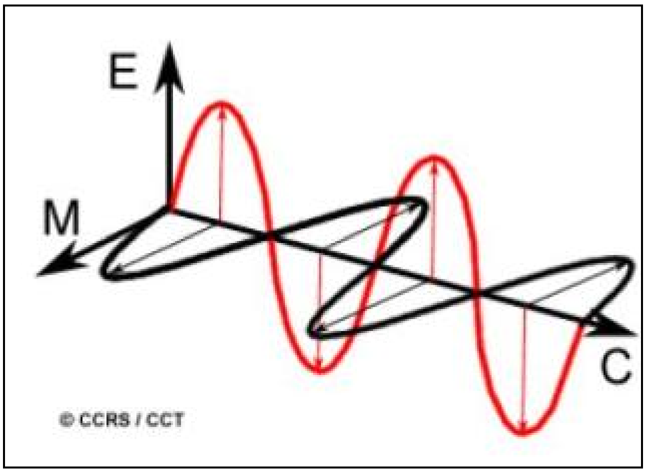

Figure 1: Electromagnetic wave (source: CCRS/CCT)

1.1.3. The electromagnetic spectrum

The electromagnetic spectrum is the division of electromagnetic waves by their wavelength and frequency. For example, solar energy is not uniformly divided across the whole of the electromagnetic spectrum. The sun emits its maximum energy in the 'visible' portion. However, other wavelengths are emitted by the sun such as the near-infrared, the mid-infrared and the thermal infrared.

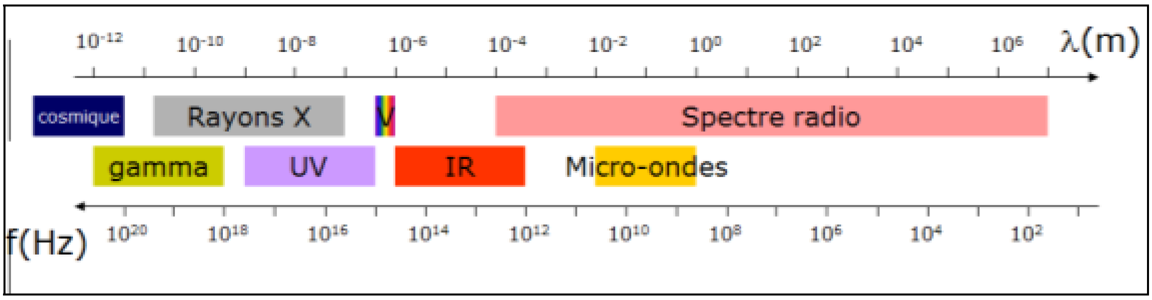

Figure 2: The electromagnetic spectrum (wavelengths and frequencies)

In remote sensing, three specific spectral areas are used:

- the visible band;
- the infrared area (comprising the near-infrared, mid-infrared and thermal infrared);
- microwaves (or hyperfrequencies).

The visible band is the portion of the spectrum which can be detected by the human eye and which enables colours to be seen. It extends from 0.4 µm (for the colour blue) to 0.8 µm (for the colour red). The sun's radiance reaches it maximum, specifically 0.5 µm in this band.

There are a number of sensors which can capture electromagnetic energy coming from different spectral windows in the visible band. For example, the American satellite Landsat has three visible spectrum bands (blue, green and red), and the SPOT satellite has two visible spectrum bands (green and red).

The infrared radiation is the radiation emitted by all bodies whose temperature exceeds -273°C ("absolute zero"). Infrared wavelengths extend from 0.7 µm to 100 µm. The infrared range is generally sub-divided into four infrared areas, namely the near-infrared whose range extends from 0.78 to 1.2 µm, the mid-infrared whose wavelengths are between 1, 2 and 3 µm, the thermal infrared spread between 3 µm and 15 µm, and the far infrared of between 15 µm and 100 µm.

In remote sensing, the near and mid-infrared are of particular interest. For this reason, many of the satellites launched in the last few years have been equipped with sensors which are sensitive to these wavelengths. The near-infrared is strongly reflected in plants and therefore reveals vegetation cover. Therefore, the near-infrared tends to determine the quantities of biomass because it is receptive to the morphology of plants as well as the leaf structure. The mid-infrared can reveal another quality of the leaves: the water content. The use of mid-infrared enables the effects of aerosols and scattering to be reduced.

Radar or microwaves extend over much larger wavelengths, specifically from 1 cm to 1m. These wavelengths enable the surface of the Earth to be observed during the day and at night regardless of the atmospheric conditions. In effect, the atmosphere is almost transparent at these wavelengths. The radiation therefore crosses through clouds without a problem. In remote sensing, the microwave band is particularly used by those active sensors (i.e. RADAR, LIDAR and SONAR) which emit their own radiation.

Measuring energy propagated in this way is called radiometry. The sensor measures the flow of energy being transported by the electromagnetic waves. Usually the sensor determines the values of radiance and reflectance. Radiance is the power emitted in a given direction by an unpointed surface, per unit solid angle. It is expressed as $W.m^{-2}.sr^{-1}.\mu m^{-1}$.

One of the constraints of this calculation is that it only allows comparisons to be made between objects in the same image. Temporal monitoring of a surface over the course of time cannot be done using radiance because it is dependent on incident light (the energy received from all directions by the surface receiving the electromagnetic waves). The radiance must therefore be converted into a size independent of the incident light, namely the reflectance. The reflectance is therefore the relation between the radiation measured by the sensor and the directional incident light. It is a unit-less scale between 0 and 1. It should also be clarified that the definitions given here for radiation, light and reflectance depend on the narrow range of wavelengths.

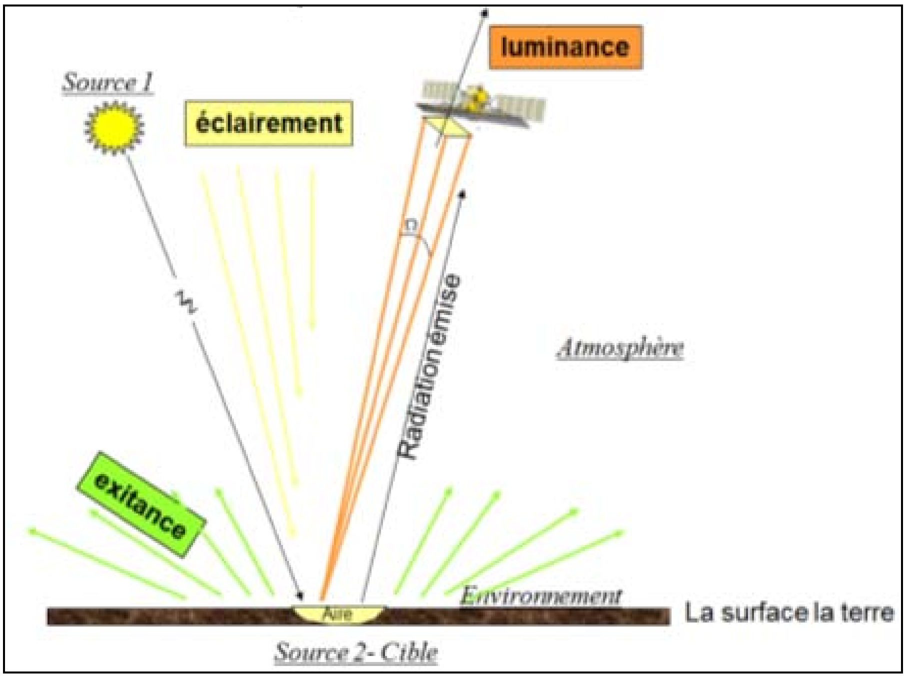

Figure 3: The different radiometric measurements (source CCRS/CCT)

As well as being reflected, energy can also be transmitted by the surface or absorbed by the target. It is all three of these phenomena which characterise each target. This combination determines what we call the spectral signature of an object. It is the characteristic emission of an object based on the wavelengths.

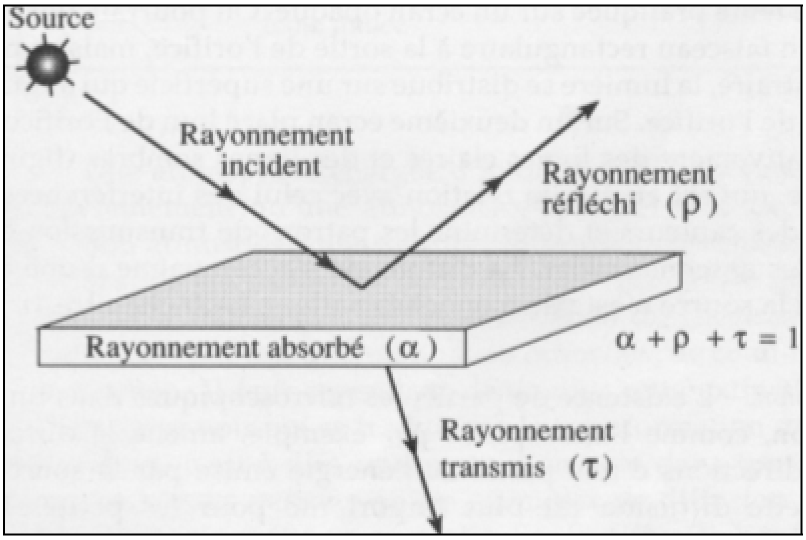

Figure 4: Interactions of the incident light with the target

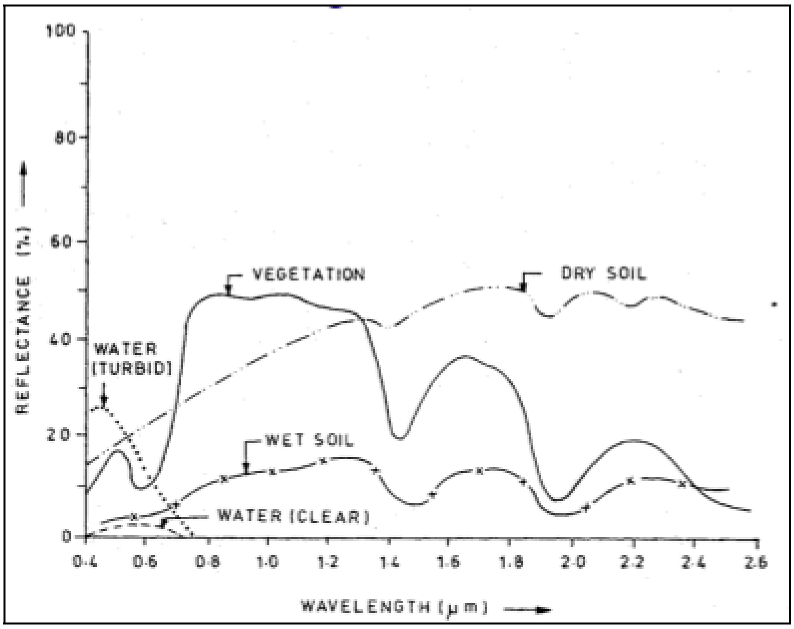

Figure 5: Variation in the reflectance based on the wavelength and the soil type

1.1.4. The satellite orbit and swath

The trajectory taken by a satellite when it moves around the Earth is called the orbit. The orbit of a satellite depends on the technical capacities of the sensor it carries and the specific aims of its mission. The choice of orbit is determined by the altitude (the height of the satellite above the Earth's surface), and the orientation and rotation of the satellite in relation to the Earth. Some satellites are constantly flying over the same region of the Earth's surface. They are in geostationary orbit in the equatorial plane of the Earth. These angular satellites have an altitude of around 36,000 kilometres and they travel at a speed that matches that of the Earth, which gives the impression that they are stationary. This orbital configuration enables a satellite to observe and continually gather information on a specific region. Communication satellites and satellites observing weather (meteorological) conditions are situated in orbits such as these. The high altitude of some meteorological (weather) satellites enables them to observe clouds and the conditions which cover an entire hemisphere of the Earth.

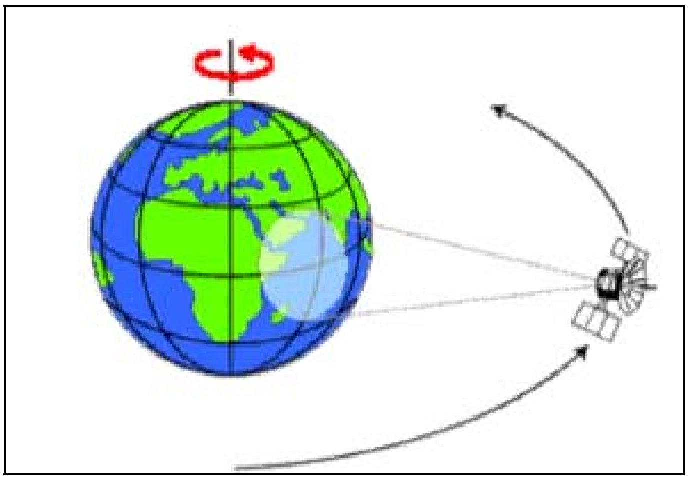

Figure 6: Geostationary orbit

Other spatial platforms follow a slightly inclined (in relation to the polar axis) orbit. This configuration, combined with the rotation of the Earth (west-east) means that for a given period, the satellites can observe nearly the entire surface of the Earth. This type of orbit is called quasi-polar orbit due to the inclination of the orbit of the satellite relative to a line passing through the north and south poles of the Earth. The majority of satellites with a quasi-polar orbit also have a sun-synchronous orbit, which means that they always observe each region of the planet at the same local solar time. For a given latitude, the position of the sun in the sky at the moment when the satellite flies over a certain region in a given season will always be the same. This orbital characteristic ensures that there will always be similar radiation conditions when data is gathered for a particular season over several years or for a particular region over many days. This is an important factor when it comes to comparing two successive images or when producing a mosaic with adjacent images, because the images do not have to be corrected to take into account the solar radiance.

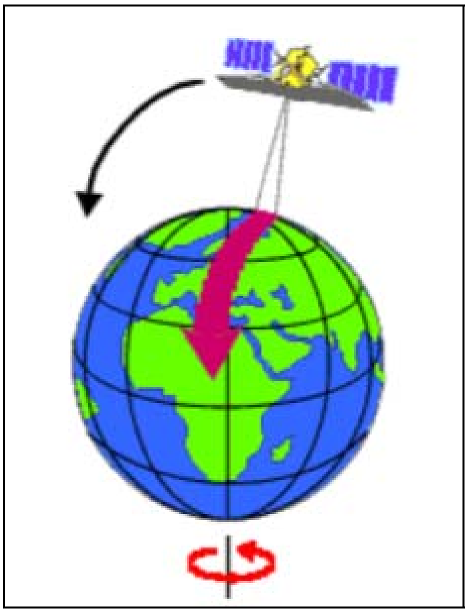

Figure 7: Quasi-polar orbit

Today, the majority of satellite platforms are placed in a quasi-polar orbit. They are therefore located towards the north on one side of the Earth and towards the south for the other half of their orbit. These two types of satellite paths are called ascending orbit and descending orbit respectively. The sensors which record the solar energy reflected by the Earth only gather information during their descending orbit, when the Earth is illuminated by the sun.

Active sensors which have their own source of light or passive sensors which record energy emitted by the planet (for example, thermal infrared energy) can gather data during both the ascending and descending orbits of their satellites.

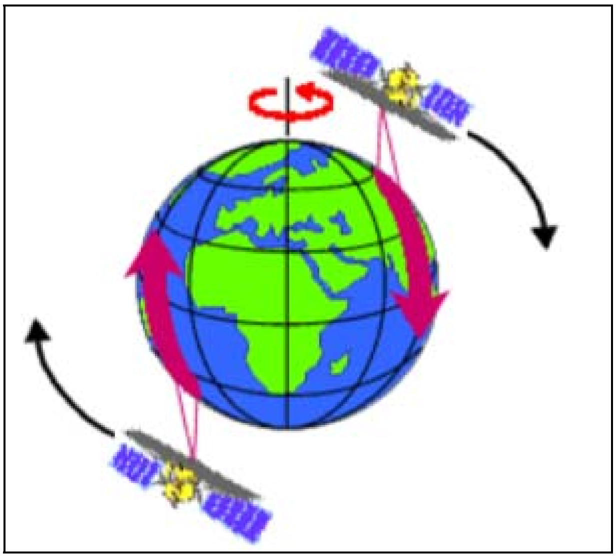

Figure 8: Ascending and descending paths

When a satellite is in orbit around the Earth, the sensor 'observes' a certain part of the surface. This surface is called the swath. The size of the swath of sensors on a spatial platform generally varies from between about ten to several hundreds or even several thousands of kilometres. For quasi-polar satellites, the satellite is located according to a north-south trajectory. However, the satellite trajectory has a westward component due to the rotation of the Earth. This apparent movement of the satellite enables the swath of the sensor to observe a new region with each consecutive sweep of the satellite. The orbit of the satellite and the Earth's rotation enable the whole of the planet's surface to be covered after a complete orbital cycle.

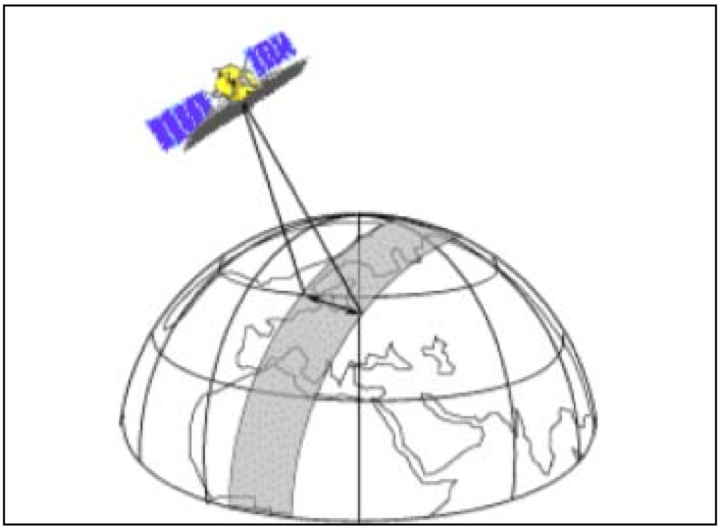

Figure 9: The swath of a satellite

1.1.5. The resolutions of satellite images

One of the main considerations is the choice of satellite and the associated sensor (and therefore the satellite image) and the decisions to be made in terms of the spectral, spatial and temporal resolutions required.

1.1.5.1. The spatial resolution

The spatial resolution of a sensor is expressed and defined by the pixel. It usually corresponds to the smallest detectable and discernable distance on the ground. It is commonly expressed in metres. We can provide an overall ranking of sensors according to the pixel size in the following way:

- Low resolution (LR) spatial data for which the pixel size is more than 1000 metres. For example, the METEOSAT-VISSR and NOAA-AVHRR satellites.
- Medium resolution (MR) data for which the pixel size is between 20 and 1000 metres. For example, the SPOT-VEGETATION, MODIS-Terra and MODIS-Aqua satellites.
- High resolution (HR) data with a pixel size of between 10 and 20 metres. For example, EOS-ASTER or Landsat-TM and Landsat-ETM+ satellites.
- Very High Resolution (VHR) spatial data for which the pixel size is located between 1 and 10 metres. For example, the SPOT-5, QuickBird, Ikonos, WorldView-1 and WorldView-2 satellites.

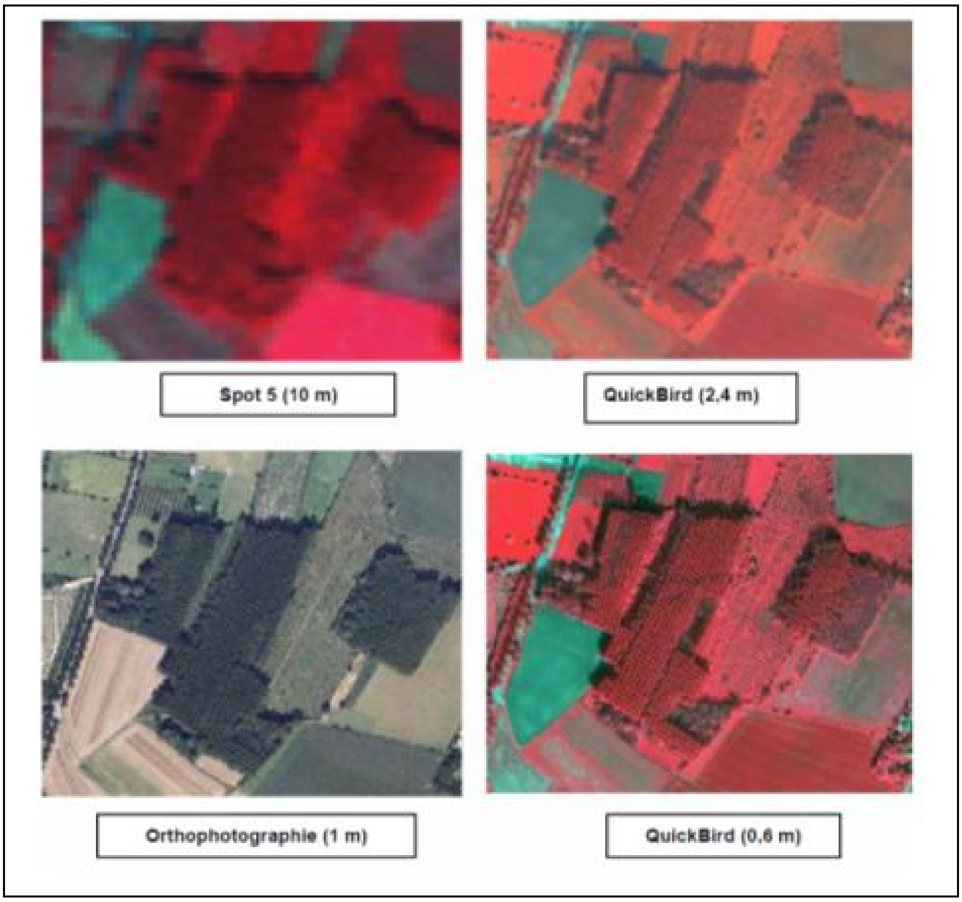

Figure 10: Comparison of four spatial resolutions

Improving spatial resolution is one of the main areas of research in the field of remote sensing and satellites. In recent years, the number of satellite platforms capable of producing very high resolution data, which has up until now been limited to airborne platforms with a pixel size of between 1 to 10 metres, has increased considerably.

1.1.5.2. Spectral resolution

The size of the spectral range and the number of spectral bands varies depending on the sensor used. The larger the spectral range and the more numerous and tight the associated bands are, the better the detection of specific phenomena in certain spectral fields will be. This is called the spectral resolution.

1.1.5.3. Temporal resolution

Each satellite has what is called the revisit time. This is the time in-between two consecutive paths over the same area. The revisit time can extend from a few days to around ten days. In theory, the revisit time is shorter than the time between two dates required for monitoring. Consequently, the temporal resolution may seem unimportant. However, the presence of clouds on the scenes is a major obstacle to collecting unaffected images.

1.2. Sensors attached to satellites

As we saw earlier, the measurement and recording of a signal is carried out at the level of the satellite platform by the sensors. There are passive and active sensors.

1.2.1. Passive sensors

1.2.1.1. Background information

Passive sensors use the reflective properties of the sun's rays in the optical band (e.g. visible and near infrared), in the thermal infrared and in the microwaves band in order to characterise objects on the Earth's surface.

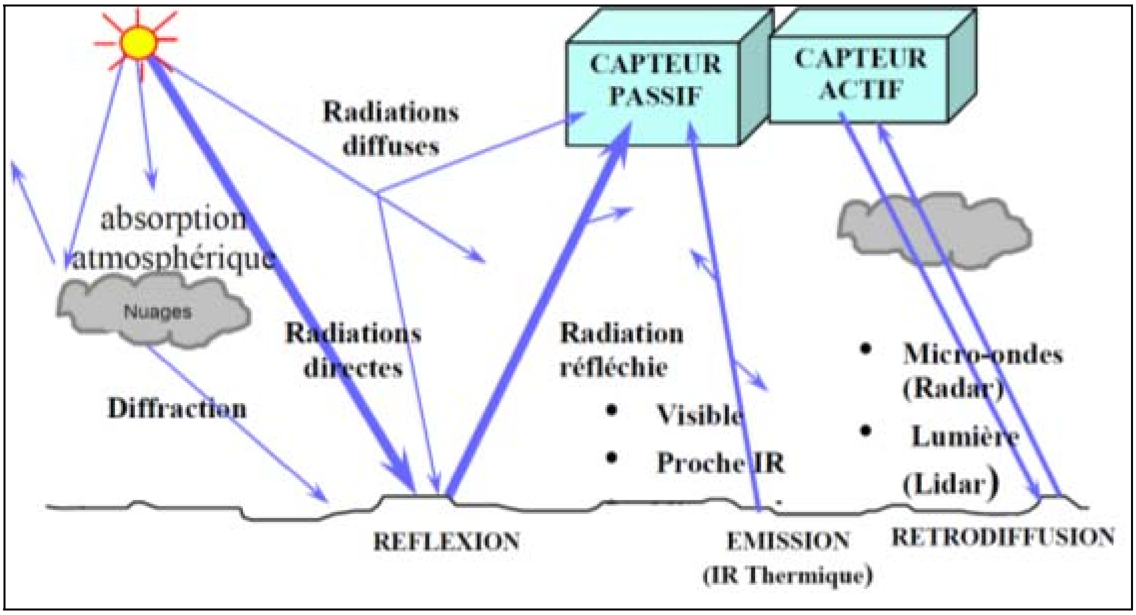

Figure 11: Remote sensing sensors

A major advantage of satellite systems in relation to aerial photography technologies is the size of the scene of the image. This advantage would enable the data processing costs of vast study areas to be reduced.

However, the passive sensor can only perceive energy reflected by the surface when it is illuminated by the sun or when the energy is transmitted by the Earth. Atmospheric conditions are major obstacles to using these sensors. The passive sensor is therefore only a receptor.

There are different types of Earth observation satellites depending on the field of application (i.e. meteorology, oceanography, etc.) and depending on the different systems for acquiring images. The data from satellites varies depending on the characteristics of the sensor attached to the satellite for measuring electromagnetic radiation reflected by the Earth's surface:

- For visible and near infrared electromagnetic waves, the sensors used are optical, this means that they receive the light reflected by the Earth's surface and do not emit any signal.
- For thermal infrared, thermal detectors are used.

Finally, a scene is principally acquired in the following two modes:

- The panchromatic mode corresponds to one single image, produced using the spectral range which the sensor is sensitive to (visible and often a portion of the near infrared). This image is translated into greyscale.
- The multi-spectral mode corresponds to the mode by which several images are taken simultaneously, each in a different portion of the electromagnetic spectrum.

Due to their potential, there could be many possible applications for passive sensors. Remote sensing offers many advantages for mapping, specifically due to:

- Frequent repetition, quick delivery, regional coverage, lower (manual) labour costs, near total cover of the planet, digital data storage, easy integration with GIS and easy updating.

Also, it can be used for applications relating to:

- Agriculture
  - crop type classification;
  - assessing the health of crops;
  - estimating the total harvest production;
  - mapping the characteristics of soil;
  - mapping the land management practices;
  - monitoring compliance with laws and Treaties.

- Forestry
  - identifying the types of forest cover;
  - mapping clearcutting;
  - evaluating regeneration;
  - deforestation by fire;
  - creating inventories of forests;
  - estimating the biomass;
  - environmental monitoring such as deforestation (e.g. Amazon forests and mangrove colonies);

  - inventories of species;
  - coastal protection (e.g. mangrove forests);
  - health and vigour of forests.

- Geology
  - mapping surface deposits;
  - lithological mapping;
  - structural mapping;
  - exploration and exploitation of aggregates (sand and gravel);
  - mineral exploration;
  - oil exploration;
  - environmental geology;
  - mapping and monitoring sedimentation rates;
  - mapping and monitoring of natural phenomena;
  - mapping geological risks;
  - planetary mapping;
  - geobotany.

- Hydrology
  - mapping and monitoring marshlands;
  - evaluating the moisture content of soil;
  - mapping and monitoring the extent of snow cover;
  - measuring the snow depth;
  - assessing the amount of water in a surface of snow;
  - monitoring river and lake ice;
  - mapping and monitoring floods;
  - monitoring the movement of glaciers (i.e. ablation and thrust);
  - detecting changes in rivers and deltas;
  - mapping and modelling watersheds;
  - detecting leaks in irrigation canals;
  - planning irrigation schedules.

- Land use and urban areas
  - managing natural resources;
  - protecting wildlife habitats;
  - expansion and urban development;
  - identifying the extent of damage (from tornadoes, floods, volcanoes, earthquakes, fires, etc.);
  - determining legal boundaries for assessing taxes and properties;
  - detecting targets such as: identifying locations for runways, roads, clearings, bridges, land-water interfaces, etc.;
  - base maps for GIS data;
  - planning schedules and logistics for seismic exploration activities and extracting resources.

- Oceanography
  - identifying ocean patterns;
  - forecasting storms;
  - evaluating fish stocks and marine mammals;
  - oil spills;
  - maritime transport;

- Intertidal zones.

- Ice
  - the concentration of ice;
  - the type, age and movement of ice;
  - detecting and monitoring icebergs;
  - surface topography;
  - identifying channels for navigation, transport and emergency services;
  - the condition of the ice;
  - the historical condition and movement of ice and icebergs for planning;
  - wildlife habitats;
  - monitoring pollution;
  - meteorology and research on climate change.

1.2.1.2. The different types of satellites

The aim of this chapter is to identify, as fully as possible, the different VHR, HR and MR remote sensing satellites. The different satellites and the technical specifications of the sensors attached (i.e. the spatial resolution, spectral bands, temporal resolution, etc. of the satellites) are presented in the form of summary tables in Annexes 1 to 4.

1.2.2. Active sensors

Active sensors are used in the band of microwaves (energy emitted by the sensor itself and backscattered by the Earth's surface). The active sensor produces its own energy in order to illuminate the target object. The energy reflected by the target is then detected by the sensor in order to be measured. The active sensor uses wavelengths which are not produced in sufficient quantities by the sun, like microwaves. One of the advantages of this type of sensor is that it can take measurements regardless of the time of day or the season.

There are different forms of active sensors, in particular: RADAR (*RA*dio *D*etection *A*nd *R*anging) and LIDAR (*LI*ght *D*etection *A*nd *R*anging). RADAR functions in the ultra high frequencies (microwaves from 1.0 millimetre to 1.0 metre) and LIDAR generates a series of laser pulses.

1.2.2.1. RADAR

RADAR therefore refers to those sensors which illuminate the Earth's surface by generating a source of energy in the microwave band in the desired direction. These sensors are capable of functioning at both day and night-time. In addition, because they function at wavelengths in the order of centimetres and millimetres, they are relatively unaffected by atmospheric conditions (e.g. clouds and rain).

By convention, RADAR systems are characterised by a letter designating the range of wavelengths (or frequencies) of the electromagnetic signal generated and the polarisation of the signal (horizontal = H and vertical = V). The majority of RADAR systems function in band X (2.4 – 3.8 cm), in band C (3.8 cm – 7.5 cm), band L (15 cm – 30 cm) or band P (30 cm – 100 cm).

Up until now, the majority of satellite systems launched (into the atmosphere) could only collect data on one single band. RADAR technology is currently developing very quickly and the possibility of multi-band and multi-polarisation systems looks very promising.

In the future, more and more of the satellite systems deployed will be *a priori* capable of collecting data on several bands, improving the ability to discriminate between objects.

From a habitat monitoring perspective, RADAR sensors have several advantages.

Firstly, the spatial resolutions are often better quality than those of passive sensors which do not produce regular images at adequate spatial resolutions. From a technical point of view, these captors enable images to be produced with pixel sizes of up to 1 metre.

In addition, the capacity of these sensors to gather data regardless of the atmospheric conditions gives them an additional advantage over passive sensors from an operational point of view.

Furthermore, the development of techniques using interferometry enables information on the height of objects to be obtained (a pair of sensors attached to the platform which capture two images of the same scene but slightly offset).

RADAR systems can be used to study forested areas. RADAR technology has the potential to distinguish between wooded areas and other surfaces. Even though the use of images with only a single band is perhaps not the best solution for habitat mapping, L-band data, for example, can distinguish between low and medium vegetation in forested or urban areas, with acceptable accuracy levels in the order of 80% for forests.

For larger wavelengths, L- and P-band data, the penetration of the signal into the canopy is more significant. The images enable information to be gained on the lower levels of the forest.

However, there are still certain technical problems specific to processing RADAR images. The pixels of the images are sensitive to certain characteristics on the surface (other than the presence of vegetation), such as for example the roughness or topography. With regard to vegetated surfaces, RADAR images are sensitive to moisture and their structure.

Furthermore, these images are affected by a specific source of random noise called "*speckle*" which can lead to degradation in the spatial resolution from the start. This reduction in the spatial resolution would be particularly significant when only one band is available for mapping.

Due to their potential, there may be many possible applications for active sensors. RADAR could be used for applications relating to:

- agriculture;
- using in information systems and crop modelling;
- identifying the type of agriculture and the acreage for crops, such as unploughed or partially ploughed land used for cultivation, land permanently used for grazing and land ploughed conventionally;
- forestry;
- monitoring regions with frequent cloud cover, such as tropical forests for example;
- mapping cutting and regeneration areas;
- geology;
- detecting faults and lineaments;
- oceanography;

- size of waves;
- ship detection;
- oil spill detection;
- ice;
- mapping;
- detecting icebergs;
- hydrology;
- determining the water content in the ground and vegetation;
- flood monitoring;
- hydrological models;
- the littoral zone and forestry.

1.2.2.2. LIDAR

LIDAR refers to a range of instruments whose main characteristic is to transmit a series of laser pulses (usually in the near infrared) towards a target on the ground which retransmits part of the energy. The return signals are detected by the LIDAR sensor, and changes in the properties of the radiance are used to determine one or several of the properties of the target. The simplest LIDAR instrument uses the delay in the response to accurately determine how far away the target is. When the instrument is carried by an aerial platform (i.e. a plane or a helicopter) whose position and direction is controlled using a GPS positioning and inertial guidance system, it is then possible to determine the height of the terrain. LIDAR technology enables data with a spatial resolution of 1 to 2 metres and heights measured in metres to be obtained.

In particular, LIDAR technology offers interesting possibilities for monitoring forests. Moreover, while passive sensors and RADAR sensors are less sensitive to the structural properties of dense forests, research indicates that LIDAR instruments can provide estimates on many structural characteristics within dense populations, such as temperate coniferous and deciduous forests, as well as dense tropical forests, for example.

Thus LIDAR technology enables, for example, the height of trees, the percentage of canopy cover, the volume of the wood, and the biomass quantity to be determined. In contrast, it is not yet possible to distinguish species using LIDAR technology. Coupled with the technology of passive sensors, LIDAR could enable wooded areas, scrubland and grasslands to be identified.

LIDAR could have additional applications in the following areas:
- the littoral zone;
- flood prevention;
- bathymetry;
- hydrology;
- glaciers and avalanches;
- landslides;
- forestry, for example with the creation of Digital Terrain Models (DTM) or Digital Elevation Models (DEM) or determining the height and structure of trees;
- monitoring volcanoes;
- transmission lines;

- mapping roads.

1.3. Data pre-processing

Before being able to manipulate satellite images, a series of pre-processing treatments must be carried out in order to make the raw data usable and to eliminate certain imperfections. Once the signal is received by the satellite sensor, after being reflected by the object, the information is called raw data. This signal is pre-processed at the level of the satellite platform and then sent to the ground to be processed (or not, as the case may be) by teams of scientists. These processes enable the usual additional corrections (e.g. radiometric and geometric) to be made. Each stage in the processing chain corresponds to a level of data processing which constitutes an accessible product to the user.

Currently, each image producer uses their own nomenclature which is not transferable from one sensor to another.

In the future, the desired trend is towards an official international nomenclature for images in order to make the names used for the different levels of image correction more understandable. Moreover, the further the image is along the chain of processes, the more it costs to buy. This is why it is possible to buy uncorrected images and to carry out the aforementioned corrections internally.

1.3.1. Calibration

Calibration consists of transforming the raw data recorded by the sensor on the satellite in order to obtain useful information. In effect, the raw data does not correspond to any parameters to which a user could associate physical meaning.

Firstly it involves transforming the digital number (DN) raw data in to a physical measure (the radiance) and then secondly an absolute calibration can change the relative values of the digital image into measurements of reflectance.

This stage is particularly important because it enables a coherent set of images from a spectral point of view to be obtained, regardless of the date taken or the sensor used.

1.3.2. Radiometric correction

The aim of radiometric correction is to re-assign each pixel with a radiometric value which is as accurate as possible to that measured on the ground.

These radiometric corrections enable the different phenomena inside the sensor, synonymous with the radiometric noise of the image, to be corrected (e.g. linearity of the scan mirror, sampling errors made over time, systematic errors due to the detector, geometry perspective, panorama distortions, etc.). These phenomena are essentially due to the sensor getting old, not functionally properly or it being disturbed. Restoration is among the regular radiometric corrections. This involves re-assigning a spectral value to pixels where the information is missing. It is thus possible to correct lines of missing or damaged pixels by taking into account the surrounding lines using interpolation, median filter or by correcting the lineage effects (e.g. regular bands of noise due to scanning during the functioning of the sensor) by harmonising the histograms.

The data producers who carry out the radiometric pre-processing internally are often responsible for carrying out these corrections.

1.3.3. Geometric correction

Even if they have a spatial reference (reference system or an associated projection), satellite images can show a geometrically distorted position. The image taken is never a completely faithful reproduction of the surface viewed. A multitude of factors can result in distortions to an image. Remote sensing images taken under certain specific conditions will present geometric distortions. The causes of these distortions can be classified into three categories:

- distortions caused by the satellite: the altitude of the platform or the movement (direction and speed) of the scanning system and the platform (pitch, roll and yaw);
- distortions caused by the sensor: speed of the mirror movement, irregularity in the mirror, angle of the viewpoint, perspective, etc.;
- distortions relating to the Earth: rotation, curvature of the Earth and topography.

Finally, there can be a gap of several metres, even around ten metres, between the reality on the ground and the image.

A geometric correction of the image therefore enables these distortions to be corrected. It is vital that these corrections are undertaken in order to be able to compare two images taken at different times for example, or to be able to superimpose the satellite image onto a digital topographical map (to find out the ground coordinates using an accurate system, provide additional information for interpretation, update a map, ensure an accurate adjustment of the interpretation, etc.) or to a thematic map from a GIS interface.

There are two methods for correcting these geometric distortions:

- direct method;
- inverse method.

The direct method is by far the most complex. It involves mathematically modelling each of the phenomena detailed above, which geometrically affect the image and then correcting the distorted image using these models. Given the difficulty of modelling the many different distortions, this method is very seldom used.

The inverse method is consequently the most frequently used. It involves establishing a mathematical relationship between the raw image and a reference image (i.e. a satellite image of the same region, which has already been corrected, a vectoral map or even a reference map). In other words, the same points are located on the image which needs correcting and the reference image. After identifying these points, the mathematical function which will enable the transformation to be carried out must be defined.

There are two approaches to doing this:

- the planimetric transformation model;
- the non-planimetric transformation model.

The latter is the most commonly used method because it is completely independent of the geometry of the sensors and it enables those distortions which are difficult to model to be easily corrected. Using sets of coordinates of reference points (or ground control points) and the points on the image to be corrected, the idea of this method is to construct a polynomial of 1, 2 or even more degrees, depending on the size of the distortion, by identifying the relation between the points on the original image and the points on the reference image, which will then enable the distorted image to be transformed.

The more the degree of the polynomial is increased, the more stretched the transformed image will be. In addition, each degree of the polynomial requires a minimum number of ground control points (related to the number of unknowns of the polynomial). It is also vital that the ground control points are distributed over the whole of the image because otherwise the parts of the image for which no reference point is established will remain distorted.

Once the transformation has been made, the image is no longer represented on a rectangular mesh. In other words, the points in the original system of coordinates do not fall exactly on to the mesh points of the new reference grid. A re-sampling is also necessary in order to determine the new radiometric value of the corrected pixel.

Several re-sampling methods exist:

- the nearest neighbour method (this method consists of placing the points from the old mesh on to the nearest points of the new mesh);
- the linear interpolation method (this method is based on the weighted average of the four closest pixels in the old mesh);
- the cubic convolution method (this is the same as the linear interpolation, but with a matrix of 4 x 4 pixels).

The first method, in contrast to the other two, has the advantage of being spectrally faithful to the original values. However, it can have skipped and duplicate values, as well as a staircase effect. The two latter approaches are spatially more accurate.

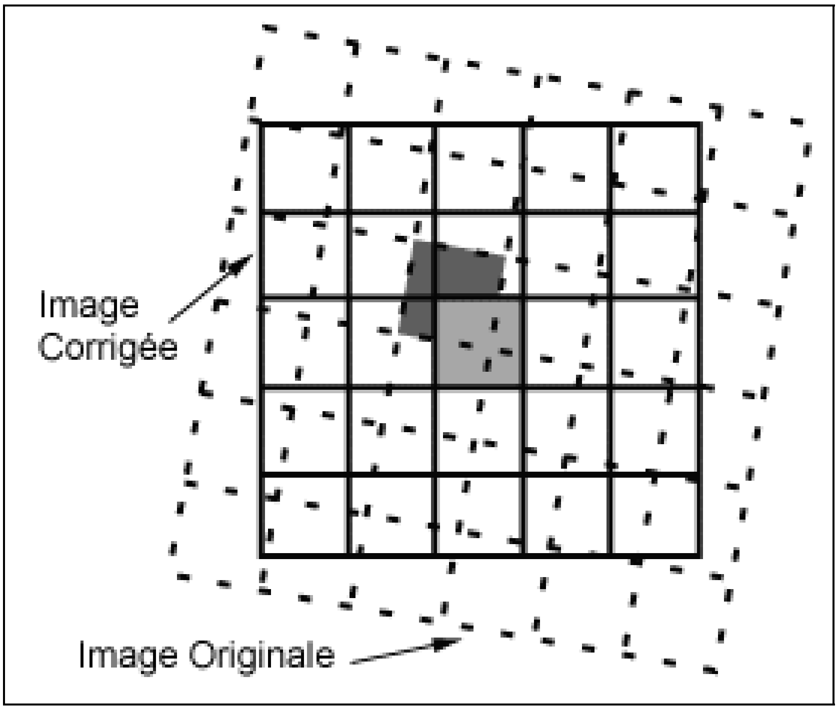

Figure 12: Re-sampling

1.3.4. Atmospheric correction

In remote sensing, the atmosphere (because of its composition) is considered to be a disruptive environment for electromagnetic radiation. Gas molecules, drops of rain, snow, ice crystals, suspended particles (e.g. aerosols, dust, smoke, etc.) are all factors which affect radiation, especially as the electromagnetic signal measured at the level of the sensors passes through the atmosphere twice.

The contribution of the atmosphere in the radiometric value of a pixel can exceed 50% in some wavelengths, for example in the blue wavelength. The effects of the composition of the atmosphere on radiation is seen in two types of interaction which are: scattering, which divides into three forms (Rayleigh, Mie and non-selective scatter), and absorption. It is therefore vital that these phenomena are taken into account when the electromagnetic signal measured by the sensor is disturbed by these interactions.

The disturbances vary depending on the composition of the atmosphere, the wavelength, the optical depth and the angle of incidence (i.e. zenith angle).

For scattering phenomena, the Rayleigh scatter relates to molecules that are smaller than the wavelength, the Mie scatter relates to molecules whose size is close to the wavelength and non-selective scatter relates to particles which are bigger than the wavelength.

The following is a list of examples of the sizes of molecules and particles found in the atmosphere:

- Gas molecules (i.e. nitrogen, oxygen, argon and carbon dioxide): size = 10^{-8} cm or 0.001 µm;
- Solid aerosols: 0.1 µm to 1 µm;
- Ice crystals in clouds: 1 µm to 100 µm;
- Industrial smoke and fog: 0.5 µm to 50 µm;
- Pollen and ash: 10 µm to 100 µm;
- Clouds and haze: 20 µm to 300 µm;
- Water droplets: 0.5 µm to 5000 µm;
- Hailstones: size up to 10 cm.

Aerosols are solid or liquid particles of natural or industrial origin, with different chemical compositions suspended in the atmosphere. These particles can originate from combustion, erosion, the oceans, volcanoes or photochemical interactions.

Aerosols play an important role in the atmosphere. They are the principal mechanism for atmospheric pollution and are the most active atmospheric component from an optical point of view. In addition, they influence the radiation balance of the atmosphere (affecting the ground albedo) and are involved in the processes which form clouds and precipitations. Lastly, they are involved in the transport processes of matter in the atmosphere (i.e. the principle motor for atmospheric pollution).

The term 'atmospheric windows' is used to refer to the region of the spectrum where the atmosphere is transparent to radiation. Absorption is limited in certain specific areas of the electromagnetic spectrum.

For example, in the visible band (from 0.4 to 0.7 µm), the atmosphere is relatively transparent and is therefore a wide atmospheric window. In contrast, in the infrared (from 8 to 14 µm) the atmosphere is opaque from 22 µm to 1 mm, which explains why this portion of the spectrum is not used in remote sensing.

In microwaves, the atmosphere is transparent beyond 3cm, but becomes opaque for wavelengths above 30 m. Therefore, by observing the atmospheric windows available and taking into account the two most common sources of energy (the sun and the Earth), those wavelengths of most use to remote sensing can be determined.

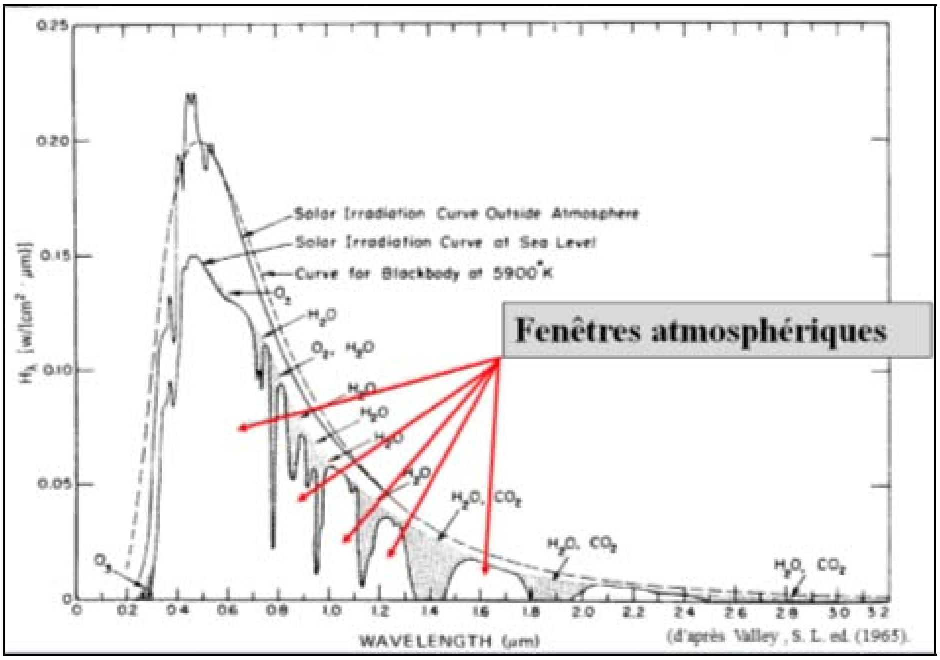

Figure 13: Atmospheric windows

Atmospheric corrections can be carried out using remote sensing software. In ENVI software, the FLASH module enables atmospheric disturbances to be taken into account and images to be corrected.

1.3.5. Examples of the levels of corrections offered by suppliers

For the producer of SPOT Image data, the levels of correction are divided as follows (extracts):

- Level 1A: “Level 1A involves somewhat raw pre-processing where only radiometric corrections are carried out. This level is particularly for users who want data which has undergone as little processing as possible. In radiometry, only instrumental effects are corrected using a linear model which equalises the sensitivity of the sensors. At this level of pre-processing, no geometric correction is carried out.”
- Level 1B: “Level 1B involves basic processing including radiometric and geometric corrections. The latter take into consideration the characteristics of the view the image was taken from and the satellite/Earth system used. Corrections: the same radiometric corrections as in level 1A are applied. The geometric corrections relate to systematic effects such as the panorama effect, rotation and curvature of the Earth, and variation in the altitude of the satellite in relation to the reference ellipsoid, etc.”
- Level 2A: “Identical radiometric correction as that carried out at level 1A. Geometric correction carried out in the standard map projection (e.g. UTM WGS84, by default), without ground control

points. By taking into account the possible shift in location, it enables the image and the different types of geographical information (e.g. vectors, raster maps and other satellite images) to be combined."

- Level 2B: "Map projection with Ground Control Points removed from the maps or by measuring the GPS site. The image is corrected to a medium altitude in a standardised projection and map cut. Used when distortions due to the relief (e.g. flat terrain, etc.) cannot be determined."
- Level 3: "Map projection using Ground Control Points and DEM from Reference3D to remove distortions due to the relief."

For the DigitalGlobe (QuickBird, Ikonos and WorldView satellite images) data supplier, the levels of corrections are divided as follows (extracts):

- Level 1: "*Basic Imagery with the least amount of processing (geometrically raw), designed for customers desiring to process imagery into a useable form themselves. Sensor corrections: Internal detector geometry; optical distortion; scan distortion; line rate variations; mis-registration of the multispectral bands*."
- Level 2: "*Standard Imagery with radiometric and geometric correction, and delivered in a map projection. Sensor corrections: idem Basic Imagery, but has a coarse DEM applied to it, which is used to normalize for topographic relief with respect to the reference ellipsoid. The degree of normalization is relatively small, so while this product has terrain corrections, it is not considered orthorectified*."
- Level 3: "*Orthorectified Imagery with radiometric, geometric, and topographic correction, and delivered in a map projection. Require DEMs and/or Ground Control Points to remove relief displacement and to place each pixel into its correct map location*."

From these examples, we can see that each image provider currently use their own nomenclature. There are not always direct correspondences between them. As a result, these nomenclatures are not transferable from one sensor to another. Generally, level 1 corresponds to the level of raw data or data corrected for errors within the satellite, level 2 to the level of data corrected by external data (e.g. georeferencing), and level 3 corresponds to the level of thematic data.

Sometimes, providers do not offer hierarchical levels of correction (i.e. in numbered levels, as above), but with their own typology. For example, e-geos which offers Geoeye-1 data classifies its correction levels as follows: GEO – GeoProfessional – GeoProfessional Precision – GeoStereo – Geostereo-Precision. Finding correspondences in this case is therefore even more complex.

In the future, the desired trend is towards an official international nomenclature for images in order to be able to understand which level of image correction is being referred to.

1.4. Processes

1.4.1. Colour composite

When the images are captured and recorded by the satellites, they are coded in greyscale. It is therefore possible to view the images in black and white. However, it is also possible to view the images in colours in the form of a colour composite.

These composites enable colour images to be produced by taking into account the spectral signature of the objects. They are frequently used to highlight the different surface types on multi-spectral images or to highlight certain environmental phenomena.

The principle of colour composite is therefore used. It is based on the Red-Green-Blue colour space or the RGB model developed in 1931 by the International Commission on Illumination (ICI) and the principle of cathode channels in a screen. This is the ideal model for explaining additive colour synthesis because it represents the colour space using the three primary colours which are red, green and blue.

An image is assigned to each channel (red, green or blue), which usually corresponds to one of the spectral bands available on the satellite image. The resulting colours are based on the radiometric values of the pixels in each of the three spectral bands selected. The higher the value of the pixels, the more saturated the assigned colour will be.

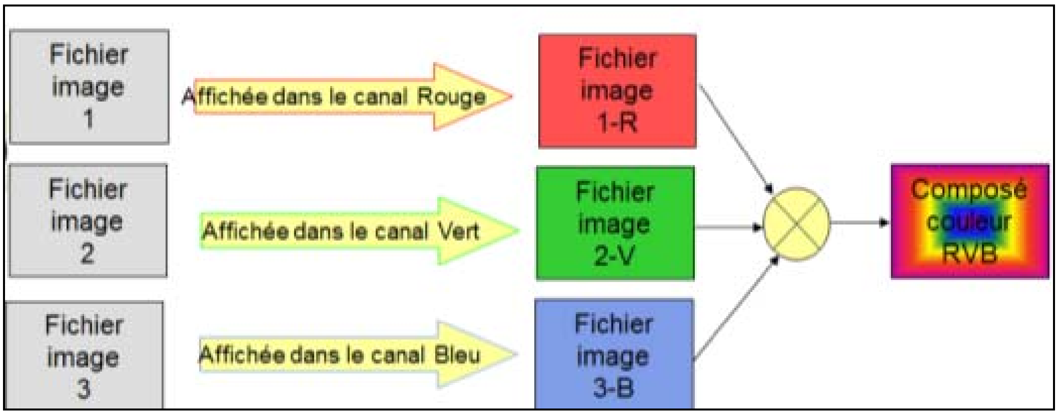

Figure 14: Principle of colour composite

For example, assigning the red, green and blue spectral bands of the satellite image respectively to the red, green and blue channels of the RGB space enables the scene to be viewed in pseudo-colours as if the scene is being viewed from the satellite. However, different band combinations are possible depending on the needs of the user. For example, assigning the near-infrared, red and green spectral bands of the satellite image respectively to the red, green and blue channels of the RGB space enables better visualisation of vegetation and land use. In this false colour composite, the vegetation appears in red because the spectral response of vegetation is stronger in this spectral range.

1.4.2. Filtering

The noise contained in satellite images is a phenomenon which tends to mask the useful information. This noise can come from two distinct sources:

- External sources - principally the atmosphere, the relief and geometry of the ground;
- Internal sources such at the measuring system, unequal response by the detectors, electronic noise or transmission noise.

Noise present in a satellite image can be random and periodical. If the noise is present in a homogenous way in the whole of the image, then a spatial filter is applied directly to the image. The filters not only reduce the noise present in the images, but can also be used to enhance certain characteristics of the image.

Firstly, the spatial frequency needs to be defined. The spatial frequency is not connected to the frequency of electromagnetic waves coming from the ground. In this instance, it relates to the intensity variation of each pixel in the image. This means low spatial frequencies when the region considered is of the same intensity, as for example, with the sea. The high spatial frequencies characterise regions with contrasting intensity, such as for example where the sea meets the coast.

The spatial filters are local operators. In other words, the spatial filters take into account the neighbours of a pixel in order to enhance, reduce or extract a local property. This type of filter connects the value of the pixel being processed, located in the centre of the filter window, with its neighbouring pixels. The parameters to consider could be the size of the filter window, the influence of the distance using weight co-efficients, and the isotropy or ansitropy of the phenomena being processed.

- Low pass filter: this filter enables the high spatial frequencies to be removed. The low pass filter therefore smoothes the image. It is used to highlight homogenous regions with pixels of similar spectral characteristics. Amongst the low pass filters, are the mean (box) filter and the median filter. The first adds together all the values in the mask and calculates the mean value to be assigned to the central pixel. The second uses the median value of the mask.

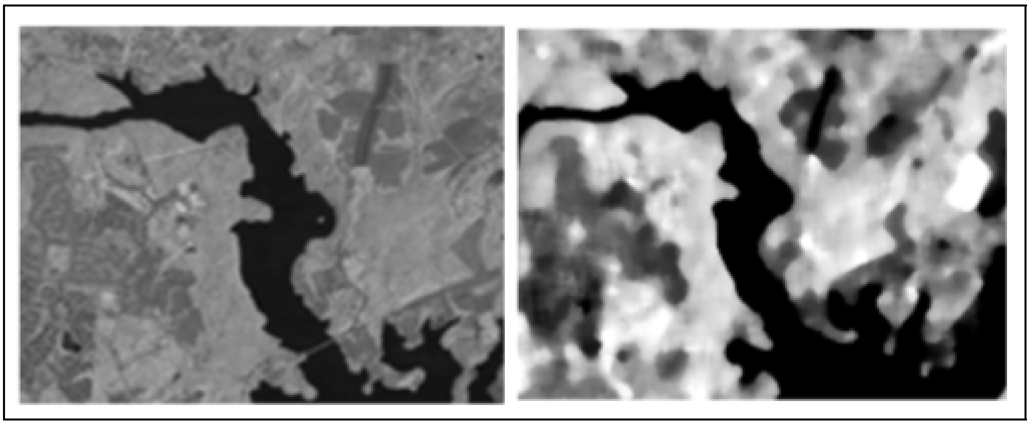

Figure 15: Low pass filter

- High pass filter: this filter enables the low spatial frequencies to be removed. The high pass filter has a tendency to enhance details and contours and enable the edges to be detected. Among the high pass filters are the Prewitt filter, the Sobel filter and directional filters. The latter are used to highlight information using a specific direction.

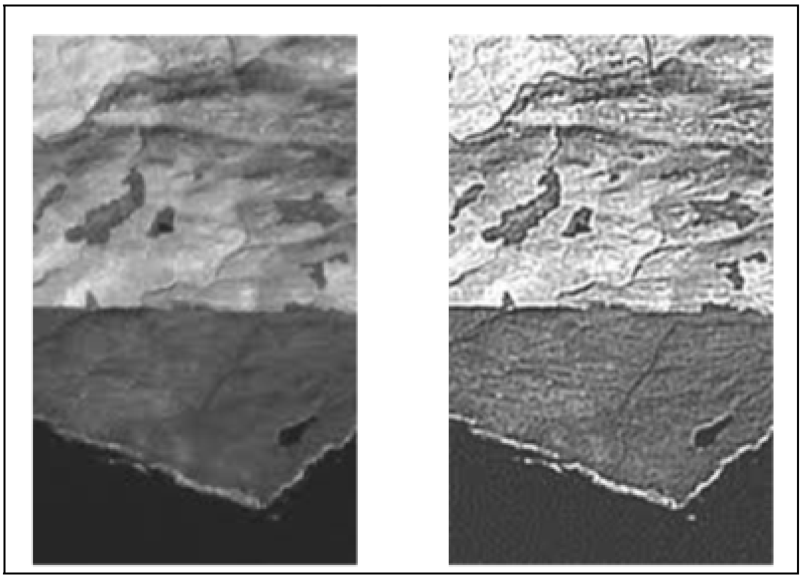

Figure 16: High pass filter

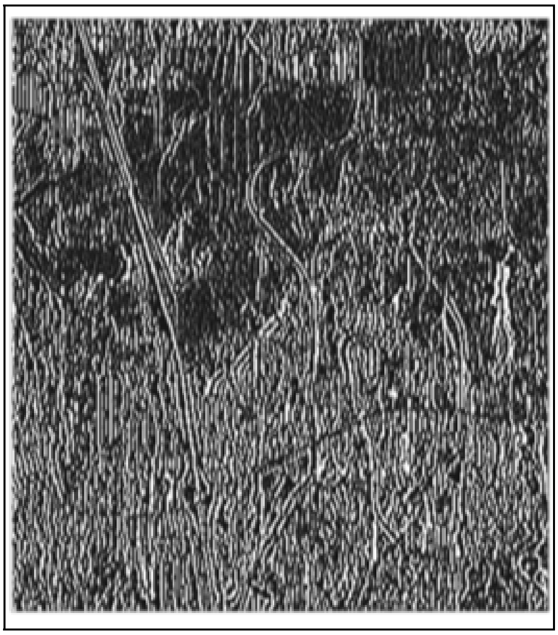

Figure 17: Directional filter (vertical structures)

- Adaptive filter: the particular advantage of this filter is that it reduces the speckle noise present in radar images. The speckle is caused by random interference of the electromagnetic waves in one cell of reflection of the surface of the object. The presence of speckle degrades the radiometric resolution by reducing the possibility of identifying small structures. The most effective filters for reducing this phenomenon are adaptive filters whose function is adapted to the spatial variations of the signal by using the local statistics of the noisy signal.

  Among the adaptive filters, are the mean and median adaptive filters, the Frost filter, Wallis filter and Lee filter.

1.4.3. Data fusion

Data fusion refers to the use of data from different sources in order to produce output data with added value or which is more useful than each of the input data used individually. Originally, this technique referred to the combination of high spatial resolution panchromatic data with a lower resolution multispectral data in order to produce a pan-sharpened image. However, the technique for data fusion has since developed beyond this approach.

Many studies have focused on the fusion of multispectral data with panchromatic data with a better spatial resolution, with images acquired from the same platform. For example, the combination of 15 metre spatial resolution panchromatic data with 30 m multispectral data from the Landsat-ETM+ satellite, and also 5 metre panchromatic data with 10 m multispectral data from the SPOT-HRG satellite.

However, the technique does not require that data acquired from the same sensor is used. Thus, approaches combining aerial photographs with Landsat satellite data have been explored. Whichever satellite data is used, the principal objective of this type of processing is to obtain an image with the finest level of spatial detail whilst still preserving the radiometric properties of the objects in the image.

One of the major advantages of this technique is the use of the data in classification algorithms. The integration of pan-sharpened data enables better classification results to be obtained.

The combination of multi-temporal data can also improve the classification accuracy.

1.4.4. Indices

Each wavelength has its own characteristics, enabling it to characterise one precise phenomenon. This information cannot be directly measured using the spectral bands of multispectral satellite images.

In effect, reflectance (or luminance) does not correspond to our usual way of understanding physical phenomena. In contrast, the use of a combination of observations of reflectance, in two or several spectral bands, enables this information to be extracted.

This relates to indices. It involves an empirical approach which enables the state of a given phenomena to be described. Several operations are possible in order to combine the different spectral bands, such as the arithmetic operations (subtraction, addition, division), for example.

Among the most well-known and the most regularly used indices are the vegetation indices, which enable vegetation cover to be identified and its behaviour and development over time to be monitored, and also urban areas and infrastructures to be identified.

1.4.4.1. Vegetation indices

Over the last few decades, several vegetation indices have been developed.

They take the form of either very basic expressions (simple difference or simple ratio), or more complex formulae. Thus, some of these vegetation indices enable certain parameters of the cover to be assessed, such as the biomass, the vegetation’s capacity for photosynthesis or the water content. Other indices have been developed for studying the structure of the canopy. They can be indices for rough or normalised vegetation.

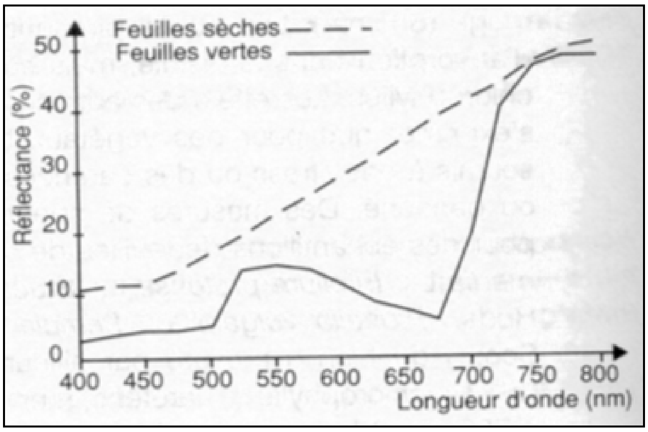

Figure 18: Spectral signature of leaves

One of the most used indices is the *Normalized Difference Vegetation Index* (NDVI). It was created by Rouse in 1973 and has undergone several revisions. This is the most commonly used index in environmental research. The NDVI enables the chlorophyll activity of vegetation to be monitored using the reflectance in the red and near-infrared. It is calculated as follows:

$$NDVI = (NIR - R) / (NIR + R)$$

Where NIR is the reflectance of the near-infrared, and R is that of the red.

However, the influence of aerosols (whose presence is partly due to biomass combustion) and clouds greatly limits the interpretation of observations made by satellites. In general, the temporal evolution of the NDVI is greatly connected to variations in the atmosphere such as the variation in aerosols and clouds.

For example, in tropical regions, the data acquired during the rainy season is biased by the persistent cloud, while in the dry season contaminations by aerosols greatly reduce the reproduction of the NDVI.

Furthermore, this index has limitations due to saturation at high levels of biomass. With values between -1 and 1, the NDVI has the tendency to saturate for values over 0.80. In fact, as the forest environment becomes more and more dense, the reflectance values in the red cannot fall below a certain limit, which is being quickly approached, while those in the near-infrared continue to increase for longer. The result is saturation at about 0.80. Above this value, the NDVI is no longer considered capable of identifying the chlorophyll activity sufficiently.

Water vapour can also have an influence on the NDVI.

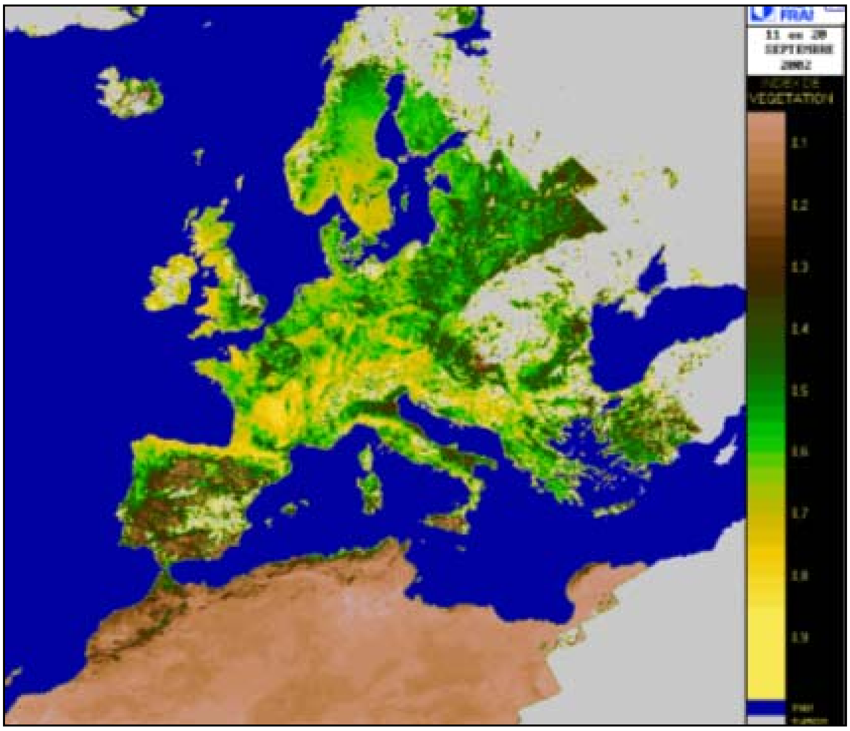

Figure 19: NDVI of Europe (source: Meteo France)

There are more basic and older indices, but which have limited use. Among these are the *Difference Vegetation Index* (DVI) and the *Ratio Vegetation Index* (RVI). They are calculated as follows:

$$DVI = NIR - R$$

and

$$RVI = NIR / R$$

Where NIR is the reflectance of the near-infrared and R is that of the red.

The disadvantage of these indices is that they are extremely sensitive to atmospheric variation and the spectral contribution of soils. They also have a higher tendency for saturation than the NDVI.

As we have seen, atmospheric conditions greatly influence these indices. As a result, some indices have been developed to reduce these distortions, for example, the *Enhanced Vegetal Index* (EVI). Historically, the development of this index is connected to that of the MODIS satellite (by Huete in 2002). It is an improvement to the NDVI and therefore enables chlorophyll activity to be monitored.

This index has several advantages in comparison to previous indices such as the NDVI. In effect, this index takes into account the contamination of pixels caused by aerosols or effects due to the soil. Thus, this index shows very low saturation over a year for high levels of chlorophyll activity.

The EVI index also takes into account the effects of the soil. That is, it can correct or at least reduce the influence that soils under the cover of vegetation have on the signal measured by the satellite sensor.

The EVI index applies to the reflectance in the near-infrared of the sensor and the blue band. The latter is sensitive to atmospheric conditions and is often used to correct phenomena related to the atmosphere (e.g. detecting clouds, mist, etc.). In fact, the EVI adjusts the reflectance in the red channel in accordance with the reflectance in the blue channel. It thus enables atmospheric effects to be reduced.

This index can be implemented as follows:

$$EVI = 2.5\ (NIR — R) / (NIR + 6.R - 7.5.B + 1)$$

Where NIR is the reflectance in the near-infrared, R is that of the red and B is that of the blue.

Other indices also take into account atmospheric effects by exploiting the properties detailed previously. For example, the *Atmospherically Resistant Vegetation Index* (ARVI), created by Kaufman and Tanré in 1992, is an index which enables these effects to be reduced by also using the blue band. The index is calculated as follows

$$ARVI = (NIR – \rho) / (NIR + \rho)$$
$$\text{with } \rho = R – \gamma.\ (B – R)$$

Where NIR is the reflectance of the near-infrared, R is that of red, B is that of blue and γ is an atmospheric auto-correction factor depending on the type of aerosol. It is calculated using the reflectance in the blue and red bands.

Pinty and Verstraete (1992) proposed the *Global Environmental Monitoring Index* (GEMI). This index also enables atmospheric disturbances to be reduced. It is more complex to implement and is calculated as follows:

$$GEMI = \eta.\ (1 – 0.25.\ \eta) – (R – 0.25)/(1 – R)$$
$$\text{with } \eta = (2.\ (NIR^2 – R^2) + 1.5.\ NIR + 0.5.\ R) / (NIR + R + 0.5)$$

Where NIR is the reflectance of the near-infrared, R is that of the red and B is that of the blue.

As with the Enhanced Vegetation Index, there are other indices which enable the effects of soils to be taken into account, and therefore for the influence of soils under the cover of vegetation to be reduced. For example, the *Soil-Adjusted Vegetation Index* (SAVI) created by Huete (1988). This index introduces an adjustment parameter which characterises the soil and its rate of cover by the vegetation. It is calculated as follows:

$$SAVI = (1 + L).\ (NIR – R) / (NIR + R + L)$$

Where NIR is the reflectance of the near-infrared, R is that of the red and L is the adjustment parameter which has a value of 0.25 for high density and 1 for very low density of vegetation, and 0.5 for intermediate density.

Improvements have been made to the SAVI. A couple of examples are the *Transformed Soil-Adjusted Vegetation Index* (TSAVI) proposed by Baret in 1989 and the *Modified Soil-Adjusted Vegetation Index* (MSAVI) developed by Qi in 1994. These indices introduce correction parameters based on the straight line of soils.

Other vegetation indices enable different information to be extracted. For example, the *Normalized Difference Water Index* (NDWI), the *Shortwave Infrared Water Stress Index* (SIWSI) or the *Land Surface Water Index* (LSWI) depending on the sensor and bands used, proposed by Gao in 1996 is a water stress index which particularly enables estimates to be made on the water content of the foliage in forest cover. This index also uses two bands, namely the near-infrared and the mid-infrared. The use of the mid-infrared enables the effects of the soils to be removed, in part.

The NDWI is calculated as follows:

$$NDWI = (NIR — MIR) / (NIR + MIR)$$

Where NIR is the reflectance of the near-infrared and MIR is that of the mid-infrared.

1.4.4.2. Soil indices

Bare soil is much more complex to analyse and many indices have been developed for roughness, colour, Munsell colour, composition (clay index), granulometry, etc.

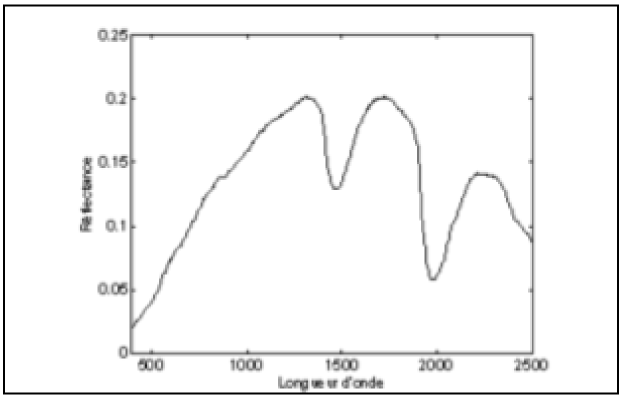

Figure 20: Spectral signature of a standard soil (average of 564 spectres measured at the beginning of the 1980s)

Among these different soil indices, the *Normalized Difference Soil Index* (NDSI), in particular, is used in soil sciences. It enables vegetative cover to be differentiated from mineral tracts.

The NDSI is calculated as follows:

NDSI = (MIR – MIR)/(MIR + NIR)
Where NIR is the reflectance of the near-infrared and MIR is that of the mid-infrared.

Lastly, the *Brilliance Soil Index* (BSI) and *Soil Moisture Index* (SMI) enable the brilliance and the dryness/desertification of soil to be characterised, respectively. They are calculated as follows:

$BSI = (R^2 + NIR^2)1/2$
and
SMI = ETa / PET
Where R is the reflectance in the red, NIR is that of the near-infrared, Eta is actual evapotranspiration and PET is potential evapotranspiration.

1.5. Remote sensing software

Lots of software exists for processing and analysing geospatial images. Nearly all the software have the same options for manipulating, managing and processing geospatial data. Some software have additional functionalities in the form of tools and modules which can be added to the original platform, or even independent software. The following is a non-exhaustive list of the functionalities and modules in the software available (please see annex 5 for a comparison and analysis of the different functionalities available):

- data visualisation and editing tools;
- tools for geometric correction and image mosaicing;
- tools for atmospheric correction;

- tools for data processing: enhancing images by manipulating the histograms, spatial or morphological filtering, re-sampling, projection, image clipping, creating pan-sharpened images, calculating indices, arithmetic operations on bands, analysis of the main components, etc.;
- tools for extracting information from multispectral images with per-pixel classification, supervised and unsupervised, neural classification, etc.;
- spatial analysis tools: creating buffer zones, database management, etc.;
- tools for managing and analysing RADAR data (calculating brilliance, texture analysis, speckles filtering, etc.);
- tools for managing and analysing hyperspectral data;
- tools for producing maps;
- tools for managing and processing Lidar data: creating Digital Terrain Models and Digital Elevation Models;
- tools for managing and creating satellite or aerial ortho-images;
- tools for managing vectoral data and compatible interfaces with GIS software such as ArcGIS®

Among the existing software, there is specialised commercial and free software:

- PCI Geomatica, Canadian commercial software: http://www.pcigeomatics.com/;
- ERDAS Imagine, American commercial software: http://www.erdas.com/Homepage.aspx;
- ENVI, American commercial software: http://www.ittvis.com/language/fr-FR/Soci%C3%A9t%C3%A9/Pagedaccueil.aspx;
- IDRISI Taïga, American commercial software: http://www.clarklabs.org/products/idrisi-taiga.cfm;
- BEAM, free software from the European Union (ESA) : http://www.brockmann-consult.de/cms/web/beam/welcome;
- SPRING, Brazilian free software (INPE): http://www.dpi.inpe.br/spring/francais/index.html;
- Orfeo Toolbox Monteverdi, French free software (CNES): http://blog.orfeo-toolbox.org/monteverdi.

The tools for object oriented classification are mainly available on independent software. For example:

- Definiens Cognition Network Technology (successor to eCognition), American commercial software: http://www.ecognition.com/products
- FeatureObjeX, commercial software following PCI Geomatica: http://www.pcigeomatics.com/index.php?option=com_content&view=article&id=9&Itemid=4
- ERDAS Objective, commercial software following ERDAS Imagine: http://www.erdas.com/products/ERDASIMAGINE/IMAGINEObjective/Details.aspx
- Feature Extraction, commercial software successor to ENVI: http://www.ittvis.com/language/fr-FR/NosProduits/ENVI/ENVIEX/fxworkflow.aspx

2. Extracting information on habitats

2.1. Mapping using field work

Historically, habitat maps were based solely on field work.

The habitat classification obtained using the Corine Biotope is a perfect example. This typology of natural and semi-natural habitats on European soil, officially published in 1991, was based on the description of vegetation from the results of phytosociological studies conducted in 1984. Using the field work, each habitat was characterised in more or less detail depending on the data available, with the corresponding phytosociological syntaxon, along with a brief description of the type of vegetation and floral formation which could be observed in the habitat.

However, while this method may have been used on a large scale for a few projects, it was more often used for habitat maps on a local scale (for example, a map of a protected area).

2.2. Image analysis to supplement field work

Today it is more and more common to map habitats using a combination of information extraction methods, such as field work and image analysis. Field work can be carried out as part of a project, and can also be used to produce exogenous data.

Whichever method is used for the analysis, the objective is to extract the homogenous zones, from both a spectral and an ecological point of view. The homogeneity derives from the method used.

2.2.1. "Traditional and operational" methods

Whichever technology is chosen, processes can be carried out to extract the useful information from the data. The aim of segmentation is to interpret the information and assign a label to the different "objects" in the image.

Historically, the first mapping methods used tracing paper superimposed onto aerial photographs or ortho-photographs. For example, the 1995/1996 update of the land-use map for the Nord-Pas de Calais region was produced using this approach. An inventory of changes could then be made using both the traced impression of the previous map and the photographs, viewed using light tables.

Today, two operational methods enable satellite images to be segmented, specifically Computer Assisted Photo Interpretation (CAPI) and automatic classification methods. Coupled with field work and exogenous data, they enable detailed habitat maps to be produced.

2.2.1.1. CAPI

Photo-interpretation is a logical and reasoned approach based on a visual examination of the images by an operator called a photo-interpreter. This logical approach is based on object recognition using reasoning through which homologous zones are identified by their colour, texture and structure.

The identification of geographical units therefore consists of characterising homogenous zones, examining their environment and researching analogous zones in order to confirm or refute an identification hypothesis. A correct interpretation therefore requires the photo-interpreter to have good basic knowledge of the geographical context and the area studied.

The images to be photo-interpreted can be analysed using either a print-out (aerial photographs or satellite images), or directly on the screen (scanned aerial photographs and digital satellite images), as is the case with CAPI.

CAPI is a mixed method for studying land use which is based on an initial visual interpretation of the images, with the interpreter having access to an interactive processing station so that they can visualise and process the base data to be interpreted. They can zoom into problem areas, carry out radiometric changes (e.g. ratios, linear combinations of spectral bands, calculating indices, examine images taken during other seasons or by other sensors or even exogenous data put into the GIS), if required.

However, the visual interpretation is often limited to one single image at a time because it is difficult to carry out a visual interpretation from multiples images in a reasonable production time. In addition, human interpretation is a subjective process which means that there will be differences between one photo-interpreter and another.

Multiple images can be used when using CAPI stereoscopic vision. Using stereoscopic vision is an approach which enables data from aerial photographs to be fully exploited when visualising reliefs on the ground. Using stereoscopic vision is possible with satellite images. The principle of stereoscopic vision is as follows: in normal binocular vision, each eye sees the same object from a different angle and therefore registers a different image on each respective retina. The fusion of these two images by the brain is what creates the impression of relief. Stereoscopic vision requires each eye to see only one photograph: each retina therefore registers a different image and recreates the conditions of binocular vision. In order to reconstruct the shape of the object in space, a dual perspective will be required. In effect, one photograph on its own will not enable the topography of a site to be completely understood. Stereoscopy is therefore the process which enables the relief to be recreated using two photos which superimpose on each other up to 60% and are called stereoscopic couples. The stereoscopic couple is the set consisting of two images of corresponding points. Stereoscopic vision is possible through using a stereoscope, and also by using specialised computer software. With the use of a stereoscope the different elements in the photo will appear in 3D. Imperceptible and undecipherable details become apparent and easier to interpret (i.e. in differentiating between plant communities using their height, for example). All aerial surveys by the National Geographical Institute and the National Forest Inventory are stereoscopic.

CAPI can be used in different way when developing habitat maps.

It can be used for most of the segmentation work. The objects digitised by the operator are the final objects. The terrain is sometimes used to support this work or for validating the classification. Projects like ARCH are a perfect illustration of CAPI (please see the guide to CAPI for further information on the methodology).

CAPI can also be used to support field work. It enables the first levels of information to be extracted, which can then be characterised on the ground.

The “Mapping the vegetation and habitats of the Natura 2000 FR9400576 site: Monte Cinto – Bonifatu area” project carried out by SIRS, which forms part of the European Union’s actions for conserving biodiversity and establishing Natura 2000 sites, perfectly illustrates this methodology. The aims of the project were to develop vegetation maps of the Natura 2000 site and the Bonifatu forest and the north slope of Cepu, to codify the vegetation maps in order that they can be used as Natura 2000 habitat maps, and lastly to computerise the maps.

In an approach such as this, the habitat map is the result of work combining Computer Assisted Photo Interpretation and field work. In this project, the approach took place in three main stages.

Firstly, the photo-interpretation of the first level was carried out using stratified sampling to identify the units of vegetation. This first photo-interpretation was used to zone the area of study and to delineate the polygons corresponding to islands of vegetation. It was based on an analysis of orthophotographs and infrared images. In addition, field surveys were also carried out during this first stage. During the field surveys, a series of polygons, which were very representative of the diversity of the site, was obtained for carrying out phytosociological surveys. Alongside these surveys, direct observation of the ground (i.e. pedestrian surveys inside the units of vegetation, observations with binoculars from opposite sides, etc.) associated with the panoramic viewpoints enabled a first map of the physiognomic units of the vegetation present on the site to be drawn up, by overlapping them with the polygons pre-identified by the photo-interpretation.

Secondly, the photo-interpretation of the second level was carried out, along with a definition of the types of vegetation using additional phytosociological surveys. The aim was to characterise the natural habitats. Each physiognomic unit presenting homogenous vegetation was the subject of a series of phytosociological surveys in order to characterise the corresponding habitat. These surveys were carried out within one zone which appeared to be homogenous and characteristic of the pre-identified unit of vegetation. The methodology used to carry out these surveys and to characterise the different 'natural' habitats was based on the Integrated Synusial Phytosociology process, which characterises overlapping in the different plant communities which can coexist within the same dominant formation. Eventually, a correspondence was established with the CORINE nomenclature in order to identify the habitat.

Finally, the last stage consisted of producing the actual map, in paper format and digital format so that it could be integrated into GIS platforms.

2.2.1.2. Automatic methods

Recent developments in remote sensing technologies, such as satellites and the associated sensors, mark a turning point. These satellites enable multispectral images in digital format with high spatial resolution on much larger spatial scales and in much larger proportions to be generated. The development of automatic procedures, more suitable than visual and manual interpretation and classification, naturally accompanied satellite imagery. The numerical analysis is therefore more objective, which enables reproducible results.

Classification is therefore a method for analysing and extracting information which consists of gathering together groups of pixels on the basis of spectral similarities. Grouping the pixels together is carried out using statistics and the spatial and spectral characteristic which each pixel has. In principle, the classes are therefore different from one another. A class only contains similar pixels and is homogenous. In other words, it involves grouping together pixels according to their spectral resemblance to determine the contours of a group of pixels so that interpretable spatial units can be formed in terms of thematic classes.

Currently, the algorithms for automatic image segmentation/classification are divided into two families depending on the object the algorithm relates to: per-pixel classifications and object oriented classifications.

Per-pixel classifications enable each pixel of an image to be analysed and assigned to a precise class with the help of its spectral signature (and sometimes with additional data annexes). The output data is the raster image, which is generally made up of the same number of pixels as the original image.

Object oriented classifications are historically much more recent than the first. This method is not applied to the pixel, but to the notion of the object. Complementing the spectral information, supplementary information is taken into account by the algorithm such as the shape and texture of the object. The output data is the vector file which can be easily integrated into GIS platforms.

The two techniques are therefore of interest to the ARCH project. These methods could form the basis of a reproducible approach to habitat surveillance and monitoring.

2.2.1.2.1. Per-pixel classification

This classification is based on two fundamental principles: all the objects (or pixels) of the same class are characterised by identical spectral signatures and all the signatures of the object classes are perfectly distinct from each other.

Commonly, there are two classification methods based on the pixel from which all the variants are derived. These are supervised and unsupervised classifications. They are used respectively to determine *a priori* and *a posteriori* the classes (or types) of land use.

The underlying classification algorithms work most commonly on the spectral information, namely the reflectance, or by default the raw data, the Digital Number. Therefore, it is assumed that the regions in the image with a same spectral signature have a similar type of land use or habitat.

Unsupervised classifications

Unsupervised classifications automatically identify groups (or classes) on the basis of the spectral information of the pixels. These classes are then associated with types of land use in order to produce the map.

This classification is made without any information *a priori* on the nature of the objects to be classified. Therefore, multispectral data is most commonly used for this type of classification as it enables the differences of the signatures between the objects to be best exploited.

Although many segmentation techniques have been developed, unsupervised classification essentially remains the same.

As mentioned previously, the pixels are identified as belonging to one class by using the spectral information, namely the reflectance values (or by default the digital number) for each band taken into account in the classification analysis.

Usually, because this process enables spectral information from three or more bands to be used, the combinations can be visualised in multi-dimensional space.

There are two large categories of unsupervised classification methods:

- Hierarchical classifications which produce larger and larger partition sequences of the classes;
- Non-hierarchical classification which produces a partition of space into a fixed number of classes.

Among the most common methods today are the methods of mobile centres and clouds of dynamic points.

Among those integrated into the majority of remote sensing software are the algorithms “K-Means” and “ISODATA” (method used in mobile centres). Whichever algorithm is chosen, the operator controls the whole of the unsupervised classification process and is required to determine the number of desired output classes.

For the ISODATA method, the operator chooses a minimum and maximum number of classes. On an operational level, these values are generally set by overestimating the number of classes required. A phase for combining the classes is required in order to group together the identical classes. The underlying idea is to produce a map which is best suited to the final desired nomenclature.

Whichever process is used during the initial extraction and the subsequent reduction of the classes, unsupervised classification requires a *post priori* interpretation of the terrain signified by the classes obtained. This is usually carried out using the terrain reference data.

Supervised classifications

Supervised classification methods firstly require a set of training data to be defined and established.

Basically, this set of training data enables a library to be established of the spectral signature types for each class which needs to be extracted in order to create the land use map. The training area chosen to establish this training set must therefore be representative of the whole study area in order to cover all the reflectance variations of the classes and to take into account the local variability of the environmental classes due to the soil type, moisture, etc.

The training sites must be exempt from anomalies and must be a suitable statistical representation of the area. There must be a substantial number of them. Once the set of training data is established, the classification process can begin.

The spectral signature of each pixel of the image is analysed and compared to the signature types established initially for each class. Assigning a pixel to a given class is based on criteria which complies with the decision rules and algorithms (whether parametric or non-parametric), which enable the image to be cut into groups.

The parametric decision rules consider the space between the points to be homogenous from a spatial point of view. Therefore each pixel is assigned to a given class.

The non-parametric rules consider the space to be discreet; each group is therefore delineated with a boundary.

Therefore, outside of these borders a pixel can be considered to be unclassified.

Different supervised classification methods are implemented in remote sensing software, such as for example minimum distance methods, parallelepipeds or maximum likelihood.

While the first two methods are the most simple to implement, they are nevertheless the least effective. In effect, when using these methods large numbers of pixels may not be assigned to any class.

In contrast, the method of maximum likelihood classification is more accurate as the decision rules are based on the notion of the probability of belonging and not on simple distances. This algorithm is therefore the most commonly used in remote sensing during the implementation of supervised classifications.

Possible applications

There are many examples of projects using these approaches. The automatic classification approach is the most widely used.

The “Mapping the littoral vegetation in a dry dune environment using remote sensing for the Réserve Biologique Domaniale de Merlimont (62)” project, carried out by SIRS under the European LIFE programme and the development of a management plan for the Biologique Domaniale de Merlimont site is a first example.

This project developed a map of the vegetation formation of 14 classes divided into three large areas (i.e. dune, in transition and forest).

In order to do this, SPOT XS data with 20 metres spatial resolution on 3 dates was used. From this data, three standardised vegetation indices could be developed in order to establish a thresholding between the vegetated surfaces and the non-vegetated surfaces (water and sharp sand), which could then be integrated into the semi-supervised classification process in 16 classes.

It was possible to check the relevance of the results using the excellent knowledge of the environment and floristic surveys on several test sites.

In this project, the use of a multi-date colour composite based on the vegetation indices produced good results in term of discriminating between the vegetation formations. However, if data with a better resolution and of a mid-infrared channel was obtained, it would have significantly improved the map and in particular highlighted the spatial variations in moisture of the vegetation cover.

Finally, the acquisition of a sequence of recent images highlighted the multiple movements of vegetation in these constantly evolving environments, in particular the closing in on grassland areas by scrub.

Project “N°6 PNRZH: Between Scarpe and Escaut: hydrosystem, biodiversity and sustainable socioeconomic changes to wetlands” which characterised the wetlands in the Scarpe and Escaut region is another example.

This project concentrated on wetlands bordered by ditches (particularly on frequently flooded areas), wet woodlands dotted with pools, previously managed marshes (small geometric plots with a mixture of ponds, vegetable plots, grasslands and poplar groves, drained marshes (old drainage systems, strengthened by an extension of the underground drainage network), wet wasteland, often partially flooded, associated with subsidence from old mines alongside slagheaps and residual bogs (Tourbière de Vred)).

Using SPOT XS multi-spectral and panchromatic images, the derived data (indices type), and exogenous data, an automatic classification was carried out. In particular, it distinguished between the marsh/non-marsh of the agricultural soil (brilliance index of bare soil by thresholding the NDVI vegetation index), identified the principle types of vegetation cover (using seasonal NDVI): afforestation, permanent grasslands, crops, water maps, and delimited the potential expansion area of the wetlands (comparison of the NDWI with the topographical data from the DTM and the hydrological data).

The "No 1 PNRZH: Wetlands of the Seine estuary and marshes. Structure, operation and management" project as part of the Seine Aval programme is another example.

From SPOT XS data and data derived from the type of vegetation index, the automatic classification method enabled the vegetation formations in the littoral wetlands in the Hode marsh to be accurately identified.

A study led my SIRS demonstrated the importance of supervised classifications for highlighting environments such as mesophile grasslands and hydromorph in the Authie valley (62 and 80).

Using a Landsat 5 satellite image and a set of training plots used for setting the classification, the use of the mid-infrared band enabled the quality of the classification to be improved for the majority of the themes, and quite significantly for the grasslands. In effect, the use of this band considerably improved the readability of the phenomena linked with hydromophy: the radiometry of wet grassland environments is considerably lower than that of mesophilic environments. The use of the mid-infrared for identifying phenomena linked to hydromorphy is widely recognised today.

Work carried out for the DIREN Champagne – Ardennes based on Landsat data and automatic classification approaches enabled good classifications of grasslands, crops and bare soil for 21 posts in 4 departments, namely: Ardennes, Aube, Haute-Marne and Marne.

The methodology was based on a series of ascending hierarchical classifications leading to the classification and mapping of 20 classes of land use, further sub-divided into 145 landscape units (aggregation by textural classification). The last stage consisted of combining the 145 landscape units by an ascending hierarchical classification into 21 rural landscape classes.

As part of the LOIS BIOTA (*Land-Ocean Interaction Study, Biological Influences On interTidal Areas*) programme, Thomson et al. (2003) carried out an unsupervised ISODATA classification. They used airborne imagery "*Compact Airborne Spectrographic Imager* (CASI)" with a 4 metre spatial resolution supplemented with other airborne data "*Airborne Thematic Mapper* (ATM)" on an intertidal zone consisting of 270 km of coastline along the estuary from Humber to North Norfolk in the east of England. The aim was to model the process of coastal erosion and accretion. A total of 50 classes were first obtained on the study area of 476 km². Then these classes were fused into 13 classes (five of which were classes of vegetation). A final accuracy of 70% was obtained from comparisons with terrain data.

Blackburn and Milton (1997) from the Universities of London and Southampton (Geography Department) obtained up to 78% general accuracy during the implementation of an unsupervised classification on airborne remote sensing data (CASI) of 2 metres spatial resolution on an 10 km² area (the New Forest). The aim of their work was to monitor gaps in the canopy for ecological purposes (process of regeneration and distribution of species). The analysis was preceded by a principle components analysis (PCA) in order to produce more accurate information on the structure of the cover. Eight classes were obtained and described by comparing them with an aerial photograph. Then the number of classes was reduced to two: the canopy and the gaps in order to study the properties of the latter. The spatial statistics were used to describe the ecological properties of the wood of different ages in the study area.

In the joint project "*The development of remote sensing techniques for marine SAC monitoring*" carried out by the English Agency for Nature and the Environment and the *Science Group-Technology*, Brown et al. (2003) used the supervised classification (maximum likelihood) on airborne data (CASI) of 2 metre spatial resolution (combined with LIDAR data) on different coastal habitats (Tollesbury): saltmarshes, shingle, mudflats, saline lagoons and sand dunes. The aim was to develop remote sensing techniques for marine surveillance, including changes in vegetation. The addition of LIDAR data enabled the accuracy of the classification to be improved. The overall accuracy of the classification was in the order of 66%. Difficulties in classifying the vegetated areas were encountered.

2.2.1.2.2. Object oriented classification

As with the per-pixel classification methods, the object oriented classification methods can be used to identify types of land use or habitats using classification algorithms.

These methods are based on human perception. The underlying algorithms do not treat the pixel in an isolated way like the per-pixel classification methods do. Instead, it is treated within its context. The image used is therefore segmented into groups of pixels showing similar characteristics. These groups are therefore considered as objects which make an interpretation based not only on the spectral data, but also on the object's set of properties possible.

The object oriented method enables a whole set of characteristics such as the size, shape or texture of the objects to be taken into account and integrated into the classification process. Other information such as the spatial context can also be included. Therefore, objects such as roads and buildings in the image can be identified with a more or less significant degree of accuracy.

As these classification methods enable natural habitats to be integrated in their entirety, these techniques therefore seem to present great potential for classification.

Before the actual classification stage, the image must first be segmented. The segmentation groups together the pixels close to each other which have similar spectral characteristics. The image is then sub-divided in order to produce a set of spatially discreet objects made up of many pixels.

Next, for each of the objects a whole set of attributes relating to their spectral, spatial, textual and contextual characteristics needs to be calculated. These properties are then used to construct what are known as the classification rules.

There are two large classification approaches, one by training and the other by constructing rules.

The first is based on an algorithm of maximum likelihood using training objects selected by the operator.

For the second approach, the operator generates rules cognitively using their own knowledge. These rules can use the colour, and also the size, shape and context of the objects which considerably improves the results of the interpretation.

Whichever method is used, the mathematical rules are used to make correspondences between the characteristics of one object in the image (e.g. reflectance, shape, surface, texture, etc.) with one of the profile types in the sample. All the objects in the image are therefore attributed a unique class or are left unclassified if the profiles of the objects are unusual.

The object oriented classifications also differ from the per-pixel classifications in the output format of the classification. The extraction of objects or polygons is done in a vectoral form. This enables the results to be integrated into a GIS platform.

Wales notably used this approach to update its first map.

While the map is the most complete and widely used semi-natural habitats map of Wales, it is, nevertheless, in a large part still based on field work carried out over many decades. The mapping was first initiated in 1979 and was only completed in 1997. Given that financial resources were limited, repeating this experience was not possible.

The object oriented approach, based on the implementation of classification rules was therefore used. This classification was developed using the eCognition software and based on multi-temporal satellite data obtained between 2003 and 2006. It enabled the semi-natural habitats and agricultural land of Wales to be mapped in order to progressively update the map produced in phase 1.

The classification of the objects in the habitat classes of phase 1 was carried out in two stages. Firstly the Welsh landscape was segmented into objects using SPOT-5HRG High Resolution (10m) orthorectified data and data from the borders of the *Land Parcel Information System* (LPIS). The classification rules were then progressively developed in order to discriminate and map the distribution of the 105 sub-habitats in Wales on the basis of SPOT-HRG, Terra-1 Advanced ASTER and IRS LISS-3 data, derived data (vegetation indices, for example) and exogenous information (the topography, for example).

The rules enabled ecologists' knowledge to be combined with the information content of the remote sensing data by using a combination of thresholds, Boolean operators, etc.

A second set of rules was then applied to translate the more detailed classification resulting from the object classification to the habitat classes in the phase 1 map. A general accuracy of over 80% was achieved (based on comparisons with field work), and an accuracy of between 70 and 80% for the majority of the classes.

Through this exercise, Wales became the first country in Europe to produce a national habitat map (as opposed to maps of land use), using an object oriented approach to satellite data. Moreover, the approach can be adapted to enable continued monitoring of the extent and status of the habitats and agricultural land of Wales.

2.2.1.2.3. Evaluating results

Regardless of the method used, an evaluation of the classification can be carried out by setting up an error matrix or a contingency table.

This matrix enables the degree of accuracy of a classification to be evaluated. This is obtained by comparing the data issued by the classification algorithm with the reference data. The latter may come from field work or aerial photographs, for example.

Whatever the source of the reference data, it is important that the source has an identical typology so that comparisons can be made, and that there is a sufficient amount of data so that each class is sufficiently represented. It is important to specify that in the case of supervised classification, the reference data must be different from that used during the classification process and the implementation of the set of training data.

The error matrix is constructed by plotting the lines, reference data, and the columns of the classification. Pixel by pixel, it enables the class assigned to each pixel during the classification process to be compared with the real class taken from the actual reality on the ground.

Using this error matrix, it is possible to establish a whole set of metrics which enable the degree of precision of the classification to be quantified. Among these metrics are:

- general accuracy: this relates to the number of correctly classified pixels (in relation to the validation training data), divided by the total number of training pixels;
- user accuracy: this relates to the percentage of pixels in a class issued by the classification which correspond to the same class in the reference data;
- producer accuracy: this relates to the percentage of pixels in a reference class assigned to the same class by the classification;
- rate of commission: this relates to the percentage of pixels in a given class, issued by the classification algorithm, which in reality belong to another class according to the set of reference data;
- rate of omission: this relates to the percentage of pixels in a given class which have not been assigned to that class.

The error matrix is usually accompanied by tables showing the percentages of error between a given class and each of the other classes.

The general accuracy of the classification provides information on the overall quality of the classification. However, it is dependent on the pixels sampled.

There are other techniques which make it possible to establish a measure of confidence in the error matrix. One of these techniques involves calculating the Kappa coefficient. The value of the Kappa coefficient varies between 0 and 1. For example, a Kappa coefficient value of 0.85 usually deemed to be the minimum value that should be achieved, signifies that 85% of the classification is not due to chance.

2.2.2. New and emerging methods

New and emerging methods are being developed which go beyond the current extraction methods described above, such as Computer Assisted Photo Interpretation, automatic classification methods (per-pixel or object oriented).

In these approaches, the remote sensing data is no longer the basis for the information extraction methodology, but is integrated as a parameter in the statistical model.

It essentially involves modelling the ecology of a living species (i.e. vegetation, animal, bacteria, etc.). These are different from the usual observation maps due to the steps taken.

In effect, the aim is not to detect or identify an object an image, but to model the ecology of a living species. It involves statistics of habitat or species distribution using many parameters which are then compared with terrain data.

These parameters can be of a different nature from each other, i.e. environmental, climatological, geological, biological, phytosociological, anthropic, physical, etc.

In the end, a probability of a living species, habitat or invisible phenomena, undetectable on a satellite image, being present is obtained. These new and emerging methods therefore seek information at a scale of less than a pixel. This is called a sub-pixel analysis method.

These processes are particularly used for plant species. It involves describing the habitat using observations derived from remote sensing data and statistics crossed with exogenous data (for example, terrain data). It is therefore possible to re-construct abundance maps or habitat maps by reconstructing the nomenclature (such as the *Corine Land Cover*, for example).

Recent work carried out by Elizabeth Farmer uses this approach as part of her thesis called “A Critical Evaluation of Remote Sensing Based Land Cover Mapping Methodologies”.

It is an approach for producing vegetation maps using what is known as ‘primitive data’ and descriptions of plant communities.

The starting point of this methodology remains the field work carried out by experts. Based on a sampling of the terrain (225 samples of 1 m²), this fieldwork enables five attributes of plant communities in the investigated sample to be characterised, thus constituting the primitive data, i.e.:

- the species present;
- the percentage of cover;
- size;
- structure;
- density.

From the definition of the classes of vegetation, in accordance with these five attributes, an initial map is produced for each sample. Coupled with exogenous data (DTM, in particular), these classifications are used as training data for the per-pixel classification (supervised classification) of a SPOT-5 satellite image.

The general accuracy obtained for the resulting vegetation map is in the order of 80%, with variation depending on the sample. The validation work is based on the use of aerial photographs. The methodology of using primitive and descriptive data therefore presents a strong potential in terms of describing the plant variability in a landscape and for mapping habitats.

These approaches are also frequently used in epidemiology for reconstructing the habitats of disease vector species. Recent work on paludism (malaria) carried out by Vanessa Machault for her thesis entitled “the use of land observation data by satellite for evaluating the vectoral densities and transmission of malaria” and recently included in the EEOS Malaria project, uses this method of indirect mapping to reconstruct the habitat of a living species, namely the mosquito.

The idea is to use SPOT-4 and SPOT-5 satellite observations of the Earth of 20 and 2.5 metre spatial resolution, respectively, to identify and evaluate the determining/ant environmental factors of malaria.

There are two types of determining factors of the disease:

- geoclimatic (e.g. seasonality, rains, humidity, temperature, vegetation and the presence of surface water);

- anthropic (e.g. agricultural activity, irrigation, deforestation, urbanisation).

For example, using satellite data it is therefore possible to establish indicators of vegetation (NDVI type), indicators for humidity (NDWI type) or soil indices (e.g. brilliance index). These factors are then associated to the spatial and temporal distribution of the biological determinants of paludism (malaria).

For example, in this case, the paludometric indicators which are: breeding sites and collections of water, anopheline aggression, transmission of plasmodiums, Plasmodium infection, and malaria morbidity come from models and maps based on the terrain data, *a priori* knowledge and opinion.

Associating environmental, meteorological and climatic data obtained using remote sensing with the paludometric indicators (mainly obtained from terrain data), enables adjustments to be made to the predictive statistical models of the habitat maps of the mosquito and maps of associated entomological risks to be designed.

For example, these could be maps of the level of risk in urban areas for preventative health measures or reasoned urbanisation (with the possibility of annual updates) or for dynamic maps for targeting anti-larval and anti-imago action in places where the risk is the highest (with the possibility of monthly or even bi-monthly updates).

Work such as this provides a better understanding of how paludism is transmitted in urban areas and the conditions for transmission which will make actions to combat malaria more effective. The interesting point is the balance between the use of remote sensing indicators and the modelling, with the biological mechanisms observed on the ground.

3. Discussion and recommendations

Mission 3 of Activity 3 of the ARCH project focused on studying the potential of new spatial remote sensing technologies and associated services for understanding and monitoring natural habitats and biodiversity in the cross-border region of Nord-Pas de Calais and Kent.

In particular, this involved looking at the possibility of updating the map which was result of Activity 1, using satellite images for the purposes of monitoring natural habitats and biodiversity on the territory.

The map from Activity 1 was based on the principle of CAPI using aerial photographs. The CAPI solution proved to be very time-consuming in terms of the amount of work required to implement it and very costly because it involved planning a large-scale airborne mission.

Exploring remote sensing tools and techniques should enable more effective solutions for updating and habitat monitoring to be proposed. Using remote sensing seems to offer many advantages, in comparison with traditional mapping techniques based on field work, such as for example, quicker production times.

For this purpose, a certain number of considerations need to be taken into account in order to ascertain and understand the challenges of such a use, and to correctly evaluate the potential of remote sensing.

However, above all, it is important to stress that the work using geospatial data coupled with automatic information extraction methods, which appears to be the best use of remote sensing technology, can never replace work done by Computer Assisted Photo Interpretation. Remote sensing can however, provide a number of interesting areas for consideration.

3.1. Nomenclature

It is evidently very difficult, impossible even, to reproduce the work of photo-interpreters, whether in terms of the geometry of objects (shapes and borders) or in terms of the complexity and detail of the mapping nomenclature.

In general, the smaller the number of classes looked at is, the simpler the classes are and the more viable the remote sensing solution is. However, in the ARCH project, the level of detail of the nomenclature and the number of posts looked at (i.e. mono-specific, oriented natural habitats of more than 60 classes) makes the full use of remote sensing over the whole of the region impossible. The usual extraction methods are the automatic methods which are based, principally, on the spectral information of the image. Thus, the spectral signatures differ very little from one forest or vegetation cover to another of the same composition, for example.

The segmentation/separation of classes cannot therefore be as detailed as that of photo-interpretation, even by using very high spatial resolution satellite images. Spatial remote sensing can contribute more to the first segmentation or level of the nomenclature.

3.2. The geographic expanse

Another challenge concerns the footprint of the map. In effect, the ARCH project is on a regional scale. The geographical expanse creates two problems. Firstly, it is very difficult, depending on the satellite chosen (and the associated sensor), to obtain consistent images from a spectral and temporal point of view of the whole geographical area covered by the project (problem of underlying phenology). It is also very complex to cover the whole extent of the geographical area using a series of satellite images from the same sensor.

For example, the use of SPOT-5 data with a spatial resolution of 20 m of which the swath is 60 km assumes the use of tens of images in order to cover the whole of the study area. The problem is even more complex if the user wishes to use VHR QuickBird or Ikonos data (with a spatial resolution of less than 2.5 m in multi-spectral mode) for which the swath is only 17 km. The agility of the satellite does not enable such an acquisition. The use of HR data is therefore more viable.

Furthermore, the satellite platforms enable a continuous band to be captured which schematically extends from the north to the south (in reality, the rotation of the Earth makes the swath slightly diagonal). However, the satellite is constrained in terms of data storage or data transmission to the receiving station. Covering the whole geographical extent of the study area is therefore complex. The problem is particularly true of VHR QuickBird, Ikonos and WorldView data.

One solution could be to produce a mosaic of the area using satellite images from sensors attached to different satellites. However, this presents the problem of spectral consistency between the images due to radiometric differences between the different scenes which are difficult to manage. This is not the best solution.

Finally, producing a mosaic of the satellite images would require data with ideal, perfect even, atmospheric conditions (no haze or clouds), covering several different points of view, conditions which are not very common in the North-West of Europe.

The detection and classification of habitats which extend generally from east to west, as here in the Nord-Pas de Calais region could prove to be a real challenge. For Kent, the problem is smaller as the region is four times smaller than the Nord-Pas de Calais region (about 3,700 km² as opposed to 12,400 km²) and so the footprint is therefore smaller.

3.3. Compromise between different resolutions

It is inevitable to have to make a compromise between the swath, spatial resolution on the ground and the spectral resolution. Thus, choosing a high spatial resolution, *a priori* required for rendering shapes which are similar to aerial photographs, would be at the expense of the spectral resolution, *a priori* required for complex classifications, or at the expense of width the swath, which is required for a consistent analysis of the large surfaces, or even at the expense of both.

3.4. Focus on an area of specific interest

On the other hand, it would be relatively easy and possible to carry out conclusive tests in terms of accurate classifications at a local level and therefore on a test area covered by one single image. It could be a specific habitat at a more localised level which is of interest ecologically and in terms of biodiversity.

The use of very high spatial and spectral resolution satellite data, in this example, could be a solution. In this respect, the use of data from the WorldView-2 satellite is currently of interest for a number of different reasons.

The images from this satellite have many interesting characteristics. Specifically they have a very high spatial resolution and a wide range of spectral bands (eight in total). Among these, it is necessary to note the presence of new spectral bands such as “Yellow”, “Coastal” and “Red-Edge”, not widely available on the different sensors currently in existence.

The latter presents a particular interest. It corresponds to a portion of the spectrum in the near-infrared. It refers to the region of rapid change in the reflectance of chlorophyll. This peak of chlorophyll activity in plants is therefore located in the near-infrared where the reflectance is the largest. This band should therefore enable better monitoring of plant activity.

While details of Red-Edge have been known for several years, its use has remained limited. Several airborne systems such as hyperspectal sensors present this band in significant spatial resolutions, but the surfaces covered by this type of system do not enable optimal exploitation of the characteristics of this band over large areas. In fact, it is not feasible to use images from airborne sensors for monitoring natural habitats at the scale of a whole region, for example.

With regard to satellite imagery, until recently hyperspectral satellites were the only satellites to measure the reflectance in this band, but at very low spatial resolutions. Recently, the WorldView-2 satellite has presented a very high resolution Red-edge band, namely 50 cm in panchromatic and 2 m in multi-spectral. This new band available on the WorldView-2 satellite therefore enables significant additional information to be obtained. It appears to be particularly significant for highlighting the different phenological stages of plant cover. It use, coupled with the traditional multispectral bands, therefore enables vegetation indices which are optimised for use to be established.

Furthermore, the high spectral resolution, coupled with the existence of new bands, is also significant in view of the information extraction phases during classifications. These procedures are principally based on the spectral information. The higher the number of bands and the more uncorrelated the bands are, the better the final result will be. In this sense, the use of WorldView-2 data on the hotpots is an attractive proposition.

However, to extend the methodology to an area covered by many images, all from different dates (at a regional scale, or even national and continental) is much more complex. Indeed, there may be changes in the spectral signatures for short periods due to changes in the phenological stage of the vegetation or different atmospheric conditions depending on the scene, or both. In addition, the agility of the current VHR satellites does not enable images covering the whole territory to be obtained.

Therefore, it is clear that the solution which fully uses the tool of remote sensing for mapping natural habitats on a regional scale and monitoring over time would not the best use of the resource if it is for the following reasons:

- using remote sensing to produce a map with a nomenclature of natural habitats as detailed as that of computer assisted photo-interpretation of aerial photographs;
- repeatability of the techniques on a regional scale for analysing habitat monitoring compared to the current published map.

On the other hand, remote sensing could be the best solution if it is used to evaluate a specific habitat on a local scale rather than to carry out mapping and monitoring at the scale of NPdC and Kent. There could be a number of potential target sites, i.e. a habitat or species which is difficult to detect using traditional aerial photographs.

3.5. Costs

Despite their openness to remote sensing, end users such as habitat monitoring organisations and managers are not prepared to use remote sensing at any price, with good reason.

For example, acquiring VHR QuickBird-2 data for the whole of the Nord-Pas de Calais region would represent an investment of €400,000 and £100,000 for Kent. In addition, this estimate does not take into account the feasibility of the operation in terms of the geographical cover, with obtaining images of the whole area in effect being impossible, as detailed above. For coverage of a study area using GeoEye HR data, the investment would be €15,000 for Nord-Pas de Calais and £4,000 for Kent.

These organisations are often confronted with the problem of limited resources for carrying out their duties. They are therefore reluctant to invest significant sums of money in using one product without knowing all the facts. These experts are looking for a specific advantage compared to traditional methods, especially in terms of cost and efficiency. While it is true that so far the numerous remote sensing services (i.e. images, software, etc.) are often still very expensive, some lower cost solutions do exist.

For example, open access software exists which enables geospatial data to be manipulated and analysed. Some examples are: BEAM software (developed by the European Space Agency), or SPRING (developed by INPE, the Brazilian National Institute for Space Research). However, while commercial software enables a general use of all types of data, the free software is often focused on, and developed for, specific data. For example, the BEAM software is essentially based on the data issued by the ESA programmes. The SPRING software is based on SPOT, Landsat and ERS-1 data, in particular.

Furthermore, as well as software, data is also available free of charge, such as Landsat satellite images. This is medium spatial resolution data (30 m).

In addition, sharing the cost of purchasing of images among the various potential users within the region can only be recommended.

3.6. Choosing the automatic classification methodology

As detailed above, there are currently many different remote sensing methodologies for extracting useful information from satellite images, which enable, for example, different types of land use to be mapped.

Usually, the choice will be between the use of per-pixel classification methods (supervised or unsupervised) or object-oriented classification methods. Therefore, the choice of using one methodology over another may seem to be complex.

Nevertheless, in practice, in the field of habitat mapping, hybrid approaches such as combining automatic extraction methods with methods for visual analysis by photo-interpretation are generally used as they lead to better results.

One of the legitimate questions that arises is whether the choice to be made makes comparisons between projects, with aims of monitoring habitats and biodiversity similar to those of the ARCH project, or between different areas of the same region as part of a unique project such as ARCH, impossible.

However, potential users of technology are too often unfamiliar with the panel of images and methodologies available. In fact, it is very difficult to choose the method best suited to their needs. It is therefore understandable that they may wish for a standard, optimal approach to be used (in terms of specifications and image processing techniques and classification).

In reality, no one technique or methodology is the best. In fact, one of the strong points of remote sensing is its capacity to integrate different data and techniques in order to meet the end users' expectations. It is therefore not possible or even advisable to force or make the use of one particular technique obligatory, at the risk of degrading the quality of the end result.

It is of interest to review the advantages and disadvantages of each of the extraction methods presented in this report and to therefore present some recommendations. The per-pixel and object oriented classification methods will be looked at successively.

With regard to the unsupervised classification methods, one of the key points of these methods is that, in the case of a precise and detailed classification of land use types or of habitats (in terms of the nomenclature) not being obtained, they enable an initial segmentation of the images into large themes to be carried out. This segmentation can then be used to focus on those areas or themes of interest for habitat monitoring, whether by additional automatic methods, such as supervised or object oriented classifications or even using CAPI methods.

On the other hand, using these classification methods, the grouping together of pixels creates classes of thematic meaning which may sometimes be difficult to identify. Rending the map is then not possible.

It is often common for the classes obtained to not correspond completely to the classes observed on the ground. It is then usual to proceed, as far as possible, with combining the classes. However, it is not possible to be able to retrieve each of the classes on the map produced during Activity 1.

An alternative involves using CAPI to complement the automatic methods for making corrections and rendering the map. The unsupervised classifications do not enable accuracy levels over 75% to be obtained (they are around 60-70%).

The advantage of supervised classifications is that they enable, in contrast to the unsupervised methods, classes to have an accurate thematic meaning. On the other hand, from an operational point of view, this method takes a long time to implement because it requires training areas to be identified and established.

This therefore involves organising field work to collect all the information, which is often long and costly.

In addition, when using these classifications with a considerable number of ground control points, it is difficult to avoid edge effects when the bands overlap. To achieve a continuous and consistent map over vast regions is therefore a real challenge. These classification methods generally do not obtain general accuracy levels of over 75-80%, for a limited number of classes (around ten classes). In comparison, the accuracy levels attained by maps using CAPI are around 85%.

Lastly, object oriented classifications have the advantage of being the most advanced method of classification which enables defined spatial objects to be extracted.

The classification process uses a set of object properties, such as for example, the surface, the shape, the spatial context and the texture. Compared to pixel-based classification methods, these classifications enable higher accuracy levels to be obtained.

The vectors (polygons) are generated automatically for each object, therefore avoiding the need for manual numbering. However, currently, while the accuracy levels for mapping urban areas are acceptable and the associated rules are easy to define, those concerning "land" or "landscape" are not as easy to establish. Indeed, it seems that knowledge is still currently insufficient concerning the best way to select appropriate values for landscapes.

As a result, the segmentation phase, establishing classification rules, and the classification process could become long and complex. The scope for investigation is still quite large and progress still needs to be made. However, the initial use of object oriented classifications in Europe demonstrates that general accuracy levels of 70% for habitat maps can be achieved.

The choice between per-pixel and object oriented classification methods also arises with regard to mapping for end users. While the object oriented classifications enable polygons in vector format to be produced which can be directly integrated into a GIS platform, the per-pixel classifications produce results in raster format for which the unit of the work and the rendering is the pixel.

However, it is true that many users of geographic data (Directors of natural areas, decision-makers, etc.) are used to using maps made up of polygons which are "perfectly and beautifully" drawn.

3.7. Can the new remote sensing technologies be used operationally?

While new technologies such LIDAR or hyperspectral data, for example, seem to offer interesting possibilities in terms of natural habitat monitoring and surveillance, using them is nevertheless relatively complex.

Indeed, the data is very expensive. In addition, there are problems with the data being available and continuous. For example, there are only a few hyperspectral sensors and LIDAR (mainly airborne) and the satellites which will be launched in the future cannot cover whole regions of Europe. They could not produce data which is as spatially detailed as the current airborne sensors. Lastly, a major obstacle relates to the size of the images which only enables habitat analysis of the smallest footprints. For example, INBO (the Research Institute for Nature and Forests) and VITO (the Flemish Technological Research Institute), two Flemish stakeholders in the natural habitat, explored the possibilities of hyperspectral data. The technology only offered real potential on a local scale and on specific habitats. It could not be considered operational on a regional scale for mapping natural habitats.

With regard to LIDAR data, many countries have carried out field work on their territories in order to produce a Digital Elevation Model (DEM). It remains to be seen whether this work will be repeated in the future. It is highly probable that the use of LIDAR will be concentrated on urban areas at the expense of natural habitats. The question is whether it is realistic to use this data in the context of operational projects. However, the inclusion of this data and its successful use in certain projects means that its existence and possible use for specific needs cannot be ignored.

3.8. Is Very High Resolution the only solution?

One of the ideas which it is necessary to refute is that Very High Resolution data is the only viable solution for mapping.

The assertion that what cannot be detected on satellite images cannot be viewed is false. On the contrary, satellite images are not limited to VHR. As detailed above, large scale cover is not possible with this type of data. In Western Europe and therefore *a fortiori* in the regions of Kent and Nord-Pas de Calais, VHR data cannot compete with aerial data.

In reality, the contribution of a satellite image can also be seen in HR data. The spatial and temporal resolution of this data is of more interest to projects such as these, particularly in terms of the phenology. The relatively lower resolution can be compensated for by using modelling, of the type presented above in the description of new and emerging methods resulting from "Research and Development".

3.9. Multi-temporality

One of the main advantages of satellite remote sensing in relation to aerial photography is the multi-temporal aspect. The multi-temporal approach enables seasonal variabilities to be considered. This makes it easier to classify habitats.

One of the most frequent requests of production teams is to have access to images from different dates and seasons so that the communities and habitats on the image can be identified. Images acquired from airborne missions do not provide access to this type of image.

However, remote sensing does enable images to be acquired on different dates and in different seasons. There are constellations of satellites (for example, the DMC constellation) which provide weekly coverage. In the future the Sentinel constellation (ref: 3.10) will also enable multi-temporality to be used.

It is through the multi-temporal aspect that remote sensing can make a difference in comparison to more traditional CAPI methods, which can only exploit one date.

3.10. European and national initiatives

The various European and national initiatives on the horizon suggest that monitoring habitats and land on an almost yearly basis will be possible in the future. Among these initiatives, two are of particular interest: GMES and GEOSUD.

There is also a British imitative called the Landmap project (http://www.landmap.ac.uk/) which is worth noting. This initiative has been financed by the *Joint Information Systems Committee* (JISC) since 1st August 2007 and is a joint project between Mimas and the Department for Geomatic Engineering at University College London. The Landmap project provides access to geospatial data (optical, thermal and RADAR sensors, and elevation data) via a web platform for Research and Development purposes. The archive of optical and thermal data consists of ortho-rectified Landsat-4/5, Landsat-7, SPOT and

TopSat satellite data and aerial photographs for the purpose of mapping vegetation, land use and coastal sediments. The RADAR collection consists of ERS-1 and 2 and ENVISAT data. Finally, the elevation data consists of data from the *Shuttle Radar Topography Mission* (SRTM), a DTM of 25 metres and from additional LIDAR missions. However, this initiative is for purely academic purposes and so does not meet the needs of the ARCH project.

3.10.1. The GMES European initiative

The European programme for monitoring the Earth or *Global Monitoring for Environment and Security* (GMES) is a joint initiative between the European Space Agency (ESA) and the European Union which aims to provide Europe with the autonomous and operational capacity to observe the Earth.

The objective is to streamline the use of data from multiple sources relating to the environment and security issues in order to provide reliable information and services.

In other words, GMES will gather together all the Earth observation and monitoring data obtained from environmental satellites and measuring instruments to produce a comprehensive and complete view of the state of our planet.

The GMES programme is made of four components:

- the spatial component consisting of satellite observation of the ground, the oceans and the atmosphere. The data obtained from satellites (optical or RADAR) will be made available free of charge;
- the in-situ component consists of instruments for measuring the parameters relating to the state of the ocean (i.e. floats, instruments on board ships, etc.), of the ground (measuring stations, seismographs, etc.), and of the atmosphere (airborne instruments, atmospheric balloons, etc.);
- the component for standardising and harmonising the data. The services of the GMES programme will produce final information in the form of thematic data and services:
    - *Core Services* which correspond to the first level of analysis at the pan-European level;
    - *Downstream Services* which produce information for specific needs at a (trans-) national, regional or local level. The corresponding informant can be derived from the *core services* or directly from the observation infrastructure which collects the data required by the services of the GMES programme. This may be land use maps (e.g. the Urban ATLAS, CORINE, or maybe ARCH?), data files, reports, targeted alerts (*Fast Track services*), etc. The different GMES services can be classified as follows:
        - terrestrial, maritime and atmospheric services. They provide monitoring and systematic forecasts of the state of the terrestrial sub-systems at regional and global levels;
        - emergency and security services. They provide assistance in an emergency or humanitarian crisis, specifically to the civil protection authorities, but also provide accurate data on aspects of security (e.g. maritime surveillance, border control, international stability, etc.);
        - services for climate change. They contribute to monitoring the effects of climate change and to evaluating the measures to reduce it.

The different services were officially launched at the GMES forum which took place in Lille in September 2008. It is planned that these services, currently in the pre-operational phase, will become operational in 2011 and that they will be fully operational by 2014.

As part of the spatial component, a set of satellites will be launched in the coming years. Among these satellites, Sentinel-2 and Sentinel-1 will enable images to be obtained in the optical and RADAR spectrums.

3.10.1.1. The Sentinel-2 mission

The Sentinel-2 mission is dedicated to surveying the land and the oceans. This mission aims to provide continuity to data obtained from the ENIVSAT satellite.

In order to do this, the pair of Sentinel-2 satellites will regularly deliver HR images in the optical spectrum.

The sensor attached to the satellite platform will obtain images in the visible bands of the near-infrared and the mid-infrared, in 13 spectral bands: four bands with a spectral resolution of 10m, six with a resolution of 20m and three with a resolution of 60 m with a scene width of 290 km. These 13 bands guarantee a good spectral resolution, as well as a series of consistent temporal images, which will highlight the variabilities in the Earth’s surface and enable the phenomena related to atmospheric variabilities to be reduced.

The orbit of the mission (at an average altitude of approximately 800 km), coupled with the pair of operational satellites, will enable a revisit time of 5 days at the equator (in cloudless atmospheric conditions) every 2 to 3 days at average latitudes.

The first satellite should be launched in 2013 (for a mission of seven years, with a possible extension of five years).

A much larger scene width and a better temporal resolution will enable rapid changes to be observed, such as change to vegetation during the growing season. Data from the Sentinel-2 satellites will be used in the fields of agriculture, forestry, disaster management, humanitarian relief programmes, as well as for observing natural disasters, such as floods, volcanic eruptions, subsidence and landslides.

The Sentinel-2 mission will generate imagery for the provision of products which will be of great use operationally, such as land use maps, changes in land use maps, and maps of geophysical variabilities which use, for example, the leaf area index, chlorophyll content and the water content of leaves. Images concerning floods and landslides will also be taken by Sentinel-2.

In conclusion, Sentinel-2 will have a wide swath, a good revisit frequency and a systematic acquisition of data on all the different types of surfaces on the Earth, at high spatial and spectral resolutions.

3.10.1.2. The Sentinel-1 mission

The Sentinel-1 mission will ensure the continuity of data produced by the RADAR SAR on board the ERS, ENVISAT and Radarsat satellites, systems which have been established by the ESA or Canada.

The Sentinel-1 satellite will be equipped with a RADAR system. The data issued by the satellite will be C-band images which will deliver images to the user services of the GMES programme, regardless of the atmospheric conditions or whether taken during the day or night.

The first satellite will be launched in 2013 and will be followed by a second satellite a few years later.

The SAR sensor will function in two distinct modes: *Interferometric Wide Swath and Wave*.

The first will take images with a swath size of 250 km and a resolution on the ground of 5 x 20 m. The revisit time of Sentinel-1, the geographical cover and the rapid dissemination of data are the key characteristics for providing operational data to the GMES programme. The pair of Sentinel-1 satellites will enable Europe and Canada and the main maritime routes to be covered in 1 to 3 days, independent of atmospheric conditions.

RADAR data can be delivered in the hour after it was acquired, which a great improvement on the existing SAR systems.

The mission will be of benefit to many associated services. For example, it will enable services to be developed relating to monitoring the expanse of the Arctic seas, mapping glaciers, surveying the maritime environment such as monitoring oil spills and detecting boats for maritime security, monitoring the earth's surfaces for risks of movement, mapping forests, land and water management and mapping for humanitarian aid and crisis situations.

3.10.2. The GEOSUD national initiative

The objective of the *GEOInformation for SUstainable Development* (GEOSUD) project, carried out by Cermagred, CIRAD, ENGREF and IRD (but also open to interested scientific and operational partners) is to develop an International research Centre for the transfer of remote sensing and spatial information for sustainable development. This project aims to develop strategies which involve monitoring changes to the environment and land in order to better understand how they are evolving (e.g. demographic growth, socio-economic growth and land development which are putting growing pressure on the environment).

The project will make available an annual High Resolution satellite coverage of the whole of France to several public and semi-public stakeholders, to ensure dissemination and administration and to actively support methodological research on spatial information.

The first national coverage will be completed by summer 2011 using data from the German RapidEye satellite with a spatial resolution of 5 metres.

The GEOSUD project aims to establish a continuum from the skills of researchers to the economic actors (i.e. public, private, local authorities and companies) in the field of geomatics, environment and land observatories. This project fits directly into the framework of the GMES and GEO (*Group on Earth Observations*) initiatives.

The GEOSUD project focuses on four objectives with significant implications:

3.10.2.1. *"Research into the methods and tools for managing spatial information for environmental and territorial management"*

These research methods involve:

- acquiring and processing spatial data, specifically using satellite techniques;
- analysing and modelling the structures and spatial dynamics of the environment and land;
- engineering information systems and designing observatories;
- mobilising and sharing information as part of management and governance practice.

They apply to different thematic fields: forestry, hydrology, environment, rural and urban areas, littoral, risks and health.

GEOSUD will host researchers from different methodological and/or thematic teams around one technological platform comprising equipment, tools and image processing methods, spatial analysis, information systems, as well as joint scientific activities.

3.10.2.2. *" Transferring methods and knowledge to public and private economic partners, local authorities and companies"*

The GEOSUD project aims to develop a partnership with economic stakeholders by transferring operational, approved and adapted methods for meeting the challenges of environmental, territorial and resource management. This transfer and partnership could take place via access to a technological platform or through joint projects, for example.

3.10.2.3. *"Engineering training and education in the field of spatial information applied to environmental management and territorial development"*

The GEOSUD project will develop a diversified, adaptable and transferable training programme aimed at a variety of partners and public authorities in the field of spatial information applied to environmental management and land development. In particular, it plans to develop a higher education training programme in the long term, comparable to the SILAT Masters (it will be in English).

3.10.2.4. *"Facilitate the scientific community's access to spatial information"*

This objective results from the belief that experts in the field of "Resource and environmental management" only seldom use spatial data. This situation acts as a brake on the development of adapted methods for mobilising the use of remote sensing and its transfer to operators.

The GEOSUD project establishes three factors which seem to explain this low uptake, namely:

- difficulty in accessing satellite images and their cost;
- lack of training on how to use these techniques;
- methodological developments not being sufficiently capitalised on within this community.

This fourth objective of the GEOSUD project aims therefore to promote greater access to spatial information by making access to images more fluid and providing assistance in how to choose the most appropriate images and data processing technique.

A summary table of the advantages and disadvantage of the different techniques from this third section can be found in annex 6.

Conclusion

At this stage of the project, taking into account the initial needs expressed by the different users (GIS or end) during the different meetings which took place and the questionnaires completed, and taking into account the prospective and potential use of satellite technology as presented in this report, several large avenues for development could be suggested to the regions of Nord-Pas de Calais and Kent in view of implementing different scenarios:

- In response to a need to be able to detect rapid changes and to be able to update the ARCH database for the whole region on an annual basis, the research into RapidEye (with a 5 metre spatial resolution) satellite data, as part of the national GEOSUD initiative, seems to be a good prospect. An automatic classification approach for an initial general segmentation (the first level of the nomenclature) coupled with CAPI could be feasible. For example, this annual updating would make it much easier to detect those areas which require site visits.

- In response to the specific localised need and need for possible occasional updating, the use of VHR data of the WorldView-2 type seems to be an excellent alternative to the aerial photographs currently used in the ARCH project. The spectral and spatial HR and the existence of new bands is a very interesting area of study for monitoring habitats of specific interest, where detection by aerial photographs is both difficult and time-consuming.

- Possible future use of Sentinel data, High Resolution spatial (10 metres) and temporal (almost weekly) data, could be significant for updating the ARCH databases. The use of such data would enable phenology to be integrated into habitat maps due to the high temporal frequency, thus enabling a more detailed characterisation of communities. This was in fact a need expressed by the photo-interpretation production teams. Based on the current ARCH map, a proposal could be to acquire a set of images from the DMC constellation (images with 20 metre spatial resolution) on a test zone of 4/5 images. It would then involve carrying out tests for mapping and updating natural habitats, by exploring the automatic approaches (object oriented classification, for example). The DMS constellation enables simulations of the Sentinel service to be made.

- Finally, with regard to future needs which may be expressed and depending on the data available, exploring and integrating new technologies such as LIDAR (and also RADAR) into the existing ARCH database could be a possibility. However, this approach is subject to the availability of such data, taking into account the significant investment involved.

Annexes

1) Annex 1: Satellites (and their characteristics) currently in orbit around the Earth (passive sensors)

Satellite in orbit	Sensor	Type	Launch date	Country	Number of bands	Spectral range (nm) (min-max)		Spectral range Panchromatic (nm) (min-max)		Spatial resolution Multispectral (m)	Spatial resolution Panchromatic (m)	Swath (km)	Revisit (days)	Altitude (km)	Cost (€/Km2) (archive programming)		Minimum order (€) (archive programming)		Provider
IRS Resourcesat-2	LISS4	VHR	20/04/11	India	3	520	860	n/a	n/a	5.80	n/a	24	5	817					Euromap
IRS Cartosat-2B		VHR	12/07/10	India	n/a	n/a	n/a	500	750	n/a	0.80	9.6	4	630					Euromap
WorldView-2		VHR	08/10/09	United States	8	400	1040	450	800	2.0	0.50	16.4	1.1 to 3.7	770					Digital Globe
GeoEye-1		VHR	06/09/08	United States	4	450	920	450	800	1.65	0.41	15.2	3	681					e-geos
RapidEye (5 satellites)	REIS	VHR	29/08/08	Germany	5	440	850	n/a	n/a	6.50	n/a	77	1	630	0.95	0.95	950	4750	RapidEye
IRS Cartosat-2A		VHR	28/04/08	India	n/a	n/a	n/a	500	750	n/a	0.80	9.6	5	635					Euromap
WorldView-1		VHR	18/09/07	United States	n/a	n/a	n/a	400	900	n/a	0.50	176	1.7 to 5.4	496	11.92	15.43	3241.96		Digital Globe
IRS Cartosat-2		VHR	10/01/07	India	n/a	n/a	n/a	500	850	n/a	0.80	96	4	630	7.70	n/a	n/a	n/a	Euromap
KOMPSAT-2	MSC	VHR	28/07/06	South Korea	4	450	900	500	900	4.00	1.00	15	3	685	5.20	10.40			SPOT Image
EROS B		VHR	25/04/06	Israel	n/a	n/a	n/a	500	900	n/a	0.7	7		500					ImageSat International
TopSat		VHR	27/10/05	United Kingdom	3	450	700	500	700	5.70	2.90	17	4	686					Infoterra UK
IRS P5 (Cartosat 1)		VHR	05/05/05	India	n/a	n/a	n/a	500	850	n/a	2.50	30	5	618	2.469	n/a	1,800	n/a	Euromap
Formosat-2	RSI	VHR	20/04/04	Taiwan	4	450	900	450	900	8.00	2.00	24	1	888	4.34	5.20	2500		SPOT Image
IRS P6 (ResourceSat-1)	LISS4	VHR	17/10/03	India	4	520	860	620	680	5.80	5.80	24	5	817	0.510 to 0.918	n/a	2500 to 4500	n/a	Euromap
QuickBird-2	BGIS-2000	VHR	18/10/01	United States	4	430	918	405	1073	2.69	0.67	18.6	2.4 to 5.4	496	11.92	15.43	3241.96		Digital Globe
EROS A		VHR	05/12/00	Israel	n/a	n/a	n/a	500	900	n/a	1.9	14		500					ImageSat International
KOMPSAT-1	EOC	VHR	20/12/99	South Korea	n/a	n/a	n/a	510	730	n/a	6.60	15	3	685					SPOT Image
IKONOS-2	OSA	VHR	24/09/99	United States	4	445	853	526	929	3.28	1.00	11.3	3	681	12.62	16.13	1262		EU SPaceImaging
DMC AlSat-2A	NAOMI	HR	12/07/10	Algeria	4	450	890	450	900	10.00	2.5	17.5	1	690			n/a		DMCii
CBERS-2B	CCD	HR	19/09/07	China/Brazil	4	450	890	510	730	20.00	20.00	113	3	778					INPE
ALOS	AVNIR-2	HR	24/01/06	Japan	4	420	890	n/a	n/a	10.00	n/a	70	2	697	0.10	n/a	500	n/a	SPOT Image/Eurimage
ALOS	PRISM	HR	24/01/06	Japan	n/a	n/a	n/a	520	770	n/a	2.50	70	2	697					SPOT Image/Eurimage
CBERS-2	CCD	HR	21/10/03	China/Brazil	4	450	890	510	730	20.00	20.00	113	3	778					INPE
SPOT-5	HRG	HR	03/05/02	France	4	500	1750	480	710	10.00	2.50	60	26	822	0.75	0.97	2700	3500	SPOT Image
Terra	ASTER VNIR	HR	18/12/99	United States/Jap	3	520	860	n/a	n/a	15.00	n/a	60	16	705	0.01	n/a	59.6	n/a	USGS

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CBERS-1	CCD	HR	14/10/99	China/Brazil	4	450	890	510	730	20.00	20,00	113	3	778					INPE
SPOT-4	HRVIR	HR	23/03/98	France	4	500	1750	610	680	20.00	10,00	60	26	830	0.53	0.75	1900	2700	SPOT Image
IRS 1D	PAN	HR	29/09/97	India	n/a	n/a	n/a	500	750	n/a	5,50	65	5	737 to 821	0.459 to 1.41	n/a	2250 to 750	n/a	Euromap
SPOT-2	HRV	HR	22/01/90	France	3	500	890	500	730	20.00	10,00	60	26	830	0.53	0.75	1900	2700	SPOT Image
SPOT-1	HRV	HR	22/02/86	France	3	500	890	500	730	20.00	10,00	60	26	830	0.53	0.75	1900	2700	SPOT Image
IRS Resourcesat-2	LISS3	MR	20/04/11	India	4	520	1700	n/a	n/a	23.50	n/a	140	24	817					Euromap
IRS Resourcesat-2	AWIFS	MR	20/04/11	India	4	520	1700	n/a	n/a	56.00	n/a	740	5	817					Euromap
DMC Deimos-1	SLIM-6-22	MR	29/07/09	Spain	3	520	900	n/a	n/a	22.00	n/a	660	1	667	0.018 to 0.058	0.125	n/a	3200	DMCii
UK-DMC2	SLIM-6-22	MR	29/07/09	United Kingdom	3	520	900	n/a	n/a	22.00	n/a	660	1	659	0.018 to 0.058	0,125	n/a	3200	DMCii
DMC Beijing-1	SLIM-6	MR	27/10/05	China	3	520	900	n/a	n/a	32.00	n/a	600	1	686	0.016 to 0.050	0,125	n/a	3200	DMCii
IRS P6 ResourceSat-1)	LISS3	MR	17/10/03	India	4	520	1700	n/a	n/a	23.50	n/a	140	24	817	0.140 or 0.347	n/a	2700 or 1700	n/a	Euromap
IRS P6 (ResourceSat-1)	AWIFS	MR	17/10/03	India	4	520	1700	n/a	n/a	56.00	n/a	740	5	817	0,012	n/a	1600	n/a	Euromap
DMC NigeriaSat-1	SLIM-6	MR	27/09/03	Nigeria	3	520	900	n/a	n/a	32.00	n/a	600	1	686	0.016 to 0.050	0.125	n/a	3200	DMCii
UK-DMC	SLIM-6	MR	27/09/03	United Kingdom	3	520	900	n/a	n/a	32.00	n/a	600	1	686	0.016 to 0.050	0.125	n/a	3200	DMCii
DMC AlSat-1	SLIM-6	MR	28/11/02	Algeria	3	520	900	n/a	n/a	32.00	n/a	600	1	686	0.016 to 0.050	0.125	n/a	3200	DMCii
Terra	ASTER SWIR	MR	18/12/99	United States/Japan	6	1600	2430	n/a	n/a	30.00	n/a	60	16	705					USGS
Terra	ASTER TIR	MR	18/12/99	United States/Japan	5	8125	11650	n/a	n/a	90.00	n/a	60	16	705					USGS
Landsat 7	ETM+	MR	15/04/99	United States	7	450	12500	520	900	30.00	15,00	185	16	705	Free	n/a	Free	n/a	USGS
IRS 1D	LISS3	MR	29/09/97	India	4	n/a	n/a	520	1700	23.80	n/a	148	25	737 to 821	3.061 or 0.306	n/a	1500 or 2400	n/a	Euromap
IRS 1D	WIFS	MR	29/09/97	India	2	n/a	n/a	620	860	188.00	n/a	812	3	737 to 821	0.001	n/a	750	n/a	Euromap
Landsat 5	TM	MR	01/03/84	United States	7	450	12500	520	900	30.00	15,00	185	16	705	Free	n/a	Free	n/a	USGS
Proba	CHRIS	HS	22/10/01	European Union (ESA)	19	415	1050	n/a	n/a	18.00	n/a	14	7	615	Free	n/a	n/a		ESA
EO-1	Hyperion	HS	21/11/00	United States	220	356	2577	n/a	n/a	30.00	n/a	7.5	16		0.55	2.23	175.28		USGS

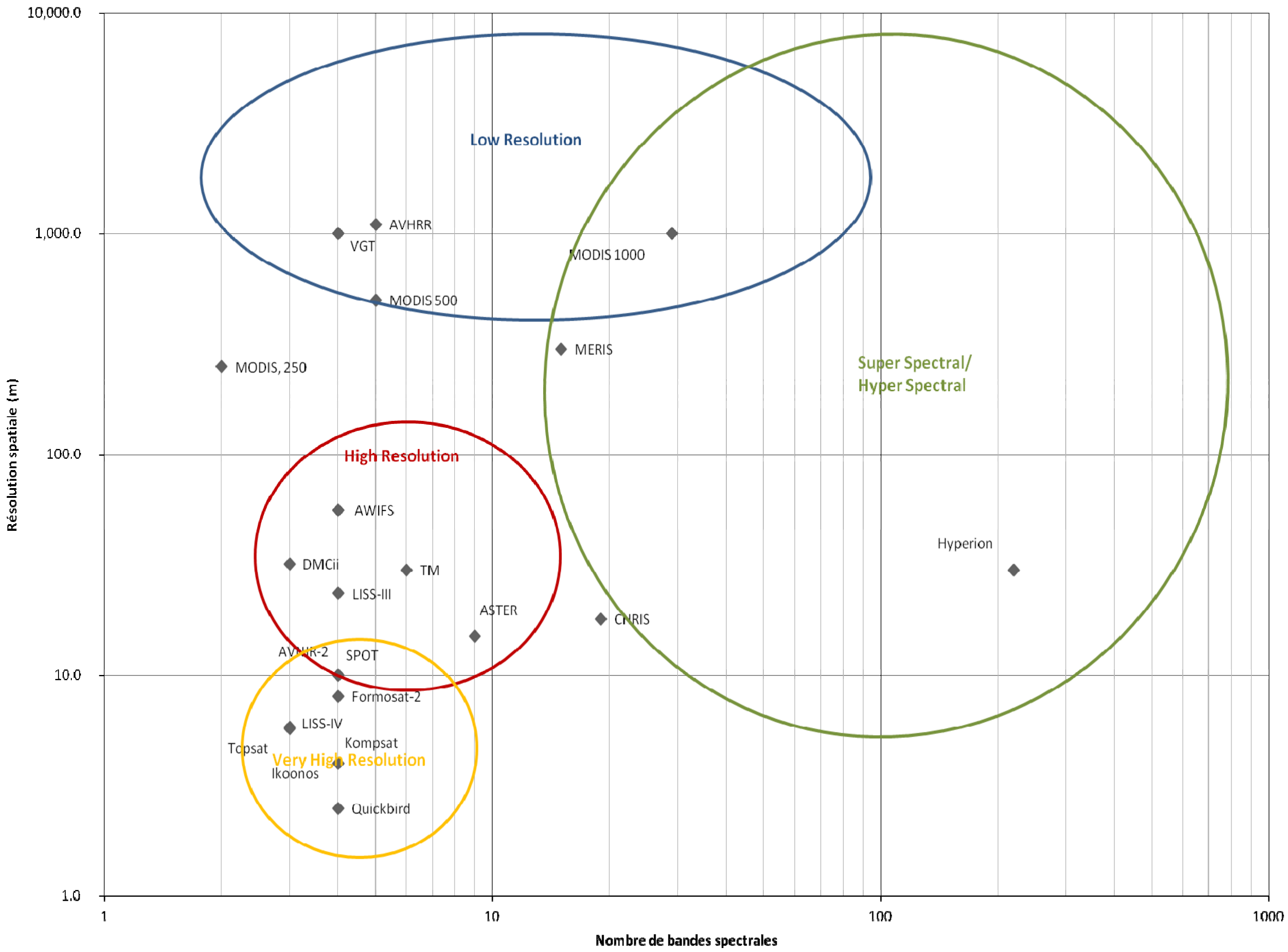
2) Annex 2: Satellites (and their characteristics) soon to be in orbit around the Earth (passive sensors).

Satellite to come	Sensor	Type	Launch date	Country	Number of bands	Spectral range (nm) (min-max)		Spectral range Panchromatic (nm)		Spatial resolution Multispectral (m) (min-max)	Spatial resolution Panchromatic (m)	Swath (km)	Revisit (days)	Altitude (km)	Provider
Pleiades 1		VHR	Fin 2011	France	4	430	950	480	830	2.00	0.50	20	1	694	SPOT Image
Pleiades 2		VHR	2012	France	4	430	950	480	830	2.00	0.50	20	1	694	SPOT Image
SPOT-6		VHR	2012	France	4	455	890	455	745	6.00	1.50	60	1	694	SPOT Image
SPOT-7		VHR	2013	France	4	455	890	455	745	6.00	1.50	60	1	694	SPOT Image
DMC NigeriaSat-2		VHR	01/05/11	Nigeria	4	n/a	n/a	n/a	n/a	5.00	2.5	20	n/a	n/a	DMCii
DMC-3 (3 satellites)		VHR	2013	United Kingdom	4	n/a	n/a	n/a	n/a	4.00	1	20	n/a	n/a	DMCii
EROS C		VHR	03/07/05	Israel	n/a	n/a	n/a	n/a	n/a	2.8	0.7	11	n/a	500	ImageSat International
CBERS-3	PANMUX	HR	2011	China/Brazil	4	450	890	510	730	10.00	5.00	60	5	778	INPE
CBERS-4	PANMUX	HR	2014	China/Brazil	4	450	890	510	730	10.00	5.00	60	5	778	INPE
CBERS-3	MUXCAM	HR	2011	China/Brazil	4	450	890	n/a	n/a	20.00	n/a	120	3	778	INPE
CBERS-4	MUXCAM	HR	2014	China/Brazil	4	450	890	n/a	n/a	20.00	n/a	120	3	778	INPE
DMC AlSat-2B		HR	n/a	Algeria	4	450	890	450	900	10.00	2.5	17,5	1	690	DMCii
CBERS-3	IRMSS	MR	2011	China/Brazil	4	760	12500	n/a	n/a	40.00	n/a	120	26	778	INPE
CBERS-4	IRMSS	MR	2014	China/Brazil	4	760	12500	n/a	n/a	40.00	n/a	120	26	778	INPE
CBERS-3	WFI	MR	2011	China/Brazil	4	520	1750	n/a	n/a	73.00	n/a	866	5	778	INPE
CBERS-4	WFI	MR	2014	China/Brazil	4	520	1750	n/a	n/a	73.00	n/a	866	5	778	INPE
Landsat LDCM	OLI	MR	01/12/12	United States	8	433	2300	500	680	30.00	15.00	185	n/a	705	USGS
Sentinel-2	MSI	MR	2013	European Union (ESA)	13	433	2280	n/a	n/a	10.00 -20.00 – 60.00	n/a	290	15	786	ESA

3) Annex 3: RADAR satellites (and their characteristics) currently and soon to be in orbit around the Earth (active sensors).

Satellite	Sensor	Type	Launch date	Country	Polarisation	Frequency (Band)	Spatial resolution (m) (min-max)		Swath (km) (min-max)		Orbital cycle (days)	Altitude	Cost (€/Km2) (archive-programming)		Minimum order (€) (archive-programming)		Distributor
RadarSat-2		SAR	14/09/07	Canada	Full	C	3	100	20	500	24	800	1.44	1.49	3600.00		MDA
RadarSat 1		SAR	04/11/95	Canada	HH	C	8	100	45	500		800					MDA
TerraSAR-X		SAR	15/07/07	Germany	Full	X	1	16	10	100	11	514	67.5	135.00	3375.00		SPOT Image / Infoterra
TanDem-X		SAR	21/06/10	Germany	Full	X											InfoTerra
COSMO-SkyMed-1		SAR	08/06/07	Italy	Full	X	1	100	10	200	1	619					e-GEOS
COSMO-SkyMed-2		SAR	08/12/07	Italy	Full	X	1	100	10	200	1	619					e-GEOS
COSMO-SkyMed-3		SAR	25/10/08	Italy	Full	X	1	100	10	200	1	619					e-GEOS
COSMO-SkyMed-4		SAR	01/11/10	Italy	Full	X	1	100	10	200	1	619					e-GEOS
ALOS	PalSAR	SAR	24/01/06	Japan	Full	L	10	100	30	350	46	697	1.02	n/a	500.00		SPOT Image/Eurimage
ERS-2		SAR	21/04/95	European Union (ESA)	VV	C	30	150	100	400	35	785					ESA
ENVISAT	ASAR	SAR	03/012002	European Union (ESA)	Full	C	30	1000	100	400	35	790	0.06	0.04	400.00		Eurimage/ SPOT Image/ ESA
RadarSat Constellation (3 satellites)		SAR	2014-2015	Canada	n/a	C	3	100	20	500	12	800					MDA
Sentinel 1		SAR	2012	European Union (ESA)	Full	C	5	40	80	400	12	693					ESA

4) Annex 4: Diagramme of the satellites currently available divided into groups according to spectral and spatial resolutions (logarithmic scales)



5) Annex 5: Comparison and analysis of the different families of functionalities in the seven remote sensing software products

	PCI Geomatica		ENVI	ERDAS Imagine			BEAM	SPRING	IDRISI Taïga	Orfeo Monteverdi
	Geomatica Core	Geomatica Prime		Essentials	Advantage	Professional				
Outils de visualisation et édition de la donnée	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Outils de correction géométrique	✓	✓	✓	✓	✓	✓	✓	✓		✓
Mosaïquage d'images	✓	✓	✓		✓	✓	✓	✓	✓	
Outils de corrections radiométriques	✓	✓	✓		✓	✓		✓	✓	
Outils de correction atmosphérique	✓	✓	✓		✓	✓	✓		✓	
Outils de traitement de la donnée										
rehaussement des images par manipulation des histogrammes	✓	✓	✓	✓	✓	✓		✓	✓	
filtrage spatial	✓	✓	✓	✓	✓	✓		✓	✓	✓
filtrage morphologique	✓	✓	✓		✓	✓		✓	✓	
rééchantillonnage	✓	✓	✓		✓	✓			✓	
projection	✓	✓	✓	✓	✓	✓			✓	
clip de l'image	✓	✓		✓	✓	✓				
création d'image « *pan sharpening* »	✓	✓	✓		✓	✓			✓	✓
calcul d'indices	✓	✓	✓		✓	✓	✓		✓	
opérations arithmétiques sur les bandes	✓	✓	✓				✓	✓	✓	✓
analyse en composantes principales	✓	✓	✓		✓	✓		✓	✓	
Outils d'extraction de l'information										
classification par-pixel non supervisée	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
classification par-pixel supervisée	✓	✓	✓			✓		✓	✓	
classification neuronale	✓	✓	✓			✓			✓	
classification contextuelle	✓	✓				✓			✓	
démixage spectrale	✓	✓	✓		✓	✓			✓	
segmentation	✓	✓				✓			✓	
Outils d'analyse spatiale	✓	✓				✓		✓	✓	
Outils de traitement séquentiel		✓			✓	✓				
Outils de gestion et d'analyse des données RADAR										
calcul de la brillance		✓	✓			✓		✓		
calibration		✓	✓			✓		✓		
analyse de texture		✓	✓			✓		✓		
filtre de chatoiement		✓	✓			✓		✓		✓
Outils de gestion et d'analyse des données hyperspectrales		✓				✓			✓	
Outils de production cartographique	✓	✓		✓	✓	✓			✓	
Outils de gestion et traitement des données Lidar										
création de Modèle Numérique de Terrain	✓	✓			✓	✓		✓	✓	
création de Modèle Numérique d'Elévation	✓	✓	✓		✓	✓		✓	✓	
Outils de gestion et création d'Ortho-images satellite ou aériennes			✓		✓	✓	✓			
Outils de gestion des données vectorielles et interface compatible avec des logiciels SIG	✓	✓	✓		✓	✓		✓	✓	

6) Annex 6: Summary table of the advantages and disadvantages of the different technologies analysed in Part 3

	Advantages/Suggestions	Limits
Nomenclature	• Use of remote sensing on an initial segmentation of the regions (first nomenclature) on a global scale.	• ARCH nomenclature, obtained using CAPI, cannot be reproduced using semi-automatic remote sensing methods.
Geographical scope	• Mosaic of the area using satellite images from sensors mounted onto different satellites.	• Obtaining consistent images from a spectral and temporal point of view of the geographical area is difficult. • Covering the whole of the geographical expanse using a set of satellite images from one single sensor would be complex (the satellite is not agile enough to acquire a set of images such as this). • Ideal, perfect even, atmospheric conditions (absence of mist and clouds) required on many different bands for different shots.
Compromise between the different solutions		• Compromise between the different resolutions - improvement to one is at the expense of the others.
Costs	• Sharing the cost of buying the images could reduce costs. • Existing European and national initiatives. • Existing free data (MR). • Open-source software.	• Covering the NPdC and Kent regions using VHR and HR data is costly. • Cost of commercial software. • Gross cost of VHR and HR satellite data. • Free software is often developed for specific sensors.
Unsupervised classification	• Carrying out an initial segmentation of the images into large themes to highlight the areas or themes of interest.	• Accurate and detailed classification of types of land use or habitats is impossible (thematic).
Supervised classification	• Classes with a precise thematic meaning.	• Approach is time-consuming to implement (field work).
Object oriented classification	• Takes into account ecological, topographical and spatial considerations applicable to remote sensing data.	• Establishing long and complex rules.
New technologies	• Interesting possibilities in terms of monitoring, evaluating and	• Data is very expensive. • Few hyperspectral and LIDAR

	surveying natural habitats. • Very large spectral width for hyperspectral data.	sensors mean problems of availability and continuity of the data. • Small size of the image often only suitable for work at a local scale (again data from airborne sensors and not satellites).
VHR	• Beyond VHR spatial, high resolution spectral with the existence of new bands, such as the *Red-Edge* band – of interest for monitoring habitats/species of specific interest (ecology or biodiversity).	• VHR as a solution for obtaining a detailed nomenclature is not viable on a global scale. • Gross costs of the data. • Low spatial footprint of the images.
HR	• More significant spatial footprint. • More and more certain potential of HR data coupled with emerging methods.	
Multi-temporality	• Main advantage of satellite remote sensing. • Seasonal variabilities (phenology) of plant communities taken into account. • Improved results for extracting information	• Not accessible using aerial photography and traditional CAPI.
European and national initiatives	• Making satellite data available for free (active and passive sensors) • High spatial and temporal data resolution. • Data frequently updated. • Data dissemination and administration.	

References

BLACKBURN, G.A. and MILTON, J.E. (1997). An ecological survey of deciduous woodlands using airborne remote sensing and geographical information systems (GIS). International Journal of Remote Sensing 18, 1919–1935.

BROWN, K., HAMBRIDGE, C. and MATTHEWS, A. (2003). The development of remote sensing techniques for marine SAC monitoring. English Nature Research Reports, No. 552, English Nature.
CONDAL, A., Laval University, Remote sensing course: "Applying remote sensing".

DANIEL, S. and GOND, V., Laval University, Remote sensing course: "Basic remote sensing".

ENVCAL – Environmental monitoring using remote sensing, Course, http://e-cours.univ-paris1.fr/modules/uved/envcal/html/index.html

ESA, http://www.esa.int/esaCP/index.html

EUROPEAN COMMISION, GMES, http://ec.europa.eu/gmes/index_en.htm

FARMER, Elizabeth, BREWER, Tim R. & SANNIER, Christophe A. D. (2010) 'Land cover attributes and their utility within land cover mapping: a practical example', Journal of Land Use Science, First published on: 22 December 2010 (iFirst)

MACHAULT, V., Use of Earth observation satellite data to evaluate the vectoral density and transmission of malaria, thesis presentation.

REMOTE SENSING DEPATMENT, GEOSUD Project, http://www.teledetection.fr/projet-geosud.html

MEQUIGNON, L., CROISILLE, G. and LEJEUNE, V., technical documentation produced by SIRS for the French Environment Institute – National Office for Hunting and Wildlife, 2005, « Applying remote sensing to studying wetland areas : identifying grasslands, reed beds, poplar groves and gravel pits ».

PENNEC, A., 2009, Characterisation of the phenology of tropical forests in French Guyana using a set of temporal satellite images. These presented for obtaining the Diploma in Engineering at ESGT.

PERONI, G., SIRS, 2010, New spectral data available for the controls in agriculture (CwRS) and for vegetation monitoring, CWRS 2010, Final Conference, Bergamo 24-26 Nov. 2010.

SIRS, 2010, Typology and Mapping habitats– Natura 2000 site No FR9400576 – "MASSIF MONTAGNEUX DU CINTO" – "BONIFATU" area, 2010, Report on the study.

STONEY, W., E., NOBLIS INC. (formerly MITRETEK), 2008, ASPRS Guide to land imaging satellites.

THOMSON, A.G., FULLER, R.M., YATES, M.G., BROWN, S.L., COX, R. and WADSWORTH, R.A. (2003). The use of airborne remote sensing for extensive mapping of intertidal sediments and saltmarshes in eastern England. International Journal of Remote Sensing 24, 2717–2737.

VANDEN BORRE, J., PAELINCKX, D., HOFFMANN, M. & SPANHOVE, T. (2010). Biodiversity monitoring beyond 2010: what role of remote sensing? Minutes of the plenary discussion of the

HABISTAT workshop "Monitoring Europe's biodiversity in a post 2010 era: the role of remote sensing for Natura 2000 reporting and ecosystem assessment". INBO.C.2010.4. Research Institute for Nature and Forest (INBO), Brussels, 9 pp. + annexes.

VANDEN BORRE, J., PAELINCKX, D., MUCHER, C.A., KOOISTRA, L., HAEST, B., DE BLUST, G. & SCHMIDT, A.M., Integrating remote sensing in Natura 2000 habitat monitoring: Prospects on the way forward. Journal for Nature Conservation (2011), doi:10.1016/j.jnc.2010.07.003

YALLOP, A.R., THOMAS, G., THACKER, J., BREWER, T. and SANNIER, C., 2004, Feasibility of remote sensing to inform site condition monitoring assessments on Scottish terrestrial SSSIs. Scottish Natural Heritage Commissioned Report No. 083 (ROAME No. F02LG15).