CEUBIOM

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CLASSIFICATION OF EUROPEAN BIOMASS POTENTIAL FOR BIOENERGY USING TERRESTRIAL & EARTH OBSERVATIONS

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DELIVERABLE D 5.1 - *REVISED VERSION* HANDBOOK FOR IMPROVING EO SECTOR ON UNDERSTANDING BIOMASS REQUIREMENTS

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SEVENTH FRAMEWORK PROGRAMME

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Introduction

This document was prepared within the framework of the CEUBIOM project which is funded by the European Commission's FP7 programme. The overall objective of the project is to develop a common methodology for gathering information on the European biomass potential using terrestrial and earth observations. The intention of this document is to provide an handbook improving EO sector on understanding of biomass requirements.

Intended readership

Although remote sensing is one of the most promising techniques for assessing biomass especially considering the need to cover large areas and with standardised methodologies, and many studies on the subjects have been published during the past 20 years, a close multidisciplinary integration of the EO and biomass assessment communities are not always easy to reach. Often this difficulty is related to the fact that people working in different disciplines adopt very technical description and jargons, which hampers a real mutual understanding.
A general goal of the WP 5 activities is that of sharing and integrating the knowledge, which shall be achieved through WEB 2.0 approaches, such as the development of a web based platform for stakeholder's interaction, but also on the dissemination level, ensuring that documents with the appropriate level of detail are exchanged.
Therefore, one of the main objectives of this document is actually to bridge this gap by describing in practical terms the remote sensing techniques are their application in the biomass domain.

Due to its nature, this handbook is closely related to other deliverables of this project, namely:

- D2.1: Methods compendium on current state-of-the-art in EO for biomass assessment
- D2.2: Study on SAR potential for direct biomass assessment

Here the same topics are reviewed and streamlined in a form that can be easily understood and followed by operators who will eventually handle the biomass data and therefore, even if not specialists of remote sensing, shall be able to understand the implications and trade-offs of the applications of certain methodologies.

How to Use this Handbook

This handbook is a practical guide on the use of remote sensing for estimating biomass. In it there are provided practical information on the use of remote sensing in biomass assessment, on the need and availability of data and EO products for a rapid and simply research, on the mainly concepts of the EO techniques of remote sensing in biomass applications. Remote sensing is a rapidly developing subject and, although every effort has been made to ensure that information is accurate at the time of going to press, readers may wish to check out recent technological advances.
The document is structured as follows:

- *Background to the CEUBIOM Research behind the handbook*: this section explains the connection between this document and the other deliverables of the project
- *Introduction to biomass assessment*: conceptual description of the biomass assessment problem
- *Use of remote sensing in biomass assessment*: short description of the advantages of using remote sensing for these analyses
- *Spectral characteristics of vegetation*: introduction to the physical variables that can be measured by remote sensing indicating how they can be exploited for the biomass assessment

- *EO methods for biomass assessment*: practical overview of the various possible methodologies. This also include some simple decision rules to assessing the most suitable method in a certain set of conditions
- *Designing an EO method for biomass assessment*: guidelines for the optimal design iof a methodology
- *Example of monitoring systems*: for the purpose of giving concrete flavour to such monitoring, example of real existing systems are provided

List of abbreviations

ARD	Afforestation, Reforestation Deforestation
CASI	Compact Airborne Spectrographic Imager
CEOS	Committee on Earth Observation Satellites
CLC	CORINE Land Cover
CLM	(Common Land Model)
DVI	Differential Vegetation Index
EEA	European Environmental Agency
EN	European Norm
EO	Earth observation
ESA	European Space Agency
FPAR	Fraction of absorbed Photosynthetically Active Radiation
GCOS	*Global Observing System for Climate*
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
LAI	Leaf Area Index
LiDAR	Light Detection and Ranging
LTER	Long Term Ecological Research
MARS	Monitoring Agriculture through Remote Sensing techniques
NASA.	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PCA	Principal Components Analysis
PVI	Perpendicular Vegetation Index
RVI	Ratio Vegetation Index
SAR	Synthetic Aperture Radar
SAVI	Soil Adjusted Vegetation Index
TM	Thematic Mapper
UNFCCC	United Nations Framework Convention on Climate Change
VI	Vegetation indexes
WDVI	Weighted Difference Vegetation Index

Background to the CEUBIOM Research behind the Handbook

The CEUBIOM project aims to develop a common methodology for gathering information on biomass potential using both terrestrial and earth observations methodologies.
For earth observation methodologies here we propose a practical handbook of EO methodology for assessing biomass estimation.
To achieve this ambitious result, within the working sequence of the project, there were well targeted studies that have investigated the problem from many points of view, like available satellite technologies, actual availability of data and products in the European country, future satellites and sensors, user’s requirements and so on.
The results of these studies are an important and comprehensive starting point for the preparation of this manual. Here follows a brief description of the results of the CEUBIOM studies about these matters that constitute pre requirements for this document.

Recommendations about the use of EO technologies

In the Work Package 2 (WP2 – Streamlining research results into a common methodology for using EO biomass potential assessment) currently available methodologies for land cover assessment using different satellite data types were thoroughly investigated. A detailed study of different remote sensing systems is included and for each system several featuring characteristic, basic conditions, limitations and potentials were considered.
The conclusion of this work is that the use of remote sensing, in combination with field surveys, is probably the most cost-effective solution to monitor large areas in regular intervals.
All available EO data, future missions and international projects and products for European users were investigated and this Work Package was closed up with preliminary recommendations about the use of EO technologies for Biomass assessment.
All recommendations are summarized in detailed tables that analyze the advantages and disadvantages of:

Various multispectral remote sensing systems (satellite and airborne) for earth monitoring, grouped according to their spatial resolution (pixel size) and thus their application area.

Satellite products, International and European, based on Remote Sensing data.

Methods used for assessment of biomass-for-energy

Concurrently, the Work Package 3 (WP3 - Current Terrestrial Methods and Activities for Biomass Potential Assessment) has investigated current terrestrial methods and activities for biomass potential assessment. During this activity data were collected using a questionnaire, developed as part of the project, divided in Pan-European, South Eastern Europe and Eastern Europe**.** The questionnaire asked for information on methods used for assessment of biomass-for-energy potential and for information on activities utilized to perform the assessments. The questionnaires were addressed by users of various types. With the questionnaires CEUBIOM partners have provided a lot of information for each country that will provide an important overview on the situation in each country about the general status of biomass-for-energy policies, biomass-for-energy use, and methods and activities concerning:

- Kind of data used (statistical data combined with expertise, other data collection)
- National vs. regional assessment
- Kind of potential assessed (theoretical, economic, etc.)
- Snapshot view vs. scenario calculation
- Environmental considerations for impact of included crop changes.

This information, although not explicitly related to the topics of remote sensing, is very valuable and helps us to build a handbook user particularly focused on the real needs of the user.

The results of the survey on national use of biomass potential assessment in Europe shows that the assessments are mainly based on national information on production of biomass and on national information on land use (including forest inventories, if available). Only very specific assessments are done based mainly on primary data, and these typically applies only for small regions.

The assessment methods are very similar and follow a rather uniform scheme. Typically, based on national statistical information the biomass potential is generated using agricultural and forestry expertise for assessing the results of productivity development and/or land use changes (soil fertility, environmental effects etc.) and for consideration of restrictions induced by specific boundary conditions (e.g. economic, socio-economic, environmental and social)

The indicators include also special information on soil fertility, condition of the forest (plant density, crown condition), and stock of living biomass but the forest inventories are not available for all countries.

The final result of the WP was an identification of barriers at strategic management and national-policy levels, at technological and methodological level and the assessment of data formats.

User requirements and main technical limitations.

In Work Package 4 (WP4 – Combination and Harmonization of EO and Terrestrial Methods) the goal is to develop a Technical Concept for a Harmonized Approach with Respect to User Requirements.

Among the results of this WP there is a ‘Summary of country reports of requirement that allowed us to collect information (all national user requirements as given in the questionnaires) user requirements and main technical limitations.

In particular important information is that the spatial component (map) is needed at all. The result is very clear: 42 out of 43 interviewed partners want and need spatially distributed information. Regarding the question of what scale such a raster file should have, the results were much less distinct. Most users (58 %) couldn’t give a representative scale at all, while the remaining answers range from 10 m to 1000 m pixel size with a slight tendency towards a scale between 1:50.000 and 1:200.000 (I. e. about 20 – 60 m pixel size).

Finally, the users were asked on acceptable time delays for processing from basic data availability to the final results. For most users (82 %), the time between available data and result should not exceed 12 months, a large majority (85 %) of the users would be satisfied with a processing time of about 6 – 9 months (or more).

Real availability of data and products

In this Work there were also investigated the availability of real data and product in all CEUBIOM countries. The list of data will be taken into strong consideration in the proposal of a suite of biomass mapping methods because when they are integrated with inventory data sets, EO data will result in a scientifically defendable and more consistent approach for mapping biomass in Europe in support of national reporting on the state of forests.

Introduction to the Biomass assessment

Biomass plays two major roles in the climate system: (i) photosynthesis with draws CO2 from the atmosphere and stores it as biomass; (ii) the quantity of biomass consumed by fire affects CO2, other trace gases and aerosol emissions.

Only above-ground biomass is measurable with some accuracy at the broad scale, while below-ground biomass stores a very large part of total carbon stocks and is rarely measured. Most nations have schemes to estimate woody biomass through forest inventories (little is recorded on non-forest biomass, except through agricultural yield statistics); this typically forms the basis for the annual reporting on forest resources required by the UNFCCC.

(Source: BIOMASS background from GCOS's Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC", 2003)

Biomass is a biological material derived from living, or recently living organisms, such as wood, waste, and alcohol fuels.

The two types considered in CEUBIOM are 'forest biomass' and 'agricultural biomass'. They are defined as follows:

- Forest biomass is equivalent to 'woody biomass' according to European Norm EN 14961-1
- Agricultural biomass is equivalent to 'herbaceous biomass' and 'fruit biomass' according to European Norm EN 14961-1.

In the group of woody biomass there are: natural forest, forest and agro-industrial plantations, trees outsides forest and woodlands. In the group of non woody biomass there are all the types of herbaceous crops like agricultural crops and crop residues.

Here are excluded other types of biomass that cannot be assessed by remote sensing).

Different approaches, based on field measurement, remote sensing and GIS have been applied for biomass assessment.

Approaches for assessing biomass

The possible approaches for assessing the two types (woody and non woody) of biomass are often not completely independent, in some cases they would be the same because they have several common biophysical characteristics that conditions them.

Possible assessment approaches are:

1. **Traditional techniques**: based on field measurement (both destructive or not). They are the most accurate means for collecting biomass data. A sufficient number of field measurements are a prerequisite for developing biomass estimation models and for evaluating the estimation results. However, these approaches are often time consuming, labour intensive, and difficult to implement, especially in remote areas; also, they fail to provide the spatial distribution of biomass over large areas.
2. **GIS-based methods using ancillary data**: they are also difficult because of problems in obtaining good quality ancillary data, indirect relationships between biomass and ancillary data, and the comprehensive impacts of environmental conditions on biomass accumulation. Hence, GIS-based approaches have not applied extensively for biomass estimation.
3. **Remote sensing techniques**: are the most practical and cost effective alternative to acquiring data over larger area. Furthermore, they provide geographical information crucial to characterize the spatial distribution of biomass density. Remote sensing technology offers synoptic view and periodic measurement of the area of interest. Remote sensing techniques have been extensively used for vegetation mapping and monitoring. They have also been used to investigate land cover change and landscape patterns. The advantages of remotely sensed

data, such as in repetition of data collection, a synoptic view, a digital format that allows fast processing of large quantities of data, and the high correlations between spectral bands and vegetation parameters, make it the primary source for large area biomass estimation, especially in areas of difficult access.

The following table summarizes the major techniques for all different approaches and their characteristics.

Category	Methods	Data used	Characteristics	References
Field measurement-based methods	Destructive sampling	Sample trees	Individual trees	Klinge *et al.* (1975)
	Allometric equations	Sample trees	Individual trees	Overman *et al.* (1994), Honzák *et al.* (1996), Nelson *et al.* (1999)
	Conversion from volume to biomass	Volume from sample trees or stands	Individual trees or vegetation stands	Brown and Lugo (1984), Brown *et al.* (1989), Brown and Lugo (1992), Gillespie *et al.* (1992), Segura and Kanninen (2005)
Remote sensing-based methods	Methods based on fine spatial-resolution data	Aerial photographs, IKONOS	Per-pixel level	Tiwari and Singh (1984), Thenkabail *et al.* (2004)
	Methods based on medium spatial-resolution data	Landsat TM/ETM+, SPOT	Per-pixel level	Roy and Ravan (1996), Nelson *et al.* (2000a), Steininger (2000), Foody *et al.* (2003), Zheng *et al.* (2004), Lu (2005)
	Methods based on coarse spatial-resolution data	IRS-1C WiFS, AVHRR	Per-pixel level	Barbosa *et al.* (1999), Wylie *et al.* (2002), Dong *et al.* (2003)
	Methods based on radar data	Radar, lidar	Per-pixel level	Harrell *et al.* (1997), Lefsky *et al.* (1999b), Santos *et al.* (2002, 2003)
GIS-based methods	Methods based on ancillary data	Elevation, slope, soil, precipitation, etc.	Per-pixel level or per-field level	Brown *et al.* (1994), Iverson *et al.* (1994), Brown and Gaston (1995)

Table 3 1: Summary of techniques for above-ground biomass estimation (DENGSH ENG LU 2005)*
*Source: The potential and challenge of remote sensing-based biomass estimation DENGSHENG LU**

Remote sensing methods and instruments are very powerful and valuable tools for monitoring the Earth and have a significant impact on the manner environmental data are acquired and analyzed (Rosenquist et al., 2003) but like other monitoring methods, remote sensing methods have advantages and limitations.

In the previous studies of this research, within the framework of the CEUBIOM project, all advantages and limitations of this technology were carefully analyzed. (See the WP2 – Streamlining

research results into a common methodology for using EO biomass potential assessment - Deliverable D.2.1 Methods compendium on current state-of-the-art in EO for biomass assessment).
The overall conclusion of these studies is that the use of remote sensing in combination with field surveys is probably the most cost-effective solution to monitor large areas in regular intervals.

Key findings for a good integrate approach.

Despite the large known advantages, remote sensing cannot be considered as an alternative to field survey.
It should be seen as a complementary technology which makes field survey more cost-effective. A solely field-survey based approach to assess biomass is shown to be extremely cost-inefficient. On the other side, a remote sensing approach without extensive field survey is shown to be too inaccurate.
The needs to integrate field survey and remote sensing for a good integrate approach are summarized in the following mainly:
Cloud cover: a primary constraint which project planners need to consider when using optical imagery is cloud cover. This constraint does not apply to radar imagery such as that from synthetic aperture radar (SAR) sensors, which can operate through cloud. However, radar is of limited use in biomass assessment.
Accuracy: maps of unknown accuracy are of little value to managers: the end-user needs to know the accuracy of the biomass maps or other remote sensing products which are to be used in planning and management.
Atmospheric correction: most remotely sensed images will be supplied already geometrically corrected, so that they can be used like a map. These corrections take into account sensor peculiarities and the effects of atmospheric haze, the angle of the sun at the time the image was acquired, etc. which would otherwise make it impossible to compare one image with another in any meaningful way.
Image classification: there are three main approaches to classifying remotely sensed images. These are:

- photo-interpretation/visual interpretation,
- unsupervised classification of multispectral imagery,
- supervised (using field survey information) multispectral image classification.

All have their uses although the supervised multispectral classification based on extensive field survey was found to be most effective and generally produced the most accurate maps. Visual interpretation of remotely sensed imagery (identification by eye of vegetal class based on their color, tone, texture and context within the imagery) can often reveal considerable detail on the nature and distribution of species. However, the subjectivity and operator dependence of visual interpretation is a major drawback, particularly if comparisons over time are envisaged. Unsupervised classification produced maps with unacceptably low overall accuracies.
Mapping vegetation and assessing the status of biomass resources: a number of vegetation indices which can be derived from satellite and airborne digital imagery of vegetal areas show a close correlation with the leaf area index (LAI) and percentage canopy closure. LAI can be used to predict growth and yield and to monitor changes in canopy structure.. It is thus a good measure of the status and productivity of vegetal species. Similarly, canopy closure can be used as a measure of tree density. LAI and percentage canopy closure can be predicted with reasonable confidence from LANDSAT TM SPOT XS and CASI airborne images using the correlation between Normalised Difference Vegetation Index (NDVI) images and these parameters but there are possible significant difference of accuracy using different spatial resolution data.

Cost-effectiveness of remote sensing: the cost-effectiveness of a remote sensing survey is perhaps best assessed in relation to alternative means of achieving the same management objectives. The three primary objectives of remote sensing surveys identified by end-users were: providing a background to management planning, detecting change in land cover over time, and planning monitoring strategies. In all cases the expected outputs are vegetal class/resource maps of varying detail. The only real alternative to using remote sensing to assess the biomass resources is to carry out the mapping using land-based survey alone. Such surveys would involve inordinate amounts staff time for Destructive Sampling. In short-stature ecosystems (e.g. agricultural crops, grasslands, scrublands) direct estimates of leaf area can be obtained using area harvesting. Area harvesting involves the destructive sampling of vegetation within plots located within a vegetation community. The widespread utility of this method is limited, however, by the labour-intensive nature of these types of measurements as well as the number of plots needed to capture the spatial heterogeneity of a particular ecosystem.

Use of remote sensing in biomass assessment

The Kyoto Protocol is a mechanism established by diplomatic agreement for measuring and reporting greenhouse gas sources and sinks on a nation-by-nation basis (Grubb et al. 1999).
The Kyoto Protocol specifies a method for national carbon emission inventories related to land cover changes only with respect to Afforestation, Reforestation, and Deforestation, or ARD as it is often called. Thus, the focal point for measurement and monitoring is on forests, and in particular forests which are directly affected in these three specific ways by direct human action. Because the amount of carbon held in the vegetation and soils of terrestrial ecosystems varies spatially and temporally as a result of both human activities and natural processes, it is important to differentiate the conditions set by the Protocol and those needed for full carbon accounting, a calculation which accounts for carbon fluxes from all possible sources and sinks (Houghton and Ramakrishna 1999, Steffen et al. 1997).
The issue is whether remote sensing methods of measuring stocks and losses and accumulations of carbon are compatible with requirements of the Kyoto Protocol, and in particular whether the precision and costs of such methods will enable changes in carbon stocks to be determined over the Protocol's commitment period, 2008-2012. (David Skole and Jiaguo Qi -2001).
Estimating sources and sinks of carbon from ARD activities requires:

- repeated measurements (annually) of deforestation over large areas
- fine spatial and temporal scale analyses of the dynamics of land-cover change in order to separate and quantify re-growth (afforestation or reforestation).

About 80% of the global biomass is contained in forests, and this forms the central component of the stocks and acquisition of carbon in the biosphere.
In particular optical remote sensing has been used extensively to map forest extent, and the temporal and spatial dynamics of deforestation, re-growth, and fire ..
The two key elements of Earth's vegetation from satellite observations are that they allow scientists to track:

- the 'Leaf Area Index' (LAI)
- the 'Fraction of absorbed Photosynthetically Active Radiation' (FPAR).

LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies. FPAR is the fraction of photosynthetically active radiation absorbed by vegetation canopies.
Both LAI and FPAR are data necessary for understanding how sunlight interacts with the Earth's vegetated surfaces.

Satellite data and products

More than 150 Earth-observation satellites are currently in orbit, carrying sensors that measure different sections of the visible, infrared and microwave regions of the electromagnetic spectrum.
There are two kinds of remote sensing:

Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, Infrared, charge-coupled devices, and radiometers.

Active sensors emit energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speed and direction of an object.

The majority of Earth-observation satellites carry “passive” sensors measuring either reflected solar radiation or emitted thermal energy from the Earth’s surface or atmosphere. Newer satellites also employ “active” sensors that emit energy and record the reflected or backscattered response, from which information about the Earth can be inferred.
The features of the instruments depend on the purpose for which each was designed, varying in several aspects. In simple terms, these are:

Spatial resolution: the size of a pixel that is recorded in an image typically pixels may correspond to square areas ranging in side length from 1 to 1,000 metres (3.3 to 3,280 ft).

Spectral resolution: the wavelength width of the different frequency bands recorded - usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

Radiometric resolution: the number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of colour, in each band.

Temporal resolution: the frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

In order to create sensor-based maps, most remote sensing systems expect to extrapolate sensor data in relation to a reference point including distances between known points on the ground. This depends on the type of sensor used. For example, in conventional photographs, distances are accurate in the center of the image, with the distortion of measurements increasing the farther you get from the center. Another factor is that of the platen against which the film is pressed can cause severe errors when photographs are used to measure ground distances. The step in which this problem is resolved is called georeferencing and involves computer-aided matching up of points in the image (typically 30 or more points per image) which is extrapolated with the use of an established benchmark, "warping" the image to produce accurate spatial data. As of the early 1990s, most satellite images are sold fully georeferenced.
In addition, images may need to be radiometrically and atmospherically corrected.
Radiometric correction: gives a scale to the pixel values, e.g. the monochromatic scale of 0 to 255 will be converted to actual radiance values.

Atmospheric correction: eliminates atmospheric haze by rescaling each frequency band so that its minimum value (usually realized in water bodies) corresponds to a pixel value of 0. The digitizing of data also make possible to manipulate the data by changing gray-scale values.

Within the framework of CEUBIOM Project there were analyzed all different available remote sensing systems (present and future) and various international and European projects of interest.
About the multispectral remote sensing data various multispectral remote sensing systems were considered. Satellite and airborne for earth monitoring were be grouped in three type according to their spatial resolution (pixel size) and thus their application area.

For each group the respective potentials and limitations were analyzed, also considering the spatial and temporal resolution, the thematic classifications possibilities and the data-plus-processing costs.

The CEUBIOM study on International and European Products (like CORINE data, JRC forest map, LUCAS) has demonstrated that most projects/initiatives are in some way re-usable for CEUBIOM. Their usage could be either methodological or as direct use of the mapping results. Direct use of mapping results on a transnational basis only makes sense, if (almost) all the project area is covered in a uniform way.
The final recommendation is to use the available European products, especially the core service “Euroland” from the Geoland II project.

For the full list and details on existing remote sensing products see CEUBIOM Deliverable D2.3.

WEB catalogues on the EO data and product

On the CEOS web site (Committee on Earth Observation Satellites - CEOS). there is a complete list and analysis of all missions and sensors, called ‘CEOS Earth Observation Handbook’, for a variety of readers. It presents the main capabilities of satellite Earth observations, their applications, and a systematic overview of present and planned CEOS agency Earth observation satellite missions and their instruments. All EO satellite missions are arranged both chronologically by launch date and alphabetically by mission name.

http://www.eohandbook.com/eohb2008/PDFs/satellite_instruments_chart.pdf)

Another useful catalogue is The Land Measurements Portal (http://landportal.gsfc.nasa.gov/) preparing by Nati onal Aeronautics and Space Administration - NASA. This catalogue provides a single location to find information and data products related to terrestrial observations across agencies and institutions. The portal also serves as a way to promote new products and projects and stay informed about international coordination efforts, news, and meetings.

On the WEB there are also a number of Web-based tutorials and information pages available on remote sensing and geographic information systems (GIS).

Committee on Eart h Observation Satellites Tutorial
NASA Remote Sensing Tutorial
NASA Landsat 7 Science Data Users Handbook
NASA Earth Observing System Glossary

Data and product access conditions

(Source : ‘Report from the Workshop on Developing a Strategy for Global Agricultural Monitoring in the framework of Group on Earth Observations’ (GEO), 16-18 July 2007, FAO, Rome) there was presented)

Coarse Resolution Data (4km – 250m)

As a consequence of an effort made by several space agencies, effectiveness of existing systems has improved and large volumes of data can now be made available a few hours after acquisition. This results in data generally easily accessible, often with reduced lag-times (near real-time access can be

provided in many cases) and at limited or no-cost (example: all MODIS and MERIS RR data, worldwide, and to all MERIS full resolution data acquired in European coverage are made available in NRT on the Web at no cost). No-cost data are more likely to be associated with on-line dissemination as order and data handling costs are eliminated. In the case of value-added products (e.g. data processed to extract specific geophysical parameters), examples of free and unlimited access also exist. E.g.: archived standard 10-days Vegetation synthesis products from VITO (http://free.vgt.vito.be/), ESA global products from Globcover)
(http://www.esa.int/due/ionia/globcover) or Globcarbon)
(http://dup.esrin.esa.int/ionia/globcarbon/products.asp)

Moderate Resolution Data (60m- 10m)

A few examples of data distributed at no (example: Landsat Geocover or the SPOT1-4 Level1A data acquired over Europe the latter distributed by ESA with specific geographic limitations) or marginal cost (example: ASTER data) exist: it is hoped that this will generate some momentum and stimulate space agencies to facilitate access to further assets (E.g. in the framework of GEOSS discussions are ongoing to facilitate the access to C-BERS data), allowing for free and open sharing of data. The situation is different when considering data managed and distributed by private entities with commercial goals.

Fine Resolution Data (< 10m)

Data costs respond to market logic and may vary considerably as a function of processing (and quality) level, with an international inequity in pricing and distribution policies. A reduction in price of these data, especially for targeting agricultural lands in regions where food security is a priority issue would be important. Restrictions on availability and access to the data limit their utility and may hinder possible improvement of agricultural practices. The cost of data presents a serious obstacle for many users of satellite data, particularly in developing countries or developed countries, when large volumes of data are needed, and in addition it discourages research activities on interoperability of data from various platforms. Data policy and pricing inequities present a major obstacle to developing integrated observing systems.

Satellite data provision and availability

Remote sensing data and product are acquired and distributed in EUROPE mainly by European Space Agency ESA. The eoPortal catalogue client gives access to catalogues that provide a standard query interface; the current set of catalogues includes examples from **ESA**, **DLR** and **NASA ECHO**. The eoPortal Catalogue Client allows finding earth observation data products from many data providers, data products from different sources can be compared side by side, geographic coverage and reduced resolution images are displayed to allow you to determine the data that best match your requirements.

EOLi (Earth Observation Link) is the European Space Agency's client for Earth Observation Catalogue and Ordering Services. Using EOLi, you can browse the metadata and preview images of Earth Observation data acquired by the satellites ENVISAT, ERS, Landsat, IKONOS, DMC, ALOS, SPOT, Kompsat, Proba, JERS, IRS, Nimbus, NOAA, SCISAT, SeaStar, Terra/Aqua.

DESCW (Display Earth remote sensing Swath Coverage for Windows) is a multimission software tool created to allow you to display Earth Observation satellites (ERS-1, ERS-2, LANDSAT-5, LANDSAT-7, JERS-1, TERRA/MODIS and, preliminarily, ENVISAT) coverage over the Earth Map. It will help you in selecting and ordering your remote sensing products from several missions at once.

The conditions of data distribution depend on the Category of use the data products fall into.
Two **Categories of use** are defined:

Category 1 use: Comprises data which are used for research and applications, including research on long term issues of Earth System science, research and development in preparation for future operational use and ESA internal use. ESA provides Category 1 use data either at reproduction costs or free of charge.

Category 2 use: Comprises all other data which do not fall into Category 1 use, including operational and commercial data. Category 2 use data are provided by Distributing Entities appointed by. For more information see the EOLI-SA User Guide

http://earth.esa.int/EOLi/EOLi.html

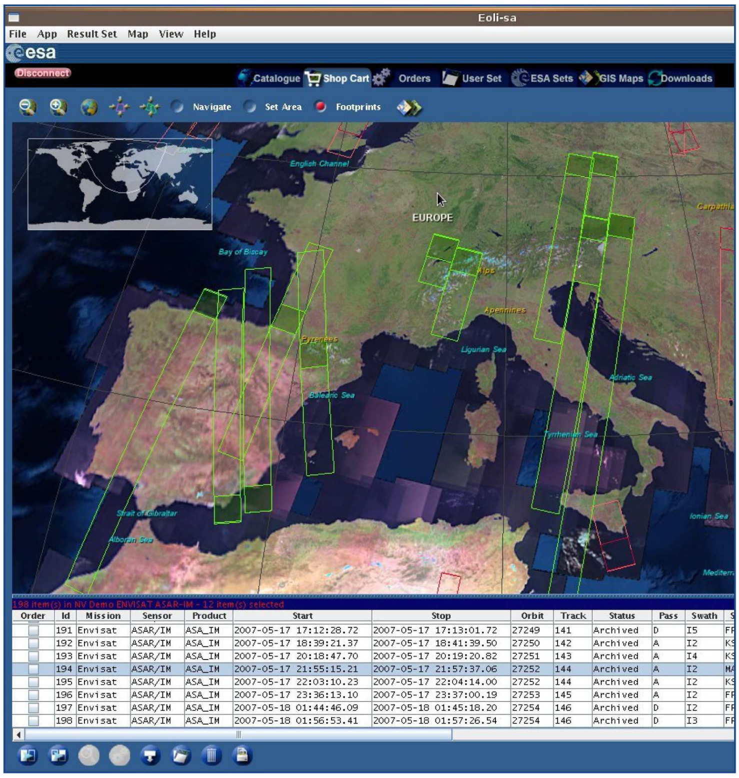

Figure 4 1 EOLI Catalogue Interface
Source: http://earth.esa.int/EOLi/EOLi.html

Remote Sensing USGS Gallery.

This is a gallery of examples of the use of remote sensing to monitor compliance with international environmental treaties.

Declassified Intelligence Satellite Imagery. A wide selection of satellite imagery from the 1960s and 1970s has been declassified by the U.S. intelligence community. Images may be browsed and ordered through the EROS Data Center. Availability: no page at: http://edcwww.cr.usgs.gov/dclass/dclass.html

Earthsat Satellite Corporation (EarthSat). The EarthSat home page describes a range of EarthSat applications related to geology, flooding, agriculture, environment, transportation, and weather. Availability: http://www.earthsat.com

EarthWatch, Inc. EarthWatch provides high-resolution imagery, digital terrain models, and digital maps through its Digital Globe *(TM)* database. EarthWatch is planning to build and launch two commercial high-resolution imaging satellites, EarlyBird and QuickBird. EarlyBird is scheduled for launch in the summer of 1997. The WWW site includes a short primer on remote sensing. Availability: http://www.digitalglobe.com.

Ecosystem Science and Technology Branch, NASA Ames Research Center. The Ecosystem Science and Technology Branch hosts a number of research efforts involving applications of remote sensing, including the Center for Health Applications of Aerospace Related Technologies (CHAART), the Global Monitoring and Human Health Program, the Landsat Program, temporal urban mapping, use of synthetic aperture radar (SAR) to investigate high latitude wetlands, and new sensor development. Availability: http://geo.arc.nasa.gov/sge.html

Eurimage. Eurimage is a consortium of four European Earth observation companies: British Aerospace (U.K.), Dornier (Germany), SSC-Satellitbild (Sweden), and Nuova Telespazio (Italy). It provides access to current data from a range of platforms including Landsat, ERS 1 and 2, TIROS, RESURS-01, JERS-1, Kosmos (KVR 1000, TK-350, and MK-4), and the Russian MIR Space Station as well as archived data from the Coastal Zone Color Scanner (CZCS), the Heat Capacity Mapping Mission (HCMM), the Marine Observing Satellite (MOS), Seasat Synthetic Aperture Radar (SAR), and the Metric Camera. The WWW site provides detailed technical information, a discussion of applications, and access to the EiNet on-line catalogue (by subscription). Availability on :http://www.eurimage.it/

The GeoTIFF Web Page. This site provides information on the effort to establish a TIFF-based interchange format for georeferenced raster imagery. Last updated in June 1996, the site provides access to the official release version of the GeoTIFF Specification and lists GeoTIFF data providers and software vendors. Links are provided to a GeoTIFF ftp archive maintained by SPOT IMAGE. Availability: http://trac.osgeo.org/geotiff/

NOAA/NASA Pathfinder Programs. The U.S. National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration have sponsored a range of "pathfinder" activities to reprocess existing satellite data in support of global change research. Pathfinders include data based on the Advanced Very High Resolution Radiometer (AVHRR), the TIROS Operational Vertical Sounder (TOVS), the Geostationary Operational Environmental Satellite (GOES), the Special Sensor Microwave/Imager (SSM/I), and the Land Remote-Sensing Satellite (Landsat). Availability: http://nsidc.org/daac/development/visualizations/

ORBIMAGE. ORBIMAGE provides data from the OrbView 1 and 2 satellites and the planned OrbView 3 satellite. OrbView 1 includes two sensors, the Optical Transient Detector (OTD) and the GPS/MET instrument. OrbView 2 (SeaStar*(TM)*) was successfully launched on August 1, 1997, carrying the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS). OrbView 2 data will be made available through an on-line OrbNet*(SM)* Digital Archive after launch. The ORBIMAGE WWW site also provides access to the SunCast® Data Service, which provides next-day forecasts of ultraviolet radiation to the general public. Availability: http://www.orbimage.com

Remote Sensing and Modeling. The Center for Energy Studies at the Ecole des Mines de Paris has a Remote Sensing and Modeling group which focus on Earth observation from space and the modelling of processes contributing to the signal measured by spaceborne sensors. Applications include urban climate and air quality, urban mapping, oceanography and coastal zones, and meteorology and solar meteorology. Availability: http://www-cenerg.cma.fr/eng/tele/

Satellite Images in the Network Office Archive. This collection includes multiple satellite images of Long Term Ecological Research (LTER) sites primarily from Landsat Thematic Mapper (TM) and SPOT from the late 1980s and early 1990s. Availability: http://www.lternet.edu/research/technology/satellite/

Space Imaging EOSAT's Online CARTERRA *(TM)* Archive. This commercial digital archive contains panchromatic, multispectral, and wide-field data from the Indian Remote Sensing satellite IRS-1C; high-resolution digital photography; and selected radar and sub-meter products. Availability: http://www.euspaceimaging.com/products/61/

Space Shuttle Earth Observations Project (SSEOP) Database of Photographic Information and Images. This is an on-line database of photographs taken using hand-held cameras from the Space Shuttle. The database may be searched by feature and location and returns a jpeg image and text description of shuttle photographs. Information on ordering hard copy photographs is also provided. Availability: http://eol.jsc.nasa.gov/sseop/clickmap/

Space Science and Engineering Center (SSEC) Real-Time Data. The SSEC at the University of Wisconsin at Madison provides real time data from geostationary satellites such as the Geostationary Operational Environmental Satellite. This site contains browse-quality images only. Availability: http://www.ssec.wisc.edu/data/

SPOT IMAGE. The French satellites SPOT 1, 2, and 3 have provided high-resolution, stereo imagery since 1986. SPOT 4 is scheduled for launch in early 1998. SPOT IMAGE offers a range of data products including land classification data and high resolution urban digital imagery (both satellite and aerial). The Worldwide SPOT Scene Catalogue is available on CD-ROM and an on-line catalogue, DALI, provides meta-data for more than 4 million SPOT scenes and browse images for more than 1 million. Availability: http://www.spot.com

Stratospheric Ozone and Human Health Project Home Page. This on-line service provides access to historical and near-real-time estimates of surface doses of ultraviolet radiation based on satellite measurements from the Total Ozone Mapping Spectrometer and other instruments. The site includes an on-line bibliography on stratospheric ozone depletion, ultraviolet radiation, and human health and provides links to other related data and Internet resources. Availability: http://sedac.ciesin.org/ozone/

View from Satellite. This utility provides a view of the Earth from the current position of the selected satellite in its orbit. Orbital data for hundreds of Earth observing and communications satellites are updated regularly.

Availability: http://www.fourmilab.ch/earthview/satellite.html

Spectral characteristics of vegetation

The link between biomass and remote sensing is that the photosynthetically active vegetation presents a very characteristic spectral response and knowing these relationships is essential for the choice of strategies and methods of assessment with remote sensing techniques.

The selection of the wavelength region of the spectrum and number of bands is a research problem for remote sensing experts for utilization of data provided by the sensor system. When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths.
The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials.
This premise provides the basis for multispectral remote sensing. Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image.

This property can be used for identifying tree types and plant conditions from remote sensing images.

Vegetation biophysical parameters in remote sensing applications

Various applications of remote sensing are used to accurately study different vegetation parameters. Biophisical parameters of vegetation describe the phenological cycle of plants (thus leaf out in spring, senescence in autumn or leaf coloring due to drought stress).

This phenological cycle is the result of an interaction between the local climate and the plants. Vegetation parameters are a means to prescribe land surface vegetation in physical representations of the land surface used in climate research. These so called land surface models include soil physics and plants biochemistry processes that are strongly dependent on the state of vegetation.

The one of the most important vegetation parameter is LAI (Leaf Area Index). It is widely used to parameterize vegetation density and cover in biophysical land surface models and the ‘Fraction of absorbed Photosynthetically Active Radiation’ (FPAR).

LAI (Leaf Area Index)

LAI is a dimensionless variable. It tells us how many leaf layers we find in a plant canopy. Values range from 0 to a maximum of 8. The parameter is derived by measuring the leaf area above a certain ground area and taking the fraction of these two values. LAI has been historically measured by destructive methods, thus taking apart a certain area of canopy and counting the total area of leaves. Manual collection of these data over a large area is costly and time intensive. Satellite remote sensing is an excellent means of determining LAI on a regional or sub-continental scale.

Few such remote sensing models are available to estimate leaf area index. Algorithms and models used as an input parameter to predict or estimate ecological variables have been developed using remotely sensed datasets based LAI. For example, LAI obtained from optical remotely sensed data serves as a key parameter to estimate aboveground biomass of forest stands. Due to recent availability, fine resolution spatial and spectral (hyperspectral) remotely sensed data are being used to retrieve LAI and other biochemical contents such as chlorophyll in leaves of forests. Also in recent years, due to the emergence of light detection and ranging (LiDAR) techniques and equipment, numerous methodologies are being developed for point cloud datasets obtained from LiDAR to assess vegetation and forest three-dimensional structures.

The following table shows the difference of accuracy using different spatial resolution data.

The accuracy of LAI and percentage canopy closure prediction using three image types.

	Landsat TM	SPOT XS	CASI
Leaf area index	71%	88%	94%
Canopy closure	65%	76%	80%

Table 5 1: LAI accuracy using different spatial resolution data

Higher spatial resolution SPOT XS imagery (20 m pixel size) was more successful than LANSAT TM (30 m pixel size), with the 1 m resolution CASI being best of all. Thus, both satellite and airborne digital imagery can provide useful forestry management information which would be very difficult to obtain by field survey.

In summary, there are two broad types of methods for estimation of LAI, either employing the “direct” measures involving destructive sampling, litter fall collection, or point sampling “indirect” methods involving remote sensing instruments optical and radiative transfer models.

The non-contact indirect method is the most popular and convenient way to estimate LAI in practice. According to the working way of instrument or sensors, passive and active are two common categories for retrieving LAI in different spatial scales ranges from leaf, forest stand, landscape, to region or even global levels.

Satellite-based estimation of LAI is an indirect approach, relying on the relationship between LAI and the characteristics of reflected radiation from the canopy as measured by the satellite sensor. Besides the process of light interaction within the canopy, the satellite data are affected by the intervening atmosphere, the characteristics and performance of the sensor, and the processing of the received signal. Various approaches have been developed to transform satellite data into LAI estimates in the form of maps. While no standardization of procedures or products has been achieved to date, progress has been made in this direction, especially through convergence of approaches to validation and intercomparisons of the various methods and products. Morisette et al. (2006) reviewed the techniques employed in various countries to produce and evaluate LAI products derived from satellite measurements. They also identified the required elements for an international satellite-based products validation effort: an organizational entity, the willingness of participants to improve the consistency between methods and results, a mechanism for sharing the data along with a description of the procedure used, and the synthesis of data and results into global accuracy statements. The Land Product Validation Subgroup of the CEOS Working Group on Calibration and Validation is leading this activity which is supported by CEOS member agencies.

For more information see http://lpvs.gsfc.nasa.gov/

FPAR (Fraction of absorbed Photosynthetically Active Radiation)

FPAR (Fraction of Absorbed Photosynthetically Active Radiation), measures the proportion of available radiation in the specific photosynthetically active wavelengths of the spectrum 400-700nm that the canopy absorbs.

FPAR is important detecting index for vegetation water, energy and carbon balance, and a key parameter in the ecosystem productivity model, crop yield model, and so on. (Churkina et al., 1999; Sellers et al., 1997; Lobell et al., 2000).
Actually FPAR were estimated mainly in the empirical models of vegetation indices.
Some simple and complicate physical models, such as the CLM (Common Land Model) (Tian et al., 2004),were used. Neither LAI or FPAR are critical variables themselves, rather they are both essential intermediate variables used to calculate terrestrial energy, carbon, water cycling processes and biogeo-chemistry of vegetation. The current consensus is that LAI will be used preferentially by ecological and climate modelers who desire a representation of canopy structure in their models.
FPAR will be preferentially used by remote sensing scientists to interpret satellite data, and projects interested in simple direct estimates of photosynthetic activity and primary production without using mechanistic biome models.
(Source http://www.ntsg.umt.edu/remote_sensing/leafarea/)

Historically, LAI/FPAR retrievals from satellite data were first implemented with empirical methods applied to NOAA AVHRR data. Los et al. at NASA generated one year (1987) of global NDVI data at 1x1 degree spatial resolution for characterization of spatial and temporal variation of vegetation cover in climate models. These data set was further processed by Seller et al. at NASA to correct for atmospheric, view/illumination geometry and other effect to generate the FASIR-NDVI data set (FASIR stands for Fourier wave Adjustment, Solar zenith angle adjustment, Interpolation of missing data, and Reconstruction of NDVI data over tropical evergreen broadleaf forests). The FASIR-NDVI data set was converted to LAI/FPAR using empirical relationships derived from available field surveys. Current LAI and FPAR retrieval techniques rely mostly on optical remote sensing data, namely Red and NIR channels. The potential for incorporating SWIR channels is being explored.

Data from the following sensors constitute the major potential for LAI and FPAR retrievals:

a) Heritage data sets from AVHRR (channel data, GIMMS and PAL reprocessing)
b) Current data sets from MODIS, MISR, SPOT-VGT
c) Data from future missions (VIIRS)

In addition ancillary data sources, namely, fine resolution ETM+, IKONOS, ASTER data and ground measurements are needed for algorithm refinement and product validation purposes. (LAI and FPAR : R.B. Myneni et al)
For more information it is possible to consult the Vegetation Index ESDR white paper.
(http://landportal.gsfc.nasa.gov/veg_suite.php?tab=1)
For more information: 'LAI and FPAR' Authors: R.B. Myneni, R.R. Nemani, N.V. Shabanov, Y. Knyazikhin, J.T. Morisette, J.L. Privette, S.W. Running
http://landportal.gsfc.nasa.gov/Documents/ESDR/LAI-FPAR_Myneni_whitepaper.pdf

Access procedure to the free biophysical variables products

Recently space agencies have developed and made available EO products of biophysical variables such as LAI and fAPAR to the scientific community.
Biophysical products derived from the observations of a selection of these sensors have just been published. Modellers may now download these products from service centres and plug them directly into their applications.

These products are distributed by POSTEL, a thematic centre associating R&D and services to describe the soil and vegetation from Earth Observation satellite data, at regional and global scales. It is supported by several national public institutions. (http://postel.mediasfrance.org/sommaire.php3?langue=English).

The products are accessible on the ftp site postel.mediasfrance.org using a login and password that can be obtained after registration.. This is a POSTEL byogeophysical products catalogue available for Africa, Australia, Central America, Central Asia, Eastern Europe, Greenland, North Africa, North America, South-East Asia, South America, Western Europe.

PRODUCT	PROJECT	SPACE COVERAGE	TIME COVERAGE	SPACE RESOLUTION	TIME RESOLUTION	SENSOR
LAI	CYCLOPES	Global	1999-2003	1km	10 days	VEGETATION
	GEOLAND	Global	2002-2003	0.5°	10 days	VEGETATION
	AMMA	West Africa	2000-present	0.01°	1 month	MODIS
			1996-1997	0.05°	10 days	POLDER-1
			2003			POLDER-2
		Atlantic	2000-present	0.25°	1month	MODIS
			1981-2001	0.25°	1month	AVHRR
			1996-1997	0.1°	10 days	POLDER-1
			2003			POLDER-2
FAPAR	CYCLOPES	Global	1999-2003	1km	10 days	VEGETATION
	GEOLAND	Global	2002-2003	0.5°	10 days	VEGETATION
	POLDER	Global	1996-1997	6km	10 days	POLDER-1
			2003			POLDER-2
	AMMA	West Africa	2000-present	0.01°	1 month	MODIS
			1996-1997	0.05°	10 days	POLDER-1
			2003			POLDER-2
		Atlantic	2000-present	0.25°	1 month	MODIS
			1981-2001	0.25°	1 month	AVHRR
			1996-1997	0.1°	10 days	POLDER-1
			2003			POLDER-2
FCover	CYCLOPES	Global	1999-2003	1km	10 days	VEGETATION
	AMMA	West Africa	1996-1997	0.05°	10 days	POLDER-1
			2003			POLDER-2
		Atlantic	1996-1997	0.1°	10 days	POLDER-1
			2003			POLDER-2
NDVI	PARASOL	Global	2005-present	6km	10 days	POLDER-3
	AMMA	Atlantic	1981-2001	0.25°	1 month	AVHRR
			1996-1997	0.1°	10 days	POLDER-1
			2003			POLDER-2
		West Africa	1996-1997	0.05°	10 days	POLDER-1
			2003			POLDER-2
			2005-present	0.05°	1 day	MSG
Surface	CYCLOPES	Global	1999-2003	1km	10 days	VEGETATION
Rellectance	GEOLAND	Africa + Eurasia	2002-2003	1km	1, 3, 6 months, 1 year	VEGETATION
	GLOBCOVER	Global	2005-2006	300m	2 months	MERIS
Burnt Surface	GEOLAND	Global	2002-2004	1km	1 day	VEGETATION

Table 5.2: POSTEL byogeophyisical products

In table 5-2 the products marked with * are accessible on the geoland/CSP web site. Products marked with ** are accessible throught the AMMASAT database. Products marked with *** are accessible on the Hydroweb web site.
The typical users of POSTEL products and services are:

- the scientific, national and international community, studying land surfaces and their roles in the water, radiative and carbon cycles
- the European operational Services which are currently being set up within the framework of GMES in the sets of themes:
    a) Natural carbon flux

b) Agricultural production and food safety

Global land cover and forest changes of occupation for the verification and set up of European Union directives and international policies addressing global environment monitoring activities.

The biogeophysical products of Postel are spatialised variables related to the description of land cover the continental vegetation and soils the radiation the water cycle at regional to global scales.

For an example of all MODIS land products where the colour coding is as follows: land tiles with land products generated regularly are shown in **Green** (286 tiles globally), land tiles with land products not generated are in **Orange**, ocean tiles are in **Blue**, and tiles with only sea-ice product generated are in **Pink**.

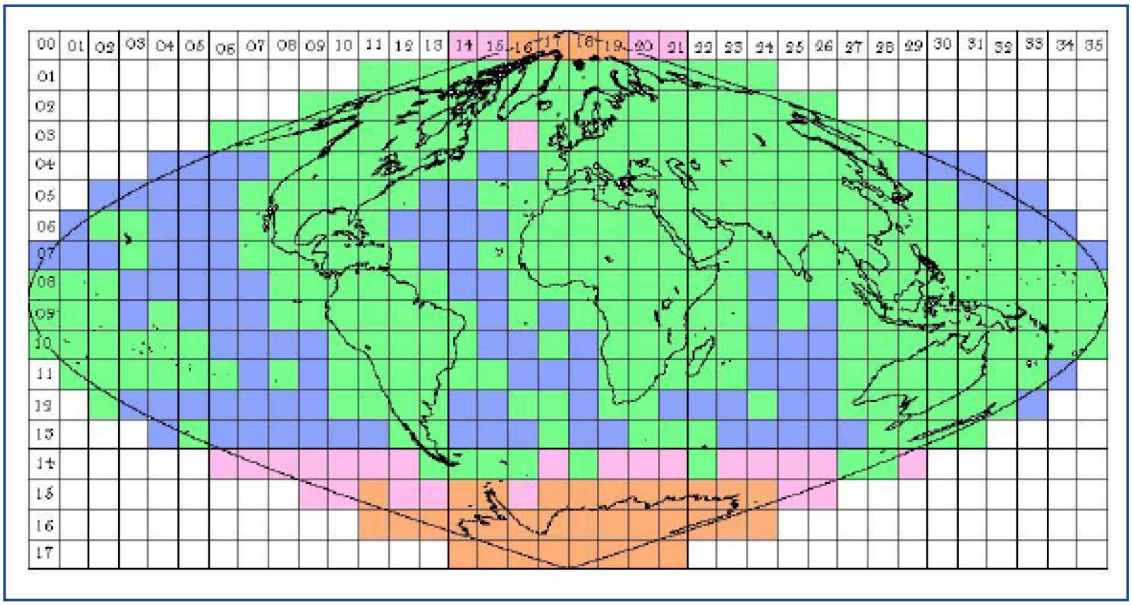

Figure 5.1: MODIS land products

Vegetation indexes

According to the typical green vegetation reflectance spectrum characterized by the chlorophyllean function, the red and near-infrared bands are used for the vegetation indexes calculation and thus biomass estimation.

Vegetation indexes are values used for characterizing green vegetation quality and extent.

A vegetation index is a number that is generated by some combination of remote sensing bands and may have some relationship to the amount of vegetation in a given image pixel.

There is a long list of existing vegetation indexes (VI). This may be an overly harsh assessment, since there is some basis for vegetation indexes in terms of the features of the vegetation spectrum discussed above. Generally the most important question to be asked is “which VI should be used?” Each VI features advantages and disadvantages and are only more or less appropriate for specific species or families.

Many previous extensive research has been conducted and their results will be our reference.

An overview of some used VIs was reported in the WP2 – Streamlining research results into a common methodology for using EO biomass potential assessment - Deliverable D.2.1 Methods compendium on current state-of-the-art in EO for biomass assessment).

Vegetation index free products

For any indices it is possible to download free products on the Land Measurements Portal of NASA. It provides a single location to find information and data products related to terrestrial observations across agencies and institutions.
This is the web address: http://landportal.gsfc.nasa.gov/veg_suite.php

	Sensor	Spatial Resolution	Temporal Resolution	Archive	Developing Institution	Funding Agency
Global Vegetation Indices	SPOT-VEGETATION	0.5deg	10-day	1998 : 2002	UNH	
LTDR-NDVI	AVHRR	0.05deg	Daily	1981 : 1999	GSFC / UMD	NASA
MERIS Global Vegetation Index	MERIS	1.2km	7-14 Days	2002 : 2009	ESA Earthnet	ESA
MERIS Global Vegetation Index - Level 3	MERIS	1.2km	Monthly	2002 : 2009	JRC	ESA
NDVI	SPOT-VEGETATION	1km	10-day	1998 : 2009	VITO	CNES

Figure 5.2: Land Measurements Portal Interface for vegetation idex products availability

EO methods for BIOMASS assessment

The aim of this chapter is to describe general methodologies concerning the thematic processing of EO data for assessing biomass with different operative approaches.
There will describe the need procedures for the construction of a consolidated path on the basis of previous experience validated in different and significant territorial realities.
Mapping biomass resources nationally is a challenging due to ecological and climate gradients across Europe, diversity of forest inventory systems, and data availability from inventoried, non-inventoried and non-productive areas.
Consequently, methods must be devised which are appropriate to the data sources and ecological conditions in the geographic regions of interest.

Guidelines for busy decision makers

Before choosing the best approach for assesses biomass resources we must ask general questions depending on several factors but, although the major factors are mainly technical, there are three prior points that must be considered at the first of any way, independently from the type of the method and technology that will be used. These three prior points are:

- Objective, needs and audience: the first step is a clearly identification of the objective and needs of the assessment and the identification of the audience because the purposes may be very different. According to the type of audience it will be different the manner in witch to present the output. For example a policy marker will need a succinctly and clear output while a project manager will need of detailed scientific data.
- Detail: second step is to understand the detail really requested because an high detail would be only a needless cost. The challenge of the remote sensing for a biomass assessment is the lower costs with the less time and higher temporal resolution feasible but it is also less detailed and typically less accurate. This would be a limit but often the required accuracy is sustainable with remote sensing techniques.
- Available information: the information already available for the particular country, or region, or local site. This is a crucial point because it saves resources and investments. It must be always explored the existing data and collaboration with national institutions.

Having found the answer to these three general questions we can start our search focusing on the technical factors.

There are two types of methods for investigating biomass from space, by remote sensing data :

a) Indirect method
b) Direct method

In the CEUBIOM Project -Deliverable D.2.1 Methods compendium on current state-of-the-art in EO for biomass assessment of WP2 – Streamlining research results into a common methodology for using EO biomass potential assessment- both direct and indirect methods have been widely analyzed, described and documented.

Their limits, constraints and possibilities depend by the input parameters and ground truth data is always needed for building the relation between a remotely sensed signal and the actual biomass on the ground.

Sensing information to biomass estimation (adapted from Rosillo-Calle et al., 2007)

Vegetative land cover

A chief use of remote sensing data is the classification of the myriad of features in a scene (usually presented as an image) into meaningful categories or classes. The image then becomes a thematic map. The most type of thematic map is the vegetative land cover. Vegetative land cover, and its changes, , has provided critical inputs to large-scale biomass and forest cover assessments because it is an important variable in many earth system processes. Vegetative land cover, generally called vegetation land cover, identifies and categorizes the various natural and man-developed features present on the surface in terms of land cover. .(the term land use is almost a synonym, but refers specifically to how the land is used for human activities). Remote sensing offers a means of acquiring and presenting land cover data in a timely manner.

Recognition of spectral measurements taken from satellite sensors of patterns for classification can be carried out if appropriate procedures are adopted. General classification methods have been developed using the image statistics, and their applicability to the processing of data is limited due to the spatial variation of natural resources. Maps and measurements of land cover can be derived from a variety of analytical procedures, including statistical methods and human interpretation. Conventional maps are categorical, dividing land into categories of land use and land cover (thematic mapping, land classification), while recent techniques allow the mapping of land covers or other proprieties of land as continuous variables or as fractional cover of the land by different categories, such as tree canopy, herbaceous vegetation and barren. Land cover datasets may be compared between time periods using geographic information systems (GIS) to map and measure land cover (and land use) al local, regional and global scales.

A major initiative of Europe is the project CORINE (COoRdinate INformation on the Environment) land cover. The European Environmental Agency (EEA) provides the CORINE land data base, a pan-European land cover/ land use map for non-commercial use. The project CORINE Land Cover 2000 (CLC2000) is an update of the database and a mapping of changes has been accomplished using the year 2000 as reference.

With CLC2000 a reliable, objective and comparable data base for the description of the current situation (at 2000) and the analysis of changes during the decade between 1990 and 2000 is available. Integrated in the European GMES activities, an update of CORINE Land Cover is under work in 37 European countries with the reference year 2006, coming close to the completion in most of the countries in beginning 2010

EEA grants free access to all its data/applications. Normally only a registration is required to obtain tiles of the seamless vector database in the form of ESRI shapefiles from [EEA's download web-service](). The raster equivalent version of the CORINE2000 map derived from the seamless vector database is of 100m pixel resolution.(http://www.eea.europa.eu/themes/landuse/clc-download)

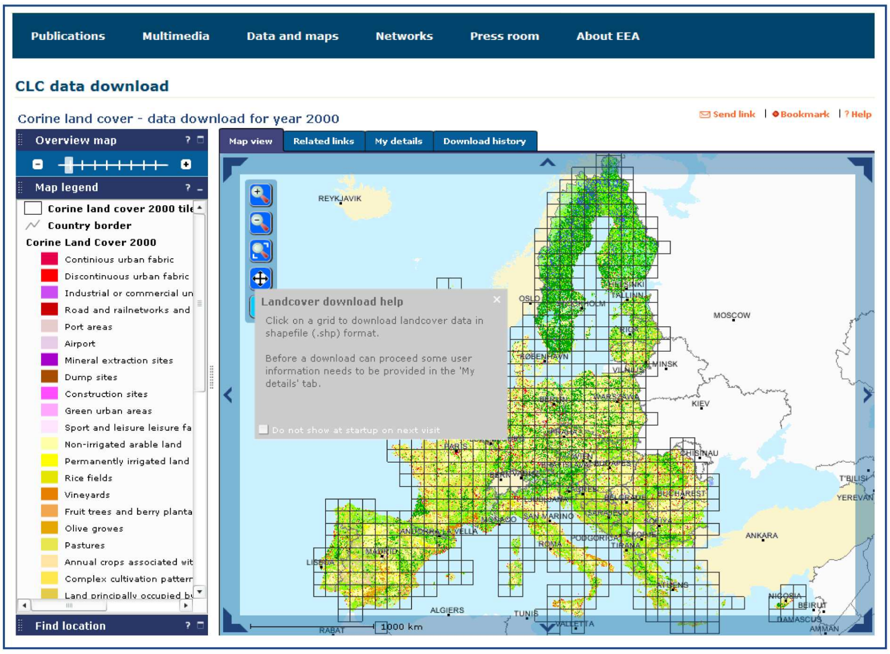

Figure 6.1: EEA's download web-service.Innterface

The CORINE land cover guide sets out the method used and its conditions of application. The method, carefully explained in the technical guide, both for the construction of land cover map and land cover changes (CLC2000) is a useful starting point for a user of remote sensing. The complete documentation and reports (methodology, nomenclature, etc.) are available at EEA's CORINE Land Cover Publications webpage.

(http://www.eea.europa.eu/publications/COR0-landcover)

Land cover Mapping methods

This mapping approach is an simple example based upon using proven indirect method. It intends to ensure delivery over the short production timelines identified. The approach will allow for provide timely and useful information for use within, and external European Countries
For remote sensing image processing and analysis several available software systems (free or commercially) have been developed specifically.

An initial baseline method is to acquire all necessary data that are of three types:

Remote sensing data
Terrestrial data: (an indirect approach need terrestrial data for the classification of the land cover and biomass data for each of the land cover types. as training sets)
Ancillary data as topographic maps in digital or analogue format, with suitable cartographic scale, for EO data geocoding; Digital elevation data, for raster digital elevation model production. Additional ancillary data, in digital and analogue format can be all administrative and lithological boundaries, roads, communities, etc.
This phase can be closed with the production of a database to support the EO data analysis, mainly oriented to a standardization of the ancillary data. It need of: quality control of supplied ancillary data; conversion of ancillary data into suitable formats; correction of errors contained in ancillary input data; transformation of input cartographic projection in a standard projection.
Regarding the EO data both optical and radar data can be used with different results.
Satellite data must be orthorectified and atmospherically corrected to top-of-atmosphere reflectance. Mosaic of images can be mapped then consistency between images can be achieved if the images are radiometrically normalized.
Image processing functions are categorized into the following four categories:

1. Pre-processing: before using remotely sensed data to estimate biophysical variables, it was necessary to calibrate digital data, in order to reduce haze effect on satellite image. The functions involved are generally grouped as radiometric or geometric corrections.
2. Enhancements are used to make it easier for visual interpretation and understanding of imagery. There are many different techniques and methods of enhancing images in order to obtain strong contrast and to create new images. These new images, as extra bands, in order to improve image classification techniques.
3. Image transformations typically involve the manipulation of multiple bands of data, whether from a single multispectral image or from two or more images of the same area acquired at different times (i.e. multitemporal image data)
4. Image classification and analysis are used to digitally identify and classify pixels in the data. Classification is usually performed on multi-channel data sets and this

process assigns each pixel in an image to a particular class or theme based on statistical characteristics of the pixel brightness values.

There are a variety of approaches taken to perform digital classification. Two generic approaches are used: supervised and unsupervised classification. For the analysis data collected during field work s can be used to create a georreferenced tabular data base. This data base can be further updated with biomass production models in order to estimate vegetal biomass.

This tabular database can be used in order to associate vegetal biomass to NDVI values calculated by image processing.

The following flow chart shows the main steps of the method:

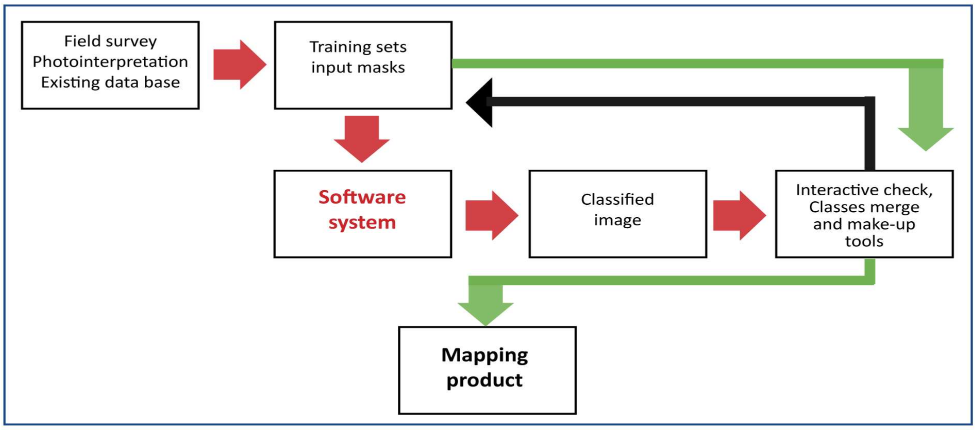

Figure 6.2: flow chart ofthe meyhod. EO method

Change detection

One interesting approach, which may be used in alternative (or in conjunction) with the standard classification techniques, is the change detection. This method simply seeks for what has changed, as opposed to re-doing the classification from scratch, ignoring the existence of pre-existing classifications.

Several approaches can be used for identifying the change. Interesting reviews of various techniques are presented in Collins and Curtis, 1996, and in Olson et al., 2004.

The most efficient approaches are based on preliminary linear transformations, which generate transformed components that shall be compared against each other.

The most useful transformations are:

• NDVI
• Principal Components Analysis PCA

For more information on PCA see the Remote sensing tutorial

http://www.fas.org/irp/imint/docs/rst/AppC/C1.html)

Designing an EO method for biomass assessment

Mapping biomass nationally is a challenge due to ecological and climate gradients, diversity of forest inventory systems, data availability from inventoried, non-inventoried and non-productive areas. Consequently there is no a best method in absolute.
Methods must be devised appropriately to the data sources and ecological conditions in the geographic regions of interest. The first differentiation of the method can be done considering the vegetative biomass in

- forest biomass
- agriculture biomass

Current satellite systems can be used to assess biomass with indirect or direct methods.
For Forest biomass assessment there are a large variety of methods in use divisible in two main groups. The main factor that determines the choice from these two groups depends on the knowledge of terrestrial data.
When terrestrial data are available with spatially explicit location the method consists into try a link between the terrestrial measurement and the pixel information in the EO data. These approaches are sometimes also called ‘bottom up approaches’. If terrestrial data are available on an aggregated basis or general equations, such as from national statistics with no more defined location other parameters such as forest age or density can be derived from EO data and then linked to ‘typical’ biomass values and with the given parameters. Methods under this group are sometimes summarized under the term ‘top-down approach’.
For a complete overview see the CEUBIOM Report D4.2 Compendium on combined methods

Another possible distinction is to subdivide the approaches according to the amount of helping variables needed to reach the biomass calculation result. This means that there are two possible methods: direct and indirect.
Most of the current remote sensing work has focused on indirect methods based on classification approach. These have been useful for mapping the extent of forest changes over very large regions and for the initial characterization of rates of forest loss for carbon cycle studies. The indirect method depends from the land cover accuracy. The classifications are primarily based on the aggregate spectral and spatial patterns to identify forest area, tree species and tree density according to three requirements of Kyoto for systems and methods capable of mapping continuous fields of forest cover and its density. Optical remote sensing data offers a good possibility for (1) repeated measurements (annually) of deforestation over large areas and (2) fine spatial and temporal scale analyses of the dynamics of land-cover change in order to separate and quantify re-growth (afforestation or reforestation).
Although optical remote sensing has been demonstrated to have potential to estimate forest biomass directly, there are several limitations because it can only penetrate to a limited depth through the forest canopy so that the spectral signature provides information for only the upper layers of forest canopies.. Direct methods can be used when terrestrial data areas available and their spatially location is know because it is always necessary to build the relation between a remotely sensed signal and the actual biomass on the ground.

Regarding the agricultural biomass assessment there are two important factors that influences the methods and results. The first is the fast and frequent change of crop types. This needed an annual or even two times a year monitoring. The second is the spatial resolution requirements that can be vary as a function of field size.

In countries where large scale agriculture is common, e.g. USA, Argentina, Australia, Russia, Brazil most requirements can be met using sensors with a spatial resolution of 30 – 80m. In other countries, for example in Africa and Europe where farm sizes are small and the agricultural landscape complex, mapping crop types and estimating agricultural biomass requires sensors with a high resolution.. In order to realize a high resolution crop type map, quite some time is needed for data processing. The solution depends from the operational capability and processing speed of crop classifications at the required resolution.

An optimization is possible using the direct biomass assessment with SAR .

GEOSS/IGOL global agricultural monitoring requirements mapped against a number of the current satellite remote sensing systems for the next 10 years (The operational timelines of these systems are approximate).

Examples of a Monitoring Systems

VITO's Remote Sensing and Earth Observation department

The initial focus of VITO department was mainly on the development of a processing centre for SPOT VEGETATION data, today it covers a larger domain. IT intends to further expand the service centre with new highly specialized services and information products, ensuring a better monitoring of environmental processes including vegetation and crop monitoring related parameters. Through the remote sensing team of VITO initiative there are:

Global Vegetation Research

The Global Vegetation Research group targets the use of medium and low resolution optical and thermal remote sensing data for the following research objectives:

- improve image processing algorithms. Design, development, and demonstration of algorithms, methodologies, and associated processing chains for products that optimally reflect vegetation growth and related parameters from raw satellite imagery.
- monitor vegetation processes. Develop, build, improve and demonstrate long term time series analysis to contribute to the understanding and monitoring of regional vegetation processes, including agricultural productivity, land cover change and modification, carbon sequestration, etc.

Project links

- Geosuccess

Global Earth Observation in Support of Climate Change and Environmental Security Studies - operational site with freely available products.

Agriculture Research

The Agriculture Research group uses corrected images and data sets from the Global Vegetation Research activities to focus on the following research objectives:

- **R&D towards improved agricultural services.** Research into and development of improved methods, applications and services for monitoring agricultural production at the regional and local level in near-real-time, with a focus on crop monitoring, crop area estimation and yield forecasting.
- **Demonstrate** the supply of new and improved state-of-the-art agricultural information services based on remote sensing data to selected key-end-users.

Project links

- **MARS**
  Monitoring **A**griculture through **R**emote **S**ensing techniques, this site offers a wide variety of information and products about the current agricultural season in Europe and other important agricultural areas in the world.

- **GMFS**
  Global **M**onitoring for **F**ood **S**ecurity, offering services and products.

For more information: http://wwwa.vito.be/english/environment/tap.htm

Monitoring of Agriculture with Remote Sensing –Food (MARS Food)

The mission of the crop production forecasts activities of the European Commission at the Joint Research Centre (MARS-Stat33) is to provide accurate, independent and timely crop yield forecasts and crop production biomass (including bio fuel crops) for the union territory and other strategic areas of the world.

MARS-Stat has been developing and operationally running a Crop Forecasting System since 1992 in order to provide timely crop production forecasts at European level. This system is able to monitor crop vegetation growth (cereal, oil seed crops, protein crops, sugar beet, potatoes, pastures, rice) and include the short-term effects of meteorological events on crop productions and to provide yearly forecasts on European crop predictions. The MARS-Stat system is made by remote sensing (NOAA-AVHR, SPOT-VGT, MODIS, MSG) and meteorological observations (observed station data and ECMWF data), agro-meteorological modelling (Crop Growth Monitoring System, CGMS) and statistical analysis tools.

Results are regularly published in the form of bulletins and via the MARSOP website including maps of weather indicators based on observations and numerical weather models, maps and time profiles of crop indicators based on agro-meteorological models and maps of vegetation indices and cumulated dry matter based on remote sensing images (http://www.marsop.info).

In addition, MARS-Stat is the depositary of techniques developed using remote sensing and area frame sampling at the European level to estimate crop areas. MARS-Stat will continue the development of new improvements (spatially and methodological) for the Crop Yield Forecasting and Area Estimate System. A new world-wide crop production estimation activity has started with the Black Sea area and will extend to Russia and China with a focus on wheat production.

MARS-Food Crop Assessment Process

In the mission of MARS-Food the satellite observations and meteorological data are integrated with baseline data on regional agronomic practices into crop growth models to develop MARS-Food ten-daily and monthly bulletins with yield forecasts by crop. Trends, similarity analysis, regression, and expert assessments are used to produce monthly reports that are intended to be directly used by food security administrators. In addition to quantitative and qualitative crop yield assessments, several indicators, like rainfall, radiation and temperature, and water satisfaction indices are published with comparisons to long-term historical average and last year indicators so that food security administrators can have a complete picture of the conditions in food-insecure areas. MARS Stat (http://agrifish.jrc.it/marsstat/default.htm) is a partner program focused on developing early, independent, and objective statistical estimates about the production of the main crops in Europe.

Conclusions

This Handbook analyses remote sensing techniques from the point of view of the final end users. It builds upon analyses already performed in previous deliverables of the project, which in the scope of the WP2, performed a detailed technical analysis of EO methodologies for assessing biomass, and streamlines the possible approaches into a practical guide. The goal of this handbook is in line with the general objectives of the WP5, which is oriented towards multidisciplinary research and interaction, information exchange (e.g. through the web-base platform developed as part of the WP5 activities).

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