INTERREG III B CADSES Programme Carpathian Project

INNOVATIVE APPLICATION OF GIS METHODS AND SATELLITE PHOTOS FOR GENERAL INVENTORY AND PROTECTION OF CARPATHIAN FORESTS

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INTRODUCTION

The forest resource assessment was one of the first applications of the satellite data and products, resulting of the international satellite sensor programs designated for Earth's monitoring, initiated 23 July 1972 by launch of Earth Resources Technology Satellite (ERTS), later known as Landsat. The early civil and military works (1961 – 1972), as well as 35 years of civil research and development (1972 – 2007), resulted in creation of many operational remote sensing satellite systems (fig. 1), providing regularly wholly available, detailed, exhaustive, standarized, repeatable and thematically comparable data.

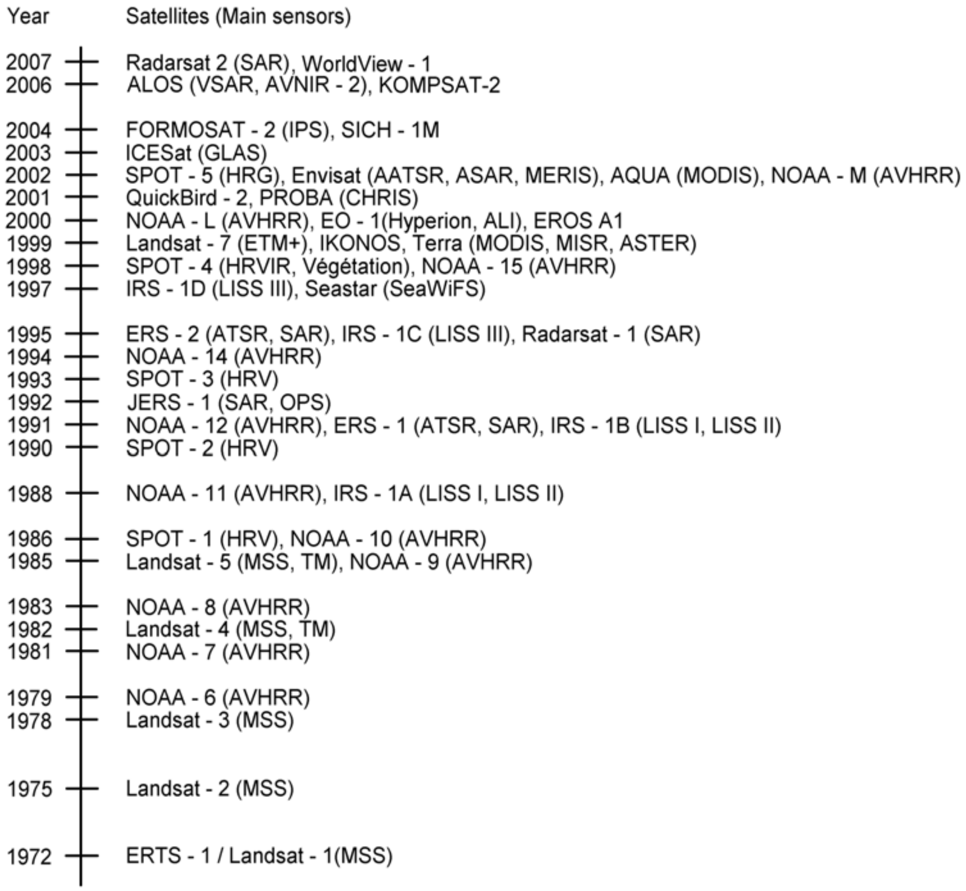

Fig. 1 Launch date of major civil long-term remote sensing satellites, affording the collection of forest resources information

During last 35 years their level of thematical detailness and geometrical precision was growing considerably. The ERTS / Landsat 1 data allowed users to create the maps and layers of level of detailness comparable to 1: 500 000 scale maps, while since 2001 in the case of QuickBird data it is possible to generate cartographic products at 1: 5 000 scale. It is to mention that despite the development of the different generations and types of sensors, no one sensor currently meets fully the requirements of a comprehensive forest resource assessment system (D.S. Boyd, F.M. Danson, 2005; J. P. Malingreau *et al*., 1992). However, almost all available sensors can provide very rich, complementary and (in big part) interoperable data, which can be used in the multitemporal forest research and detailed monitoring. Thus, the satellite remote sensing data is the principal focus of attention, which is used to enhance and increase confidence in field – based inventory and monitoring methodologies (S.E. Franklin, 2001; R.A. Mickler *et al*., 2002). With last advancements concerning the spatial resolution this multispectal and multitemporal data can replace (in big part) aerial photographs, used in the forestry during last 102 years, and became the main source material for creation of layers of detailed forest GIS-es. From the resources perspective, satellite data and products may be used to provide three levels of information, which refer to the spatial extent of the forests and theirs dynamics (1), the forests types (2) and biophysical and biochemical properties of forests (3). The second level information can be useful for detailed inventory of forest structure, while the third level information – for inventories of forest sanitary stand, soil condition, water regime and risks, air pollutants, biotic agents (including damages caused by insect pests, phytopathogenic microorganisms, wild animals), antropogenic agents. All three level informations can be useful in the case of forest management and forest monitoring, wood supply control, part of non wood production monitoring and forest protection area monitoring.

The first Geographical Information Systems have appeared at the end of 60-ties, independently in Sweden (CFD – Centralnämuden för fastignetsdata of Swedish Statistic Office) and in Canada (CGIS – Canada National Geographic Information System of Canada Land Inventory Agence) (R.F. Tomlinson *et al.*, 1977, J. Cole, A.J. Davie, 1969). The CGIS database included e.g. rich information about the soil classification, climate, protected areas and forests (S.R., Johnston, J.G., Roberts, 1971). The significant number of data layers concerning the forestry was also present in the early version of Japanese DNLI system (Y., Miyazaki *et al.*, 1986). The first fully operational forestry GIS was probably French National Forest Inventory – L'Inventaire Forestier National (Fichiers et Banques de Données, 1974). Recently all countries participating in the INTERREG III B CADSES Programme Carpathian Project dispose many specialized GIS. Big part of theirs databases includes also the remote sensing derived data, which can be used to carry out the regional level analysis concerning the forest structure, forest sanitary stand, soil conditions water regime, air pollutants, biotic agents, damages caused by insect pests, wild animals and antropogenic agents, supporting the regional level forest management and forest monitoring, wood supply control, non wood production monitoring, as well as forest protection area monitoring. Czech Republic, Hungary, Poland, Slovakia and Austria dispose also detailed forest databases, which could be regularly feed with detailed remote sensing data generated information, and served to carry out detailed and advanced analysis useful for the local level forest management and monitoring. Such a database is at the pilot project stage in Bulgaria and is designed in Ukraine.

1. INNOVATIVE APPLICATION OF SATELLITE PHOTOS FOR GENERAL INVENTORY AND PROTECTION OF CARPATHIAN FORESTS

1.1. SATELLITE DATA AND PRODUCTS

1.1.1. SATELLITE DATA AND PRODUCTS CHARACTERISTICS

Like all applications of remote sensing, the measurement of forest resources relies on the interaction of electromagnetic radiation with the target and analysis of the returned signal as recorded by a sensor. In broad terms, it is possible to distinguish three types of remote sensing satellites:

1. passive (optical) systems;
2. active (synthetic aperture radar) systems;
3. hybrid systems.

In the end of December 2007, the first group was represented by very high resolution satellites (WorldWiev-1, QuickBird, Ikonos, KOMPSAT-2), high resolution satellites (EROS A-1, Kosmos KVR–1000, SPOT–5, FORMOSAT–2), medium resolution satellites (SPOT-2, SPOT-4, Kosmos TK 350, IRS), low resolution satellites (Landsat) and 'regional view' satellites (NOAA).

The second group of active systems was relatively not numerous (ERS, Radarsat). The third group was represented by JERS, Envisat, ALOS, Terra and Sich – 1M satellites.

PASSIVE (OPTICAL) SYSTEMS

Very high resolution optical satellites products

With a 80 – 89 % share in orders, the **very high resolution optical satellites** (≤ 1 m pixel) **products** are currently the most frequently purchased remote sensing data. They are used primarily like main source material for creation and updating the reference maps as well as thematic databases and advanced, detailed thematic data products.

WorldWiev-1

Since October 2007 the most precise (45 cm pixel, resampled to 50 cm in nadir till 55 cm out to 20° off-nadir) civil satellite data is provided by **WorldWiev-1** satellite. This data is acquired in panchromatic range (0.45 – 0.9 µm) only, both in mono- and stereoscopic mode for 17.6 km width imaging swath, revisited 1.7 days at 1 m GSD or less 5.4 days at 20° off-nadir or less (51 cm GSD). Geolocation accuracy of original data vary from 3 m (in nadir) till 7.6 m. The accuracy with registration to GCP in image is 2 m. The WorldWiev-1 PAN product (fig 2) can be used as a main source material for creation or updating 1 :5 000 scale detailed reference maps, DEM-s, as well as changes inventories.

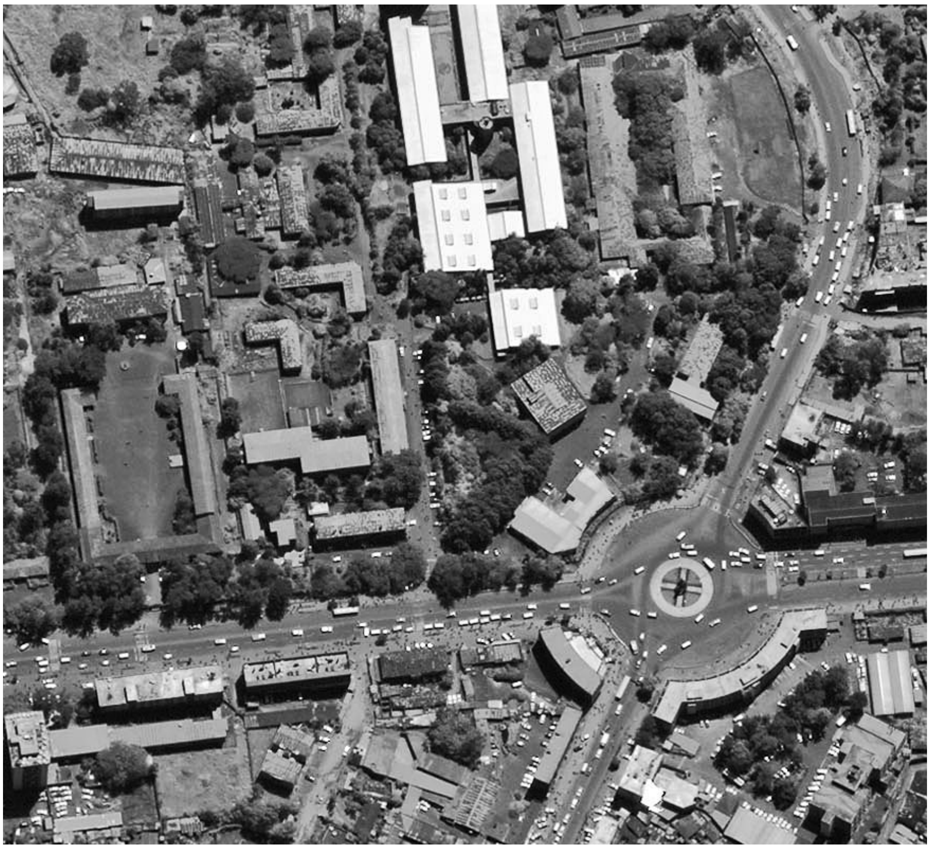

Fig. 2 WorldView-1 first PAN extract. Addis Abeba, 5 October. 2007, © Digital Globe™

However, lack of multispectral characteristics of mapped objects (e.g. trees) reduces the utility of the WorldWiev-1 PAN product in forestry. Their possible application is limited to the first levels of forest information, which refers to the spatial extent of the forests and theirs dynamics. The multispectral information will be available in the case of future WorldWiev-2 satellite, planned to launch in 2008 (M. McGill, 2005).

QuickBird

The DigitalGlobe™ satellite **QuickBird** data and products are available since October 18th. 2001. This data is acquired in **panchromatic range** (0.45 – 0.9 μm) with 61 cm pixel in nadir (resampled to 60 cm) till 72 cm out to 25° off-nadir, as well as in **multispectral mode** with 2,44 m pixel in nadir till 2.88 cm out to 25° off-nadir (resampled till 2.4 m – 2.8 m). The multispectral data is available for blue (0.45 – 0.52 μm), green (0.52 – 0.6 μm), red (0.63 – 0.69 μm) and near infrared (0.76 – 0.9 μm) range of spectrum. The data of last two channels is of fundamental importance for forestry research and detailed monitoring. Geolocation accuracy of original data vary from 7 m till 15 m. The accuracy with registration to GCP in image is 2 m. The full scene has a minimum area of 272 km² (16.5 km x 16.5 km) at nadir, which is corresponding to 27 552 columns and rows in panchromatic mode and 6 888 columns and rows in multispectral mode.
The QuickBird products are offered at three levels:

- Basic Imagery;
- Standard Imagery;
- Orthorectified Imagery.

Basic Imagery products are the least processed acquisitions and are designed for customers having advanced image processing capabilities. These products, together with supplied attitude, ephemeris, as well as camera model information are suitable for orthorectification. Basic Imagery products are radiometrically corrected (relative radiometric response between detectors, non-responsive detector fill, conversion for absolute radiometry) and sensor corrected (corrections of internal detector geometry, optical and scan distortion, line –rate variations and mis-registration of multispectral bands). In the case of these products, the minimum deliverable area is 1 scene (272 km², 16.5 km x 16.5 km). As each scene in a Basic Imagery is processed individually, the multi – scene products are not spectrally mosaiced.
Standard Imagery products are radiometrically, sensor and geometrically corrected. They are mapped to UTM projection. These products are the most frequently ordered by customers. In the case of these products, the minimum deliverable area is 25 km² for archive data, 64 km² for (new) ‘Standard’ or ‘Priority Tasking’ and 100 km² for so called ‘Rush Tasking‘ (48 h). The maximal deliverable area is 10 000 km² in the case of ‘Standard’ or ‘Priority Tasking’ and 2 500 km² in the case of ‘Rush Tasking‘.
Orthorectified Imagery products are radiometrically, sensor corrected, orthorectified and mapped to a cartographic projection and datum. They require a Digital Elevation Model (DEM) and Ground Control Points (GCPs), which may need to be provided by a customer. These products are GIS – ready and ideally suited as a reference material for creating and updating maps or GIS databases layers. They can be ordered by customers, which didn’t dispose each own image processing capabilities.

There are four **QuickBird products**:

1. *Panchromatic (pan)*;
2. *Multispectral (ms)*;
3. *Pan-sharpened* (3 or 4 bands);
4. *Bundle* (*pan* + *ms*).

The first is one channel, 60 cm resolution panchromatic file (fig. 3) The possible application of this product is limited to the first levels of forest information (spatial extent of the forests and their dynamics). The multispectral product is 2.44 m resolution 4 channel spectral data. Their possible application is corresponding to the first and second levels of forest information (spatial extent of the forests, forest dynamics, forests types).

Fig. 3 QuickBird PAN extract. Versailles, 17 June 2002, © Eurimage™

The third (*pan-sharpened)* is the 60 or 70 centimeter resolution product, which combine the visual information of the multispectral bands with panchromatic data. This product is suitable for research and analysis which concerns first two level of the forests information. Pan – sharpened product is available in three versions:

- 4 Bands (blue, green, red, infrared);
- 'Natural' Colour Composite (blue channel filtered with red filter, green – with green filter and red channel with blue filter) (fig. 4);
- 'Colour Infrared Composite'[1] (green channel filtered with red filter, red channel – with green filter, and infrared channel filtered with blue filter (fig. 5).

Fig. 4 QuickBird 'Natural' Colour Composite extract. Tallin, 4 July 2004, © Digital Globe ™

[1] known also like 'false colour composition'

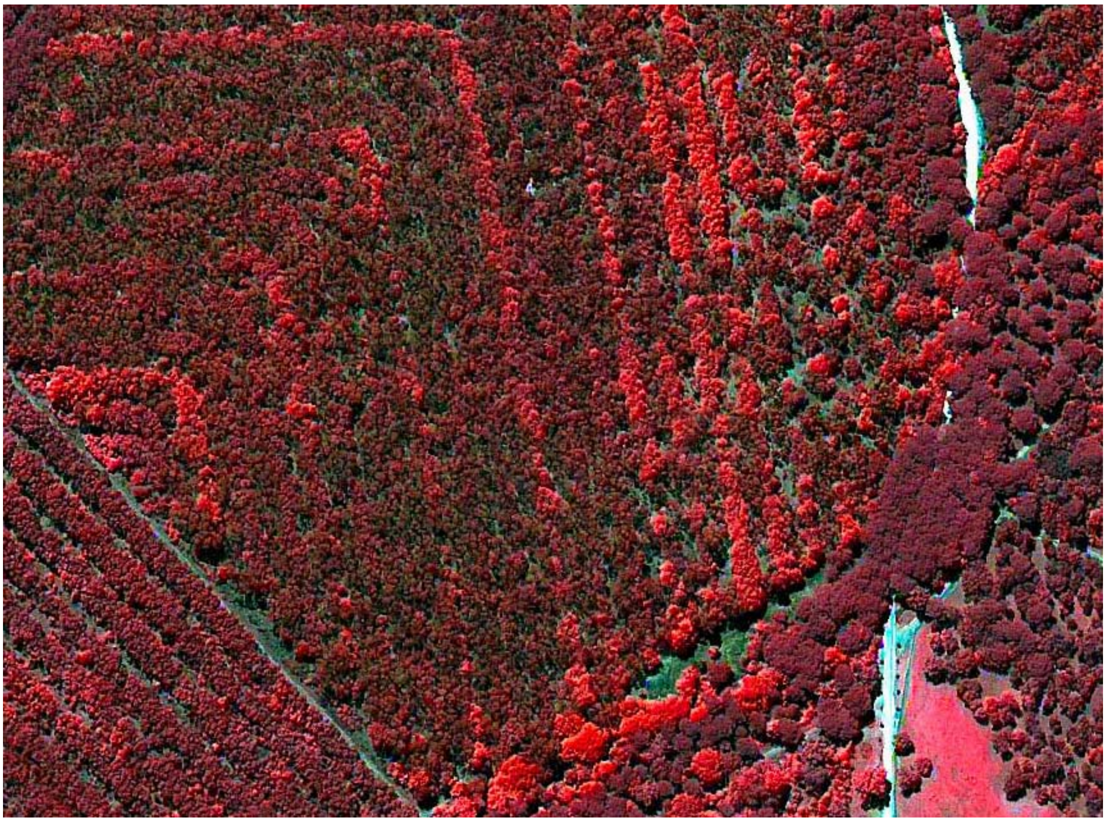

Fig. 5 QuickBird ‘Colour Infrared Composite’ extract. Castelporziano, 16 May 2002, © Eurimage™

The pan-sharpened product is very useful in the case of visual / on screen interpretation. However, their application for supervised classifications may increase the percentage of risk of errors dramatically. It is worth to mention, that due to use of the infrared channel data, the Colour Infrared Composite is much more rich in forestry information, than so called ‘Natural’ Colour Composite.

The most all-purpose QuickBird product is *Bundle*, containing one panchromatic and 4 multispectral channels. All data are processed to the same product level, the same product parameters. This product can allow user to carry out all possible image processing and to acquire the maximum of data. It is possible to use them for research and analysis which concerns all three level of the forests information. Standard Imagery Bundle is the most frequently ordered QuickBird product.

The QuickBird products and its derivates can be used as a main source material for creation or updating 1 :5 000 scale detailed maps or covers, which can be used in GIS forestry analyses, as well as elaboration of DEM-s.

Ikonos

The Space Imaging ™ satellite **Ikonos** was launched 24 September 1999. This satellite is acquiring data is in **panchromatic range** (0.45 – 0.9 μm) with 1 m pixel, and in **multispectral mode** with 4 m pixel The multispectral data is available for blue (0.45 – 0.53 μm), green (0.52 – 0.61 μm), red (0.64 – 0.72 μm) and near infrared (0.77 – 0.88 μm) range of spectrum. The full scene has a minimum area of 121 km² (11 km x 11 km). Geolocation accuracy of original data is 15 m (2 m with registration to GCP in image).

The QuickBird products are offered in three versions:

1. geometrically corrected products;
2. orthorectified products;

3. stereoscopic products.

The first version is represented by Geo product (geometrically corrected with ± 50 m precision).
The orthorectified products are as follows:

- Reference (precision of ± 25,4 m);
- Map (precision of ± 12 m);
- Pro (precision of ± 10 m);
- Precision (precision of ± 4 m);
- Precision Plus (precision of ± 2 m).

There are two stereoscopic products:

- Reference Stereo (precision of ± 11,8 m);
- Precision Stereo[3] (precision of ± 1,9 m).

All product can be delivered as panchromatic, multispectral, pan-sharpened or bundle. The pan-sharpened product is available in 'Natural' Colour Composite or 'Colour Infrared Composite' version (fig. 6).

Ikonos Geo'Natural' Colour Composite

Ikonos 'Colour Infrared Composite'

Fig. 6 Ikonos Geo 'Natural' Colour Composite and 'Colour Infrared Composite' extract. Stawiska (Poland), 1 May 2004, © Space Imaging™

The Ikonos panchromatic product is suitable for research and analysis which concerns the first level of the forests information. The possible application of multispectral and pan-sharpened products is corresponding to the first and second levels of forest information (spatial extent of the forests, forest dynamics, forests types). The bundle product is suitable for analysis concerning all three levels of the forests information. Ikonos products and its derivates can be used as a main source material for creation and/or updating 1 :10 000 scale maps or covers (Dukaczewski, D., 2005a), which can be used in GIS forestry analyses, as well as elaboration of DEM-s.

KOMPSAT-2

The Korean Aerospace Research Institute (KARI) satellite **KOMPSAT-2** (**Ko**rean **M**ulti**p**urpose **Sat**ellite) was launched in 2006. This satellite is acquiring data in **panchromatic range** (0.50 – 0.90 μm) with 1 m pixel in nadir and in **multispectral mode** with 4 m pixel. The multispectral data is available for blue (0.45 – 0.52 μm), green (0.52 – 0.60 μm), red (0.63 – 0.69 μm) and near infrared (0.76 – 0.90 μm) range of spectrum. The full scene has a minimum area of 225 km² (15 km x 15 km) at nadir. It is possible to acquire the data with viewing angle till 30° off-nadir.
The KOMPSAT-2 products are offered at three levels:

- 1A;
- 2A;
- Ortho.

The level 1A products are corrected by normalizing CCD response to compensate for radiometric variations due to detector sensitivity. There is no geometric corrections. The level 2A products have the same radiometric corrections as level 1A products and geometric corrections to match the UTM map projection on WGS84 ellipsoid, without using ground control points. The Ortho is georeferenced product – the scenes are framed in a map projection (given by customer), tied to ground control points (GCP's) from maps and pre-processed using a digital elevation model (DEM). Their accuracy depends on the quality of GCP's and DEM.
There are four **KOMPSAT-2 products**:

- *B&W*;
- *Colour*;
- *Multispectral*;
- *Bundle* (*pan + ms*).

The first is one channel, 1 m resolution panchromatic file. Application of this product is limited to the first levels of forest information. The 'Colour' product is pan-sharpened 1 m resolution file, made of 3 channels. The multispectral product is 4 m resolution 4 channel spectral data. The possible application of last two products is corresponding to the first and second levels of forest information. The bundle product, containing one panchromatic and 4 multispectral channels, can be used for research and analysis which concerns all three levels of the forests information.
KOMPSAT-2 products and its derivates can be used as a main source material for creation or updating 1 :10 000 scale maps and/or covers.

In 2009 the group of very high resolution optical satellites will increase with launch of first of Pleiades satellites of 50 cm resolution and location accuracy better than 10 meters (C. Hutin, 2007).

High resolution optical satellite products

The high resolution optical satellite products (of 1 m – 2.5 m minimal pixel) are frequently purchased remote sensing data. They are used like main source material for creation and updating the reference and thematic maps as well as specialized thematic databases.

EROS A-1

The ImageSat International N.V. of Dutch Antilles, Cyprus and Israel **EROS A-1** satellite was launched 5 December 2000. r. This satellite is acquiring 1.8 m panchromatic data (0.50 – 0.90 μm), hypersampled to 1 m. The full scene has a area of 182.25 km² (13.5 km x 13.5 km). The EROS A products are offered at four levels:

- 1A;
- 1B;
- Ortho Precision;
- Ortho Precision Plus.

The 1A level product is radiometrically corrected. The same corrections and geometric corrections of systematic effects are carried out in the case of 1B product. The Ortho Precision product is orthorectified with Digital Elevation Model (DEM) of ± 90 m precision, while Ortho Precision Plus – with DEM and terrain surveys provided by customer. EROS A-1 products can be used as a main source material for creation or updating 1 :20 000 scale maps and/or covers.

Lack of multispectral characteristics of mapped objects reduces the utility of the EROS A-1 products in forestry. Theirs possible applications are limited to the first level of forest information, which refers to the spatial extent of the forests and theirs dynamics.

Kosmos KVR 1000

The KVR 1000 instrument was installed on the board of many Kosmos satellites. This instrument is acquiring panchromatic data with resolution till 2 m. The full scene has an area of 6400 km² (40 km x 160 km). The original data are stored on high resolution photographic 18 x 72 cm film. Russian firm INNOTER GIA provides two kinds of Kosmos KVR 1000 products:

- RAW – without radiometric and geometric corrections;
- Orthorectified - with radiometric and geometric corrections carried out with ground control points (precision of ± 2.5 m) or without GCP's (precision of ± 20 m).

The KVR 1000 images, which have a mean scale of 1:220 000, can be enlarged without loss of detail up to 1:10 000. Kosmos KVR 1000 products and its derivates can be used as a main source material for creation or updating up to 1 :20 000 scale maps and/or covers. Due to the lack of multispectral characteristics of mapped objects, the utility of Kosmos KVR 1000 products in forestry is limited to the acquisition of first level of forest information.

SPOT-5

On the board of French SPOT-5 satellite, launched 3 May 2002, there is a couple of HRG instruments, one Végétation 2 instrument and one HRS instrument. Both **HRG** instruments are acquiring **panchromatic** data P (0.48 – 0.71 μm) of 2 x 5 m[2] resolution, as well as **multispectral** data: green B1 (0.50 – 0.59 μm), red B2 (0.61 – 0.68 μm), near infrared B3 (0.78 – 0.89 μm) of 10 m resolution and SWIR - short-wave infrared B4 (1.58 – 1.75 μm) of 20 m resolution with absolute location accuracy (RMS) better than 50 m without use of ground control points (GCP's). The **HRS** instrument is acquiring 10 m resolution **panchromatic** data (0.49 – 0.69 μm), continuing the SPOT-1, -2, -3, and –4 mission. The absolute location accuracy (RMS) of HRS data is better than 15 m without usage of GCP's. Both instruments offer an oblique viewing capability, adjustable till ± 27° off-nadir. The HRG

[2] with superimposition of panchromatic data of both HRG instruments, it is possible to obtain 2.5 m pixel high resolution data (so called 'supermode')

and HRS scene is 3600 km² (60 km x 60 km) in nadir till 4800 km² (60 km x 80 km) ± 27° off-nadir. The **Végétation 2** instrument is acquiring 1 km resolution **multispectral** data in four ranges of spectrum: blue/green B0 (0.45 – 0.52 μm), red B2 (0.61 – 0.68 μm), near infrared B3 (0.78 – 0.89 μm) and short-wave infrared B4 (1.58 – 1.75 μm). This data can be used for regional/continental level vegetation analysis purposes.
The SPOT-5 scene products are offered at three levels:

- 1A;
- 1B;
- 2A;

while, SPOT-5 SPOTView products at two levels:

- 2B (Precision);
- 3 Ortho.

The level 1A products are radiometrically corrected by normalizing CCD response to compensate for radiometric variations due to detector sensitivity. There is no geometric corrections. The level 1A products are designed primarily for mapping applications and used for geometric processing (to orthorectify images and create DEM), as well as for radiometric processing. The level 1B products have the same radiometric corrections as level 1A products plus basic geometric corrections (carried out for compensation of systematic effects, including panoramic distortion, the Earth's rotation and curvature as well as satellite orbital altitude variations). This level products are most frequently ordered by customers for thematic analyses. The 2A products have the same radiometric corrections as level 1A and 1B products and geometric corrections to match the UTM map projection on WGS84 ellipsoid, without using ground control points.
The 2B (Precision) level products are georeferenced – the scenes are framed in a map projection (given by customer), and tied to ground control points (GCP's) from maps or terrain survey.
The 3 Ortho level products are also georeferenced and processed using a digital elevation model (DEM) from the Reference3D database with aim to correct residual parallax errors due to relief. Their accuracy depends on the quality of GCP's and DEM.
Spot Image S.A. commercialises four versions of SPOT-5 products:

- 10 / 20 m resolution multispectral data and 10 m resolution panchromatic data;
- 10 m resolution multispectral data and 5 m resolution panchromatic data;
- 5 m resolution multispectral data and 2.5 m resolution panchromatic data;
- 2.5 m resolution multispectral (pan sharpened) data.

SPOT-5 panchromatic products and pan sharpened multispectral products can be used as a main source material for creation or updating up to 1: 25 000 scale maps and/or covers, while multispectral data – like a main source material till 1: 50 000 scale cartographic documents.
SPOT-5 products are suitable for research and analysis which concerns all three levels of the forests information.

FORMOSAT-2

Taiwanese satellite FORMOSAT-2 of National Space Programme Office was launched (under the name of ROCSAT–2) 20 May 2004. Their instruments are acquiring 2 m resolution **panchromatic** data (0.61 – 0.68 μm) and 8 m resolution **multispectral** data of green (0.50 – 0.59 μm), red (0.61 – 0.68 μm), near infrared (0.78 – 0.89 μm) and SWIR - short-wave infrared infrared (1.58 – 1.75 μm) range of spectrum. The full scene has a area of 576 km² (24 km x 24 km).

FORMOSAT-2 panchromatic products can be used as a main source material for creation or updating up to 1: 20 000 scale maps and/or covers, while multispectral data – like a main source material till 1: 50 000 scale cartographic documents.
FORMOSAT-2 products are suitable for research and analysis which concerns all three levels of the forests information.

Medium resolution satellites

The medium resolution optical satellite products (of 5 m – 10 m minimal pixel) are used like main source material for creation and updating of thematic maps as well as specialized thematic databases.

SPOT-2 and SPOT-4

In the end of December 2007 two medium resolution SPOT satellites was operational – SPOT-2 and SPOT-4. Spot Image S. A. offer also historical data acquired by SPOT–1, SPOT-3. On the board of French SPOT-2 satellite, launched 22 January 1990, there is a couple of **HRV (Haute Résolition Visible)** instruments. The same instruments were acquiring data on the board of SPOT–1 and SPOT-3. Both **HRV** instruments are acquiring **panchromatic data** P (0.50 – 0.73 µm) of 10 m resolution, as well as **multispectral data**: green B1 (0.50 – 0.59 µm), red B2 (0.61 – 0.68 µm), near infrared B3 (0.78 – 0.89 µm) of 20 m resolution. Both instruments offer an oblique viewing capability, adjustable till ± 27° off-nadir.
On the board of SPOT-4 satellite, launched 23 March 1998, there is a couple of HRVIR and one Végétation-1 instruments. The **HRVIR** instruments are acquiring panchromatic data P (0.50 – 0.73 µm) of 10 m resolution, as well as multispectral data: green B1 (0.50 – 0.59 µm), red B2 (0.61 – 0.68 µm), near infrared B3 (0.78 – 0.89 µm) and SWIR - short-wave infrared B4 (1.58 – 1.75 µm) of 20 m resolution. HRVIR offers an oblique viewing capability, adjustable till ± 27° off-nadir. The **Végétation-1** instrument is acquiring 1 km resolution multispectral data in four ranges of spectrum: blue/green B0 (0.45 – 0.52 µm), red B2 (0.61 – 0.68 µm), near infrared B3 (0.78 – 0.89 µm) and short-wave infrared B4 (1.58 – 1.75 µm).
The HRV and HRVIR scene is 3600 km² (60 km x 60 km) in nadir till 4800 km² (60 km x 80 km) ± 27° off-nadir.
SPOT-2 and SPOT-4 scene products and SPOTView are offered at the same levels of processing, as described in the chapter three levels (1A, 1B, 2A, 2B Precision, 3 Ortho).
SPOT Image S.A. commercialises 20 m resolution multispectral data and 10 m resolution panchromatic data acquired by these satellites.
SPOT-2 and SPOT-4 panchromatic products can be used as a main source material for creation or updating up to 1: 25 000 scale maps and/or covers, while multispectral data – like a main source material till 1: 50 000 scale cartographic documents.
These products are suitable for research and analysis which concerns all three levels of the forests information.

Kosmos TK 350

The KVR 350 instrument was working on the board of many Kosmos satellites. This instrument is acquiring panchromatic data with resolution till 10 m. The full scene has an area of 60 000 km² (200 km x 300 km). Russian firm INNOTER GIA provides two kinds of Kosmos KVR 350 products:

- RAW – without radiometric and geometric corrections;
- Orthorectified - with radiometric and geometric corrections carried out with ground control points (precision of ± 2.5 m) or without GCP's (precision of ± 20 m).

Kosmos KVR 350 products and its derivates can be used as a main source material for creation or updating up to 1: 50 000 scale maps and/or covers. Due to the lack of multispectral characteristics of mapped objects, the utility of Kosmos KVR 350 products in forestry is limited to the acquisition of first level of forest information.

IRS - Indian Remote Sensing Satellite

In the end of December 2007 two medium resolution IRS satellites was operational – IRS 1C and IRS 1D. Both they are fited with three remote sensing instruments:

- **PAN** – acquiring panchromatic data (0.5 – 0.75 μm) of 5.8 m pixel (resampled till 5 m) and 4410 km² (63 km x 70 km) scenes;
- **WIFS** – registering 188 m resolution scenes of red (0.62 – 0.68 μm) and near infrared (0.77 – 0.86 μm) ranges of spectrum and 591 136 km² (728 km x 812 km) area;
- **LISS – III** – recording 23 m resolution multispectral data of green (0.52 – 0.59 μm), red (0.62 – 0.68 μm), near infrared (0.77 – 0.86 μm) and 70 m resolution SWIR - short-wave infrared (1.55 – 1.70 μm) ranges of spectrum of 17 907 km² (127 km x 141 km) scenes.

There are two versions of IRS products:

- System Corrected;
- Euromap.

System Corrected IRS products are radiometrically and geometrically corrected to the user – specified parameters including output map projection, image orientation and resampling kernel (nearest neighbour or cubic convolution). Geometric corrections include Earth rotation, Earth ellipsoid, map projection, satellite attitude and iternal sensor distortions. These products can be produced like:

- path oriented (displaying the rows of the satellite acquisition scan lines)
- map oriented (north oriented).

The Euromap products are corrected only radiometrically but not geometrically.
The IRS PAN products and its derivates can be used as a main source material for creation or updating up to 1: 25 000 scale maps and/or covers, while multispectral LISS – III data – like a main source material till 1: 100 000 scale cartographic documents.
The utility of IRS PAN products in forestry is limited to the acquisition of first level of forest information. These data can be, however be used for pan-sharpening of multispectral data. The LISS – III products are suitable for research and analysis which concerns all three levels of the forests information.

Low resolution satellites

The low resolution optical satellite products (of 15 m – 100 m minimal pixel) are used like main source material for creation and updating of thematic maps as well as specialized thematic databases.

Landsat

In the end of December 2007 only Landsat-5 satellite was operational. However, a hudge set of Landsat satellites data (since July 1972 till today), which is available in remote sensing archives, is very useful for spatio – temporal analyses. The first generation Landsat satellites (Landsat 1 – 3) carried Return Beam Vidicon (RBV) cameras and Multispectral Scanner

(MSS). The **MSS** instruments are acquiring 78 - 80 m resolution multispectral data of green (0.5 – 0.6 µm), red (0.6 – 0.7 µm), near infrared (0.7 – 0.8 µm) and infrared (0.8 – 1.1 µm) scope of spectrum. These four channels were numbered from 4 till 7. The second generation of Landsat satellites (which has begin in 1982 with Landsat 4) was equipped with MSS and Thematic Mapper (TM) instruments. The **TM** instruments are acquiring multispectral data in 7 scopes of spectrum: 1 blue / green (0.45 – 0.52 µm), 2 green (0.52 – 0.6 µm), 3 red (0.63 – 0.69 µm), 4 near infrared (0.76 – 0.90 µm), 5 SWIR - short-wave infrared (1.55 – 1.75 µm), 6 thermal infrared (10,42 - 12,50 µm) and 7 middle-wave infrared (2,08 – 2,35 µm). The 1 – 5 and 7 channel data are of 30 m resolution, while 6 – thermal infrared channel data – of 120 m resolution. The third generation of these satellites, represented by Landsat 7 (15 April 1999 – 2006) carried **ETM+ (Enhanced Thematic Mapper)** instrument, acquiring the same data like TM instruments plus 15 m resolution panchromatic data (0.52 – 0.90 µm). In the case of ETM+ instrument, the channel 6 – thermal infrared channel data is of 60 m resolution It is worth to mention, that TM / ETM+ data of channels 4, 5 and 7 are fundamental for forestry.
Landsat TM and ETM+ data is offered at three levels of processing:

- ØR, RAW;
- 1R, RADCOR;
- 1G.

The level Ø reformatted (ØR, RAW) data is raw data without radiometric and geometric corrections. The pixels are not aligned per scan line and any radiometric artefacts (e.g. impulse noise, coherent noise, banding, striping, dropped lines and / or pixels) are still present in image.
The level 1R, RADCOR data is radiometrically corrected. Like in the case of ØR level data pixels are neither resampled nor are they geometrically corrected.
The level 1 System Corrected (1G) data is radiometrically and geometrically corrected to user – specified parameters (including output map projection, image orientation and resampling algorithm).
Landsat 33 489km² (183 km x 183 km) scenes can be used as a main source material for creation or updating up to 1: 100 000 scale maps and/or covers. These data is suitable for research and analysis which concerns all three levels of the forests information.

’Regional view’ satellites

The ‘regional view’ optical satellite products, represented by 500 m – 1000 m resolution data are used like an auxiliary and supplementary source material for creation of thematic maps.

NOAA

The NOAA **AVHRR (Advanced Very - High Resolution Radiometer)** instruments data is available since 1978. In the end of December 2007 NOAA 10 (AVHRR 1), NOAA 14 (AVHRR 2) as well as NOAA 15, 16 (L) and 17 (M) (AVHRR 3) were operational.
The **AVHRR-1** instrument is acquiring 1000 m resolution multispectral data of 4 scopes of spectrum using 5 channels: 1(0.58 – 0.68 µm), 2 (0.725 – 1.10 µm), 3 (3.44 – 3.93 µm), as well as 4 and 5 (10,5 – 11,3 µm). The **AVHRR-2** instrument is acquiring the same resolution multispectral data of 5 scopes of spectrum: 1 (0.58 – 0.68 µm), 2 (0.725 – 1.10 µm), 3 (3.44 – 3.93 µm), 4 (10.5 – 11.3 µm) and 5 (11.5 – 12.51 µm). Since 1998 we dispose the **AVHRR-3** 500 m resolution multispectral data of 6 scopes of spectrum, acquired using 5 channels: 1 (0.58 – 0.68 µm), 2 (0.72 – 1.0 µm), 3A daytime (1.58 – 1.64 µm) and 3B night-time (3.55 – 3.93 µm), 4 (10.3 – 11.3 µm) and 5 (11.5 – 12.5 µm).

The NOAA AVHRR data can be received directly (by antenna) or can be ordered. Currently three products are available:

- SHARP[3] 1 Level 1 (original data with geographical grid, sea line and state boundary);
- SHARP 2 Level 2A (calibrated and converted data, as well as classified images);
- SHARP 2 Level 2B (calibrated and converted data, classified images and geophysical parameters).

This kind of data can be used like a source material on weather conditions changes as well as for everyday monitoring of vegetation at 1: 1 000 scale.

ACTIVE (SYNTHETIC APERTURE RADAR) SYSTEMS

ERS

The first European Space Agency radar satellite – ERS-1 was launched 25 July 1991 and was functioning till 10 March 2000. In the end of December 2007 ERS-2 (launched 20 April 1995) was operational.
Both satellites were carrying the same four instruments:

- **AMI** (Active Microwave Instrument) including two radars:
    - SAR using C band frequency (5.3 GHz) and VV polarisation, acquiring 30 m resolution 10 000 km² scenes (100 km x 100 km) in Image Mode, as well as 10 m resolution 25km² (5 km x 5 km) in Wave Mode;
    - Wind scatterometer using C band frequency (5.3 GHz) and VV polarisation, acquiring 50 km resolution 250 000 km² scenes (500 km x 500 km);
- **ATSR** (Along – Track Scanning Radiometer) acquiring 4 channel infrared data[4] and 1 km resolution radar data using K band frequency (13.8 GHz) of 500 km swath to measure of sea – surface and cloud – top temperatures;
- **MWR** (Microwave Radiometer) – passive radiometer, providing 20 m resolution measurements of the total water content of the atmosphere;
- **RA** (Radar Altimeter) – a nadir–pointing pulse radar with two measurement modes (Ocean and Ice)[5] operating in the K band frequency (13.8 GHz) with 10 cm vertical resolution and swath width of 1.3°.

ERS – 2 satellite was also fit with GOME detector (Global Ozone Measuring Experiment), which survey the Earth's ozone layer every three days and detects other trace gases, aerosol and micro-particle pollution in the lower atmosphere. Recently two SAR Basic Image Products are available:

- RAW (Raw Data) – the telemetry data corresponding to one frame of data acquisition, including all auxiliary data for processing;
- SLCI and SLCN (single look complex image) – full and quarter frame pre-processed single look image without speckle reduction.

There are also three system corrected multilook SAR Precision Image Products:

- PRI (Precision Image) - the standard multilook product without terrain-induced radiometric effect nor geometrical corrections;

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[3] SHARP - Standard – family HRPT Archive Request Product
[4] 1(1.6 μm), 2 (3.7 μm), 3 (10.8. μm), 4 (12,5 μm)
[5] Ocean Mode is used to measure surface wind speed, wave height and sea – surface elevation for research of ocean currents and global geoid, while Ice Mode provides data used to sea/ice border survey, ice type recognition, as well as ice sheet surface mapping

- GEC (Ellipsoid Geocoded Image) – geometrically corrected multilook product without corrections applied for terrain distortion nor for radiometry;
- GTC (Terrain Geocoded Image) geometrically corrected multilook product with corrections applied for terrain distortion by applying a Digital Elevation Model.

The ERS-1 and ERS-2 data is suitable for research and analysis of biophysical and biochemical conditions of the environment, which is corresponding to the third level of the forests information.

Radarsat

Canadian satellite RADARSAT was launched 4 November 1995. On it's board there is the **SAR** instrument using C band frequency (5.3 GHz) and HH polarisation, acquiring data in 7 Modes:

- Fine (50 x 50 km, 8 m resolution);
- Extended High (75 x 75 km, 25 m resolution);
- Standard (100 x 100 km, 25 m resolution);
- Wide (150 x 150 km, 30 m resolution);
- Extended Low (170 x 170 km, 35 m resolution);
- ScanSAR Narrow (300 x 300 km, 50 m resolution);
- ScanSAR Wide (500 x 500 km, 100 m resolution).

There are three main categories of products:

- Raw data (unprocessed radar signals, CEOS formatted);
- Path – Oriented (products oriented in the geometry of the swath):
  - Single Look Complex (data stored in slant range, corrected for satellite reception errors, includes latitude and longitude positional information)[6];
  - Path Image (scene is aligned parallelly to the satellite's orbit path, while the latitude and longitude information is included in the data and represents the first, mid and last pixel positions of each line of data);
  - Path Image Plus (which uses smaller pixel spacing, than a Path Image to retain full beam resolution, what enhances ability to make detailed analyses of point and linear features);
- Map Oriented (geometrically corrected, geocoded products):
  - Map Image (product corrected to a client-requested map projection);
  - Precision Map Image (product geometrically corrected to a client provided map or ground control point – GCP's);
  - Ortho – Image (product without terrain distortions inherent in satellite imagery, corrected with a client provided DEM and GCP's).

The RADARSAT data is suitable essentially like auxiliary and supplementary source material for research and analysis of physical, biophysical and biochemical conditions of the environment, which is corresponding to the third level of the forests information.

[6] This data retains the optimum resolution for each beam mode, as well as the phase and amplitude of the original SAR data. Single Look Complex data cannot be directly viewed as images by all software. Interferometric applications will benefits from this product.

HYBRID SYSTEMS

Increasing need for detailed and exhaustive satellite data about the environment was reason to create hybrid (passive and active) satellite systems.

JERS

Japanese NASDA (National Space Development Agency) JERS - Japanese Earth Resource Satellite carried 3 remote sensing instruments:

- **SAR** (Synthetic Aperture Radar) – working in L band (1,275 GHz) with HH polarisation and acquiring 18 m resolution 5 625 km² (75 km x 75 km) scenes;
- **VNIR** (Visible and Near – Infrared Radiometer) – acquiring multispectral data of 3 scopes of spectrum, using 4 channels: 1 green (0.52 – 0.6 µm) 2 red (0.63 – 0.69 µm), 3 near infrared (0.76 – 0.86 µm) registered in nadir, 4 near infrared (0.76 – 0.86 µm) registered 15,3° off-nadir[7];
- **SWIR**[8] (Short Wavelength Infrared Radiometer) – acquiring multispectral data of 4 scopes of spectrum: 5 (1.6 – 1.71 µm), 6 (2.01 – 2.12 µm), 7 (2.13 – 2.25 µm), 8 (2.27 – 2.40 µm).

The JERS data is suitable like main source material for thematic maps and data covers of level of detailness corresponding to the 1: 50 000 scale cartographic documents, as well as auxiliary and supplementary source material for research and analysis of physical, biophysical and biochemical conditions of the environment, corresponding to the third level of the forests information.

Envisat

The European Space Agency (ESA) Envisat satellite was launched 1 March 2002. On it's board there are 10 remote sensing instruments:

- **ASAR** (Advanced Synthetic Aperture Radar) – operating at C band (5.331 GHz) in Stripmap Mode / Image Mode - using one of seven predetermined swaths (of 105 km 197 – 292 or 242 – 347 off-nadir, 82 km, 88 km, 64 km, 70 km, 56 km) and acquiring 30 m resolution data with VV or HH polarisation, as well as in ScanSAR Modes: Wide Swath Mode (acquiring 150 m resolution data with VV or HH polarisation using 400 km x 400 km swath), or Alternating Polarization Mode (acquiring 30 m resolution data with VV/HH, HH/HV, VV/VH polarisation using one of 7 swaths);
- **GOMOS** (Global Ozone Monitoring by Occultation of Stars) – instrument for day - and night-side global coverage measurement of profiles of ozone, NO2, NO3, OClO, temperature, and water vapor between the tropopause and 100 km, acquiring 250 – 952 nm channel data with altitude resolution of better than 1.7 km;
- **LRR** (Laser Retroreflector) is a passive device which is used as a reflector by ground-based SLR stations using high-power pulsed lasers for altitude calibration and support-to-satellite ranging;
- **MERIS** (Medium Resolution Imaging Spectrometer Instrument), acquiring 300 m resolution multispectral data in 15 channels (of 3.90 – 10.40 µm), which can be used for measurement of chlorophyll pigment concentration, suspended sediment concentration and of aerosol loads over the marine domain (with applications for analysis of the ocean carbon cycle, the thermal regime of the upper ocean, the management of fisheries and the management of coastal zones)[9];

[7] From this data, stereoscopic images can be made
[8] called also MIR – Middle Infrared
[9] This instrument is also capable of retrieving cloud top height, water vapour total column, and aerosol load over land

- **MIPAS** (Michelson Interferometer for Passive Atmospheric Sounding) is a Fourier transform spectrometer (operating in the near to mid infrared 4.20 – 14.60 µm) for the measurement of high-resolution gaseous emission spectra at the Earth's limb, carrying out simultaneous measurements of: geophysical parameters in the middle atmosphere, stratospheric chemistry (O3, H2O, CH4, N2O, and HNO3), chemical composition, dynamics, and radiation budget of the middle atmosphere, stratospheric O3 and CFC's;
- **MWR** (MicroWave Radiometer) is measuring the integrated atmospheric water vapour column and cloud liquid water content (as correction terms for the radar altimeter signal) and acquiring data concerning surface emissivity and soil moisture over land using K (23.8 GHz) and Ka (36.5 GHz) band with 20 m resolution;
- **RA-2** (Radar Altimeter) is measuring the ocean 3D topography using S (3.2 GHz) and Ku (13.575 GHz) band[10];
- **AATSR** (Advanced Along Track Scanning Radiometer), acquiring 1 km resolution 7 channel data (0.55 µm, 0.67 µm, 0.865 µm, 1.6 µm, 3.7 µm, 10.85 µm and 12 µm);
- **DORIS** (Doppler Orbitography and Radiopositioning Integrated by Satellite) - tracking system, using S band, providing range-rate measurements of signals from a dense network of ground-based beacons[11];
- **SCIAMACHY** (Scanning Imaging Absorption SpectroMeter for Atmospheric CHartographY) is performing 240 – 2389 nm global measurements of trace gases in the troposphere and in the stratosphere with 3 km.

There are 5 version of ASAR products:

- Level 0 (Raw) – Image Mode data after frame synchronisation, including the instrument source packet and input data (necessary for processing);
- Single-Look Complex (SLC) – single-look data with absolute calibration parameters;
- Precision Image (PRI) – multi-look basic image;
- Ellipsoid Geocoded Image (GEC) - multi-look basic image rectified to a map projection and absolute calibration parameters;
- Multi-Resolution Image(MRI) - 150 m resolution data and absolute calibration parameters.

The Envisat data is suitable like auxiliary and supplementary source material for research and analysis of physical, biophysical and biochemical conditions of the environment, which is corresponding to the third level of the forests information.

ALOS

The ALOS satellite was launched 24 January 2006. On the board of it's platform there are two optical and one radar remote sensing instruments:

- **PRISM** (Panchromatic Remote-sensing Instrument for Stereo Mapping) for digital elevation mapping provides 2.5 m resolution along-track stereoscope images by means of three independent telescopes (acquiring 70 km swath scenes in nadir position and 35 km swaths in +/- 24° off nadir position);
- **AVNIR-2** (Advanced Visible and Near Infrared Radiometer type 2) acquire 10 m resolution, 4900 km² (70 km x 70 km) multispectral scenes of 1 blue (0.42 — 0.50

[10] This data supports the research of ocean circulation, bathymetry and marine geoid characteristics, sea ice and polar ice sheets monitoring, as well as enables the determination of wind speed and significant wave height at sea, supporting weather and sea state forecasting.
[11] In addition to enabling orbit determination, these data are provided also to help in the understanding of the dynamics of the solid Earth, monitor glaciers, landslides and volcanoes, improve the modeling of the Earth's gravity field and of the ionosphere

µm), 2 green (0.52 — 0.60 µm), 3 red (0.61 — 0.69 µm), 4 near infrared (0.76 — 0.89 µm) scope of spectrum in nadir till +/–44ºoff-nadir range;

- **PALSAR** (Phased Array type L-band Synthetic Aperture Radar) for day-and-night and all-weather land observation using L-band frequency (with a cross-track pointing capability of 18º – 55º) and full polarimetry (HH, VV, HH and HV, VV and VH), working in three basic observation modes: fine resolution (10 m spatial resolution both in range and azimuth directions for 70 km of swath width), SCANSAR (100 m resolution 250 km width scenes), as well as low data rate (250 m resolution).

In daytime observation mode the PRISM instrument and AVNIR-2 can work simultaneously, while in night-time observation mode only PALSAR is working. There are 5 PALSAR products:

- FBS fine resolution (10 m resolution, single HH polarisation, 70 km swath);
- FBD fine resolution (20 m resolution, dual HH + HV, 70 km swath);
- SL SCANSAR (100 m resolution, single HH polarisation, 350 km swath);
- P fine polarimetric (30 m resolution, HH + HV + VH + VV, 30 km swath).;

and 6 PRISM and AVNIR products:

- PRISM Panchromatic 1A (raw, nadir 70 km swath data);
- PRISM Panchromatic 1B1 (radiometrically corrected, nadir 70 km swath data);
- PRISM Panchromatic 1B2 (radiometrically and geometrically corrected, 35 km swath data of triplet mode);
- AVNIR-2 Multispectral 1A (raw, nadir 70 km swath data);
- AVNIR-2 Multispectral 1B1 (radiometrically corrected, nadir 70 km swath data);
- AVNIR-2 Multispectral 1B2 (radiometrically and geometrically corrected, 70 km swath data of triple mode);

The ALOS data is suitable like main source material for thematic maps and data covers of level of detailness corresponding to the 1: 25 000 scale cartographic documents corresponding to all three levels of the forests information, as well as auxiliary and supplementary source material for research and analysis of physical, biophysical and biochemical conditions of the environment, corresponding to the third level of the forests information.

Terra (ASTER)

The Terra satellite is a platform of 5 remote sensing devices: ASTER, CERES, MISR, MODIS and MOPITT. One of more universal instruments, providing data which can be used in forestry is Japanese **ASTER** (Advanced Spaceborne Thermal Emission and Reflection Radiometer). This instrument is using three sensors:

- **VNIR** (Visible Near-Infrared) is acquiring 15 m resolution multispectral data of green 1 (0.52–0.60 µm), red 2 (0.63–0.69 µm) and near infrared 3N/3B[12] (0.78–0.86 µm) range of spectrum;
- **SWIR** (Short-Wave Infrared) is providing 30 m resolution SWIR data of six ranges: 4(1.60–1.70 µm), 5 (2.145–2.185 µm), 6 (2.185–2.225 µm), 7 (2.235–2.285 µm), 8 (2.295–2.365 µm), 9 (2.360–2.430 µm);
- **TIR** (Thermal Infrared) is recording 90 m resolution thermal infrared data of five ranges: 10 (8.125–8.475 µm), 11 (8.475–8.825 µm), 12 (8.925–9.275 µm), 13 (10.25–10.95 µm), 14 (10.95–11.65 µm).

[12] backward-viewing telescope for high-resolution stereoscopic observation in the along-track direction (3B)

Each ASTER scene covers an area of 3600 km² (60 x 60 km). There are 7 ASTER products of 3 levels of processing:

- **ASTL1A** (Level 1A) product has SWIR parallax correction (or inter-telescope geometric correction) applied. Geometric coefficients and radiometric coefficients are appended but not applied. Ancillary data of the satellite and engineering data of the ASTER radiometer are also attached.
- **ASTL1B** (Level 1B) product is geometrically and radiometrically corrected, using UTM projection and WGS84 ellipsoid. It includes the data of all ASTER sensors. The unit of calibrated radiance is W /(m*m sr m);
- **AST2B01 Surface Radiance** (Level 2B) product includes VNIR (AST2B01V), SWIR (AST2B01S), and TIR (AST2B01T) images of 15m, 30m and 90m resolutions respectively. The unit of surface radiance is W/m2/sr/m. In the case of AST2B01 product the atmospheric correction is applied and surface radiance of scenes taken on a sunny day is calculated (using e.g. surface temperature and water vapour data concerning pixels without clouds)[13];
- **AST2B04 Surface Emissivity** (Level 2B) products is generated from atmospherically corrected Ground Surface Emissivity (2B01T) data. The data is derived from the five TIR channels through a temperature-emissivity separation process;
- **AST2B05 Surface Reflectance** (Level 2B) product contains information about the surface reflectance, with resolutions of 15m and 30m for VNIR (AST2B05V) and SWIR (AST2B05S), respectively;
- **AST3A01 Ortho Image** (Level 3B) product generated from Level 1A data, including bands 3N and 3B, and relative DEMxyz (4A01X) data with SWIR high-accuracy parallax correction implements. The associated DEM data is appended;
- **AST401 Relative DEM** (Level 4) product, calculated using the data of two telescopes - nadir looking VNIR (band 3N) and backward looking VNIR (band 3B), but without ground control points (GCP's) data.

The ASTER data is suitable like main source material for thematic maps and data covers of level of detailness corresponding to the 1: 30 000 – 1: 50 000 scale cartographic documents corresponding to all three levels of the forests information.
The CERES (Clouds and the Earth's Radiant Energy System) is a NASA designed to measure both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. The MISR (Multi-angle Imaging SpectroRadiometer) instrument consists of an configuration of nine digital cameras that gather data in four spectral bands (blue, green, red, and near-infrared). One camera points toward the nadir, and the others provide forward and aftward view angles at 26.1°, 45.6°, 60.0°, and 70.5°. The data gathered by MISR are useful in climatological studies concerning the disposition of the solar radiation flux in the Earth's system. The MODIS (Moderate-resolution Imaging Spectroradiometer) capture data in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and at varying spatial resolutions (2 bands at 250 m for measurement of land, cloud and aerosols, 5 bands at 500 m for detection of land, cloud and aerosols properties, 11 bands at 1 km for detection of ocean colour, phytoplankton, 3 bands of 1 km for measurement of surface and temperature of clouds, 5 1 km bands for atmospheric temperature measurement, 3 1 km bands for detection of Cirrus and 8 1 km bands acquiring data on clouds properties, ozone, surface cloud temperature, cloud top altitude). The MOPITT (Measurements of Pollution in the Troposphere) is a nadir sounding (vertically downward pointing) instrument which measures upwelling infrared radiation at 4.7 μm and 2.2-2.4 μm. It uses correlation

[13] SWIR observation usually takes place during the daytime, however it is also possible to acquire the data at night, if the surface temperature is high enough (e.g. due to forest fires)

spectroscopy to calculate total column observations and profiles of carbon monoxide in the lower atmosphere.

Sich – 1M

Sich-1M satellite of National Space Agency of Ukraine (NSAU) was launched 24 December 2004. On it's board there are 6 remote sensing instruments:

- **RLSBO** (Side Looking Real Aperture Radar)[14] acquiring 1.7 km - 2.8 km resolution data in flight direction and 1.3 km - 0.7 km resolution data in cross track direction of 450 km to 700 km swath, using X band frequency (9.7 GHz) for Earth surface monitoring and snow coverage sea ice surveying;
- **RM-08** (Passive Microwave Scanning Radiometer)[15] providing 25 km resolution data of 550 km swath, using Ka band (6.6 GHz) frequency for monitoring of atmospheric vapor, sea ice, and sea surface temperature (SST) with an accuracy of 1-2 K;
- **MSU-M** (Multispectral Scanner of low resolution)[16] recording 1.5 x 1.8 km resolution, 2000 km swath multispectral data of 4 ranges: 0.5 - 0.6 µm, 0.6 - 0.7 µm, 0.7 - 0.8 µm and 0.8 - 1.0 µm for cloud monitoring and sea surface temperature measurement;
- **MSU-EU1 & MSU-EU2** (Multispectral high-resolution Optoelectronic Scanning Radiometers) collecting 34 m x 24 m resolution data along the track or 34 m x 66 m resolution data across the track of 3 ranges: 1 green (0.50 - 0.59 µm), 2 red (0.61-0.69 µm), 3 near infrared (0.79 - 0.92 µm);
- **MTVZA-OK** (Combined Microwave-Optical Imaging/Sounding Radiometer) is a hybrid instrument acquiring 1.1 km resolution multispectral data of 5 ranges of spectrum (0.37-0.45 µm, 0.45-0.51 µm, 0.58-0.68 µm, 0.68-0.78 µm, 3.55-3.93 µm), as well as 22 channels microwave data - channels: 1 (6.9 GHz), 2 (10.6 GHz), 3 (18.7 GHz), 4 (23.8 GHz), 5 (31 GHz), 6 (36.5 GHz), 7 (42 GHz), 8 (48 GHz) of VH polarisation and 38 m resolution; channels: 9 (52.80 GHz), 10 (53.30 GHz), 11 (53.80 GHz), 12 (54.64 GHz), 13 (55.63 GHz) of VV polarisation and 38 m resolution; channels: 14 (57.290344 GHz, 50 MHz), 15 (57.290344 GHz, 20 MHz), 16 (57.290344 GHz, 10 MHz), 17 (57.290344 GHz, 5 MHz), 18 (57.290344 GHz, 3 MHz) of HH polarisation and 57 m resolution, channel 19 (4000 MHz) of VH polarisation and 19 m resolution; channels: 20 (1.83 GHz, 1500 MHz), 21 (1.83 GHz, 1000 MHz), 22 (1.83 GHz, 500 MHz) of VV polarisation and 38 m resolution. MTVZA-OK is used for measurement of atmospheric temperature and humidity profiling, monitoring of ice and snow, sea surface wind speed, precipitation, and detection of ocean color.
- **Variant** is an international (British, Polish, French, Russian, and Ukrainian) five sensors package, including:
  - **Wave Probe WZ**[17] measuring the electric and magnetic field fluctuations in the frequency range from 0.1 Hz to 40 kHz with sensivity of 10^{-12} A/cm^2 Hz$^{1/2}$, 10^{-13} T/Hz$^{1/2}$ and 10^{-6} V/Hz$^{1/2}$;
  - **Rogovsky Belt ZF**[18] for registration of space current density, using frequency range from 0.1 Hz to 400 Hz with sensitivity of 10^{-12} A/cm^2 Hz$^{1/2}$;
  - **Electrical probe EZ**[19] recording space electric field vector using frequency range from 0.1 Hz to 200 kHz with 10^{-6} A/cm^2 Hz$^{1/2}$ sensitivity;

[14] built by Kharkov IRE
[15] built by Kharkov IRE
[16] built by ISDE, Moscow
[17] Designed by LC ISR, Ukraine, IKI, Russia, CBK, Poland
[18] Prepared by LPCE/CNRS, France
[19] Made by LC ISR, Ukraine

- o **Faraday cylinder FC**[20] acquiring data on space current density using frequency range from 0.1 Hz till 10 kHz with sensitivity 10^{-10} A/cm^2 Hz$^{1/2}$;
- o **DC magnetometer FCM**[21] for measurement of magnetic field vector **using** frequency range DC - 1 Hz.

Sich-1M satellite data is suitable like auxiliary and supplementary source material for research and analysis of physical, biophysical and biochemical conditions of the environment, corresponding to the third level of the forests information.

1.1.2. SATELLITE DATA AND PRODUCTS AVAILABILITY

In the end of December 2007, the **WorldWiev-1**, **QuickBird**, **Landsat**, **ERS**, **Envisat**, **Radarsat**, **Terra (ASTER)**, **IRS** and **ALOS** satellite data and products were provided by **Eurimage S.p.A.**[22] and its national resellers[23]. The detailed information about the resellers is available at eurimage@eurimage.com (via www.eurimage.com), Customer Office (cust.service@eurimage.com). The up-to-date information about the QuickBird, Landsat and ERS satellite data and products is available with EiNET catalogue (accessible via www.eurimage.com). The information about the ASTER data is available at http://imsweb.aster.ersdac.or.jp/gds_www2002/index_e.html. The **ERS** and **Envisat** data are also available thru **ESA – European Space Agency**.
The **SPOT**, **KOMPSAT-2**, **FORMOSAT–2**, **ERS**, **Envisat** data and products distributor is **Spot Image S.A.**[24] and its national resellers. The detailed information on resellers is available at www.spotimage.com. This address allow also access to the SIRIUS SPOT data catalogue.
The **IKONOS** data and products are provided by **SIGN**: **European Space Imaging**[25] of München (www.euspaceimaging.com) and **Space Imaging Eurasia – INTA Space Systems, Inc**.[26] („INTA SPACETURK") of Ankara (www.spaceturk.com.tr), as well as **SCOR S.A. - Satelitarne Centrum Operacji Regionalnych S.A.** of Warsaw. The central IKONOS data catalogue is available at http://carterraonline.spaceimaging.com.
The **EROS** data and products distributor is **ImageSat International N. V.**[27] (www.imagesatintl.com). Information about EROS products is available at (+ 357 25) 821 114 phone number.
The **Kosmos KVR–1000**, **Kosmos TK 350** products distributor is **INNOTER GIA** of Moscow. These products are also resselled by **Spot Image S.A**

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[20] of Sheffield University, UK
[21] developped by LC ISR, Ukraine
[22] Eurimage S.p.A., Via E. D'Onofrio 212, Roma 00155i, Italia, tel.: (+39 06) 40 69 42 21, fax: (+39 06) 40 69 42 32
[23] In few countries there are more than one reseller (e.g. in Poland: Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02 – 679 Warszawa, tel.: (+ 48 22) 329 19 70, fax: (+ 48 22) 329 19 50, e-mail: darek@igik.edu.pl and Bałtyckie Centrum Systemów Informacji Przestrzennej sp. z o.o., ul. Reja 13/15, 81-874 Sopot, tel.: (+ 48 58) 550 29 95, fax: (+ 48 58) 550 49 88, e-mail: office@bcgis.com.pl
[24] Spotimage S.A., 5 rue des Satellites, B.P. 14349, 31030 Toulouse cedex 4
[25] European Space Imaging (LLC), Arnulfstrasse 197, 80634 München, tel.: (+ 49 89) 130 142 0, fax: (+ 49 89) 130 142 22, e-mail: support@EuSpaceImaging.com
[26] INTA Space Systems, Inc. („INTA Spaceturk"), Haymana yolu 12 km, Gölbaşi, Ankara, tel.: (+ 90 312) 612 23 70, fax: (+ 90 312) 612 23 90, e-mail: info@spaceturk.com
[27] The nearest European vendor is IPT Informatica per il Teritorio S.r.l., Via Sallustiana, 23, 00187 Roma, Dr Filippo Gemma, Direttore Commerciale, tel.: (+39 06) 42 04 17 11, fax: (+39 06) 42 04 17 03, e-mail: f.gemma@iptsat.com

1.1.3. SATELLITE DATA AND PRODUCTS PRICE POLICY

All satellite data and products distributors are functioning on commercial basis. Commercialisation of the remote sensing data distribution have become widespread in the middle of the 80-ties of XX century. It is worth to mention, that almost all distributors admit the possibility of price negotiations. Eurimage, Spot Image and SIGN offer also the price reductions till 20 % in the case of data for non – commercial, scientific and educational purposes. However, in this case customers are allowed to use the data only for proposed project and are demanded to send the copy of final (and selected intermediary) products with documentation, as well as final and intermediary reports. In the case of educational institutions, it is possible also to obtain the price reduction via EARSeL organisation. In December 2007 it doesn't existed reduction programmes for state administration nor forestry administration.

The satellite data and products pricelists are published a few times a year. Their updated versions in .pdf format are available at the distributor's websites:

Eurimage S. p A.: www.eurimage.com
Spot Image S. A.: www.spotimage.com
SIGN: www.euspaceimaging.com and www.spaceturk.com.tr
ImageSat International N. V: www.imagesatintl.com

The INNOTER GIA pricelists wasn't wholly available in December 2007.

The satellite data and products prices presented in pricelists do not include taxes, duties and shipments (mentionned in pricelists). The charges for license to use the satellite data or products listed in pricelists differ depending on many factors:

- level of the processing (all distributors);
- availability in archives versus new task (and programming of the mission);
- priority of the task (all distributors);
- area of ordered data (all distributors);
- resolution of the product (Spot Image);
- date of the product (Eurimage, Spot Image);
- percentage of cloud areas (Eurimage);
- stereoscopic / monoscopic version (SIGN, ImageSat International N. V.);
- priority of delivery (all distributors);
- type of delivery: FTP on-line or on CD/DVD (Eurimage, Spot Image);
- type of license (all distributors);
- number of licensed users (all distributors);
- number of countries mentioned in license (Eurimage, ImageSat International N. V.);
- time – series set (Eurimage);
- regional – series set (Eurimage).

The order forms are available at the distributor's websites. The payment (and reject) procedures was described in the case of Eurimage in: *Eurimage Standard Terms and Conditions of License, Addendum to the Eurimage Standard terms and Conditions of License. Eurimage End User terms and Conditions of License for QuickBird Products: Single Organization*, *Addendum to the Eurimage Standard terms and Conditions of License. Eurimage End User terms and Conditions of License for QuickBird Products: Multiple Organization,* which are available at www.eurimage.com. In the case of Spot Image, these procedures are described in *Conditions Générales de Fourniture*, Spot Image S. A., and *Conditions générales de fourniture de produits ESA* (www.spotimage.com). In the case of Ikonos data, the payment procedure is described in *European Space Imaging Company/Agency License Agreement for IKONOS and IRS Products, Ikonos Imagery Products and Product Guide*, *License Agreement for Inta Space Systems, Inc Products* (www.euspaceimaging.com and www.spaceturk.com.tr), as well as *Umowa licencyjna na korzystanie ze zbiorów danych obrazowych* of SCOR S.A. EROS data payment procedures are described in *Image License Agreement for Digital Products*, available at www.ImageSat.com. There are no (wholly available) INNOTER GIA document concerning the payment rules for Kosmos KVR-1000 and Kosmos TK 350 data. All information can be received by e-mail.

1.1.4. SATELLITE DATA AND PRODUCTS LICENSE POLICY. COPYRIGHTS AND INTELLECTUAL PROPERTY RIGHTS

According to the *International Space Law* and other law regulations (e.g. *Principles Relating to Remote Sensing of the Earth from Outer Space*, 1986; *Traité sur les Principes régissant les activitées des États en matière d'exploitation et d'utilisation de l'espace extra-atmosferique, y compris la Lune et les autres corps célestes,* 1966), it is not allowed to refuse the access to the civil remote sensing data for political, military, ideological, religious, racial or others reasons. It is also forbidden to classify such a data as confidential, secret or limited access entirely or in part.

Detailed rules concerning the usage of civil remote sensing data are contained in the conditions of license published by data distributors.

Eurimage

The main Eurimage document concerning rules of usage of Landsat 1-5, 7, IRS 1C/D, ERS – 1, 2, JERS – 1, Envisat, Radarsat, ASTER, ALOS and NOAA data and products is *Eurimage Standard Terms and Conditions of License*, and in case of QuickBird and WorldView-1 products – annexes: *Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Single Organization and Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Multiple Organization*. No other terms or conditions shall be binding on Eurimage unless specifically accepted in writing by Eurimage. Signature of the data or products order spelt the acceptance of the rules contained in the *Conditions of License.*

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Enhanced Products that contain any imagery data from the licensed standard data or product require an ad-hoc agreement with Eurimage before dissemination to any third party. A few not exhaustive examples are:

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- Orthorectified Products;
- Enhanced Image Products including any histogram manipulation;
- Analogue Products (hardcopy/printed) displaying map-based Eurimage Products.

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According to the § 2 of *Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Single Organization* and § 2 *Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Multiple Organization* the 'multiple organization' means the organization which ordered and paid for the products and is the owner of the license. It includes multiple users solely within the corporations or government agencies at multiple locations within a single country and meeting one of the following conditions:

- includes up to 10 single commercial organizations (not including subsidiaries);
- includes up to two distinct levels of government entities);
- includes single commercial organizations with up to 10 subsidiaries.

Following the same paragraph, the 27 EU countries are treated as a single country.
According to the § 3 the user is permitted to:

- make an unlimited number of copies for the internal use;
- modify the products to create derived works;
- provide the products to contractors for the development of a derived work;

- release hardcopy prints on a limited non-commercial basis, contained in research reports;
- after notifying Eurimage of the URL that will be used, post products and derivated works to Internet web sites (with a resolution not better than 10 mt, for non-commercial purpose, in a non-downloadable, non-distributable way, that does not allow a third party to extract or access the products and derived works as a standalone file).

The Eurimage *Standard Terms and Conditions of License* as well as *Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Single Organization and Eurimage End User terms and Conditions of License for QuickBird & WorldView-1 Products: Multiple Organization* have been construed and enforced in accordance with the laws of Italy. The Italian Courts have exclusive jurisdiction for any dispute or controversy concerning, arising out or connected with *Standard Terms and Conditions of License* and that, within such jurisdiction, the Courts of Rome is competent. For the purposes and effects of Article 17 of the Brussels Convention of 27 September 1968, as amended, the jurisdiction of the Italian Courts has been agreed only in favor of Eurimage.

Spot Image

The main Spot Image document concerning rules of usage **SPOT**, **KOMPSAT-2**, **FORMOSAT–2**, **ERS**, **Envisat** data and products is *Conditions Générales de Fourniture*.In the case of **Envisat** data the relevant document is *Conditions générales de fourniture de produits ESA*. Both documents are available at www.spotimage.com. The signature of the data or products order spelt the acceptance of the rules contained in these documents.

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- to use the value added products ('produits à valeur ajoutée') for its own internal needs;
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According to the § 15 The French Space Agency (Centre National d'Etudes Spatiales – CNES) is the sole holder of the copyright on the SPOT, data. By signing the order the client acknowledges Spot Image's right to protection against the non-authorised reproduction and representation of the products.

All controversies between the client and Spot Image are settled under the arbitration of the Commercial Court of Toulouse. The applicable law is French law.

SIGN - Space Imaging Network

The license grant rules concerning Ikonos data, distributed by regional affiliates are based on principles comprises in *Ikonos Imagery Products and Product Guide*. The main Ikonos license documents are *European Space Imaging Company/Agency License Agreement for IKONOS and IRS Products, License Agreement for Inta Space Systems, Inc. Products* and SCOR S.A *Umowa licencyjna na korzystanie ze zbiorów danych obrazowych.* The acceptance of the rules of License can be:

- signature of the data or products order;
- full or partial (!) approval of the invoice;
- opening the product pack;
- product installation;
- damage or destruction of product (!);
- storage of product for more than 15 days.

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- breaking the seal on the package containing the ISI Data;
- installing or otherwise using the ISI Data on any computer hardware;
- making any commercial use of the ISI Data or any value added products derived from the ISI Data;
- damaging or destroying the ISI Data;
- retaining the ISI Data for more than 15 days following receipt thereof.

ISI grants a limited, non-transferable, non-exclusive, pre-paid license to use the ISI image and information products shipped with License ("ISI Data").
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- make one copy of the ISI Data solely for backup or archival purposes and use only the original ISI Data, or transfer the ISI Data to a single hard disk and use the hard disk version of the ISI Data provided you keep the original ISI Data solely for backup or archival purposes;
- analyze, process, and display the ISI Data within organization, and make such ISI Data and the results of such analysis or processing available to employees of organization for use in accordance with this License;

[28] Notification of posting must be provided to regional affiliates web master

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INNOTER GIA

In December 2007 the legal basis of functioning of INNOTER Geo-Innovation Agency is Federal Agency for Geodesy and Cartography licence PK 10231 (ПК10231). The rules of use of Kosmos satellite data are subject of negotiations with INNOTER GIA team. The applied law is Russian law.

1.2. POTENTIAL APPLICATIONS OF SATELLITE DATA AND PRODUCTS

In spite of the fact that (terrestrial) remote sensing techniques were applied for the first time in European forestry over 102 years ago (e.g. for detailed forest mapping), for many years, the only widely published and wholly available information on European forests was statistical, from data collected in different ways, at different times, using different underlying definitions. With the advent of the satellite remote sensing data and products it became possible to have access to detailed, rich and homogeneous forest information for transborder areas. These data have assumed great importance in forest type and forest structure identification (detailed forest mapping, inventory & updating, change detection, fragmentation analyses)[29], forest sanitary stand analyses (condition health analyses, soil conditions, water regime, air pollutants, biotic[30] and antropogenic agents of damages), as well as forest management and forest monitoring, fire damage monitoring, wood supply control (e.g. the increasingly important problem of illegal logging), non-wood production monitoring and forest protection area monitoring.

In many European countries the government organizations have using satellite data and products for 35 years as a supplementary, then auxiliary and recently main tool in creating forest maps. As a result, government users represent the most mature sector of the market. Currently the demand for forestry information is driven by International and European environmental conventions. Many national governmental forestry agencies are introducing remote sensing derived forestry data and information into the specialized GIS, being an important component of the National Spatial Data Infrastructures (NSDI).

As it was described in chapter above, the civil remote sensing satellites are acquiring a big amount of diverse data. The synthesis for passive (optical) data was done in tab. 1. Although the diversify of acquired spectral ranges is considerable, it is possible to see a few regularities, and analogies. The scope of acquired panchromatic data is the same in the case of WorldView-1, QuickBird, Ikonos and KOMPSAT-2 (first group); EROS, Kosmos KVR-100, Kosmos TK 350 (second group); IRS and SPOT1-4 (third group) plus 'isolated' solutions in the case of SPOT 5 and Landsat ETM+. In the case of visible part of spectrum, there are analogies between QuickBird, KOMPSAT-2, Formosat, Landsat TM and Landsat ETM+. There is also an analogy concerning provided near infrared data between QuickBird, KOMPSAT-2, Landsat TM and Landsat ETM+ group (first group) and Formosat, SPOT (second group).

In the case of forest ecosystems:

1. The **blue** range of spectrum can be a source of information useful to distinguish broadleaf, coniferous forests and young groves[31];
2. The **green** range data bring us information about the vigor of vegetation. It also let us delimitate the areas of exposed soil, rocks and concrete;
3. Strong absorption of **red** range of spectrum by chlorophyll, allow to distinguish the types of vegetation (it is possible to make a distinction between broadleaf forests and coniferous forests, as well as between coniferous and broadleaf young groves) and to map the logging areas;
4. The strongest reflection of electromagnetic waves by chlorophyll and their maximal absorption by water in the **near infrared** allow to mapping a biomass, to distinguish broadleaf and coniferous forests[32], as well as healthy and sick trees, to differentiate

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[29] Concerning types of the forest, tree species. Till today it is rather difficult to detect the area of the same age of trees. This kind of information can be deducted indirectly
[30] insect pests, phytopathogenic microorganisms and wild animals
[31] However, it is worth to mention, that spectral response of young groves is near to the spectral characteristic of water bodies
[32] The spectral responses of broadleaf forest and broadleaf young grove in this spectrum is very proach, after all

the trees and bushes, to identify the types of meadows, and to delineate the wet and water areas;

5. The **first SWIR** range (1,55 - 1,75 μm) data can be a source of information about humidity content in vegetation and in soils, forest sanitary stand, as well as snow and ice mapping. With these data it is also possible to differ between broadleaf, coniferous forests and young groves as well as between the meadows and pastures;
6. The **second SWIR** range (2,08 - 2,35 μm) data provide information on forest sanitary stand, rocks and exposed soils differentiation and hydrothermical mapping;
7. The **thermal infrared range(TIR)** data can be a source of information about Earth's. thermal radiation (in the case of night-time acquisition), stress of vegetation, soil humidity. (A. Ciołkosz, A. Kęsik, 1989; F. Bonn, G. Rochon, 1992).

The most useful source of forest information in the case of optical satellite data is data, acquired in 0,5 μm - 1,3 μm, 1,5 μm - 1,79 μm and 2 - 2,4 μm ranges of spectrum. This situation is caused by relatively big diversity of spectral response of the forest areas in these ranges and possibility of the exact identification of the classes. This level of exactitude, concerning the forest land use classes, is still not possible in the case of SAR data.

The synthesis for active (SAR) and hybrid (active / passive) satellite systems data was done in tab. 2. In the case of C, K, Ka, Ku and S band the most versatility system is ENVISAT, while in L band – JERS and ALOS satellite. The most useful passive source of detailed forest information is data acquired by ALOS and Terra (ASTER) satellite.

One of the main advantage of SAR data is weather – independent possibility of data acquisition[33]. Envisat is acquiring data in C, K, Ka, Ku, S band, ERS – in C and K band, ALOS – in C and L band, Sich 1 M - in Ka and X, while RADARSAT in C band only. The research of J. A. Driemann et al., 1989; P. W. Muller and R. M. Hoffler, 1985; M. D. Thompson and R. V. Dams, 1990 has proved that for correct distinction of forest classes of land use it is necessary to dispose the C, L and X band data. The C band beam is reflected from the inside of the crowns of the trees and bushes. The X band beam is reflected by surface of the crowns of the trees, bushes and other vegetation, whereas the L band beam is reflected by soil surface. It is worth to mention, that research of N. C. Mehta (1984) D. Hoekman (1987) prove, that SAR data provided by instruments working in L band (especially using VH polarization[34]) can allow to distinguish between the forest and other vegetation. However, research of team of R. M. Hoffer (1985) have demonstrated that this possibility is conditioned by the glancing angle of beam, which still constitute the a major limitation of utility of these data for forest land use interpretation in the mountains. It is possible to distinguish broadleaf and coniferous forests in the case of data of instruments working in all available bands (F. Bonn, 1996), but X band data can give better possibilities of correct interpretation, than L band data L (A. J. Sieber, W. Noack, 1986; R. A. Shuchman et al., 1978). Research on efficiency of broadleaf trees species SAR interpretation have revealed moderate possibilities of use C, X, and L band data (R. A. Shuchnam et al., 1978; A. J. Sieber, W. Noack, 1986) with HH polarization and moderate beam angle (D. A. Anthony, 1986; J. B. Cimino et al., 1986; J. Way et al., 1990) for these investigations. Some coniferous trees species identification is possible using L band HH polarization data (R. A. Shuchnam et al., 1978). **In the case of mountains forests the trees species and trees types with SAR data can be unreliable**. As it was proved by team of A. J. Sieber, in the case of broadleaf forests the beam is dispersed in big part by the limbs and branches. The research of team of R. M. Hoffer (1985) has reveal that in the case of the coniferous forests the way of dispersion of beam is influenced by glancing angle.

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[33] The wavelength of the radiationis several orders of magnitude larger than the atmospheric particles (J.R Baker et al., 1994; S. Quegan, 1995)

[34] P. W. Muller and R. M. Hoffer (1985)

Spectral range	µm	Satellites															
		World View 1	Quick Bird	Ikonos	KOMPSAT-2	EROS	Kosmos KVR-1000	Kosmos TK 350	IRS	Formosat	SPOT				Landsat		
											HRV	HVIR	HRG	HRS	MSS	TM	ETM+
		resolution (meters)															
Panchromatic	0,45 – 0,90	0.50	0.61	1	1												
	0,49 – 0,69													10			
	0,50 – 0,75								5.8 (5)		10	10	5				
	0,50 – 0,90					1.8 (1)	2	10									
	0,52 – 0,90																15
Blue	0,45 – 0,52		2.44 (2.4)		4					8						30	30
	0,45 – 0,53			4													
Green	0,50 – 0,59										20	20	10				
	0,52 – 0,59								23								
	0,52 – 0,60		2.44 (2.4)		4					8					80	30	30
	0,52 – 0,61			4													
Red	0,61 – 0,68									2	20	20	10				
	0,62 – 0,68								23/188								
	0,63 – 0,69		2,44 (2,4)		4					8					80	30	30
	0,64 – 0,72			4													
Near Infrared	0,76 – 0,90		2,44 (2,4)		4											30	30
	0,77 – 0,86								23/188								
	0,77 – 0,88			4													
	0,78 – 0,89									8	20	20	10				
	0,80 – 1,10														80		
SWIR 1	1,55 – 1,70								70								
	1,55 – 1,75															30	30
	1,58 – 1,75											20	10				
SWIR 2	2,08 – 2,35															30	30
TIR	10,40 – 12,50															30	30
	10,40 – 12,60														80		

Tab. 1 Spectral ranges of passive (optical) satellite systems

Frequency	Polarisation	Satellite						
		ERS	JERS	RADARSAT	ALOS	TERRA-ASTER	Sich 1 M	ENVISAT
C	VV	■						■
	HH			■	■			■
K	VV	■						■
Ka	VV, HH, VH						■	■
Ku	VV, HH, VH							■
L	HH		■					
	HH, VV, HH and HV, VV and VH		■		■			
S	VV, HH, VH							■
X							■	
Ranges of spectrum	**µm**							
Panchromatic	0.45 - 0.90				■			
IV / Blue	0.37 - 0.45						■	
Blue	0.42 - 0.50				■			
	0.45 - 0.51						■	
Green	0.50 - 0.59						■	
	0.50 - 0.60						■	
	0.52 - 0.60		■			■		
	0.55							■
Red	0.58 - 0.68						■	
	0.60 - 0.70						■	
	0.61 - 0.69		■		■		■	
	0.63 - 0.69		■			■		
	0.67							■
Near Infrared	0.68 - 0.78						■	
	0.70 - 0.80						■	
	0.76 - 0.86		■					
	0.76 - 0.89				■			■
	0.78 - 0.86					■		
	0.79 - 0.92						■	
	0.865							■
SWIR 1	1.60 - 1.70					■		
	1.60 - 1.71		■					
	1.60							■
SWIR 2	2.01 - 2.12		■					
	2.13 - 2.25		■					
	2.145 - 2.185					■		
	2.185 - 2.225					■		
	2.235 - 2.285					■		
	2.27 - 2.40		■					
	2.295 - 2.365					■		
	2.360 - 2.430					■		
	3.55 - 3.93						■	
	3,70							■
TIR	8.125 - 8.475					■		
	8.475 - 8.825					■		
	8.925 - 9.275					■		
	10.25 - 10.95					■		
	10.85							■
	10.95 - 11.65					■		
	12.00							■

Tab 2 Active and hybrid satellites data

The research of R. M. Hoffer and K. S. Lee (1989), F. J. Ahern and J. A. Dreman (1988), as well as of I. D. Kneppeck and F. J. Ahern (1989) can allow to a conclusion that logging and forest regeneration zones can be detected using C band VH polarization data. It is, however, worth to mention that R.V. Dams et al. (1987), M. D. Thompson and R. V. Dams (1990), as well as D. Werle (1989) are signaling problems with interpretation of such a zones in the mountains, due to the interferences of signal, reflected by different slopes. The research of P. N. Churchill and M. A. Keech (1984) revealed the possibility of detection of sick and impaired trees using C and X band data. However, the results of research of K. Stankiewicz (1998, 1999) carried out for the Izerskie Mountains have proved, that detection of these classes is very difficult. Because of interference of beams reflected by slopes in this case it was possible to detect the dense forests and logging areas only. In this situation combined usage of optical and SAR data seems to be a good idea.

Due to the spatial resolution and thematic scope of information which can be received from available channels satellite data / products can be used like a main, auxiliary or supplementary source material for preparation of topographic / thematic maps and databases (tab. 3).

Satellite data	Topographic / thematic maps and databases scale							
	1: 500	1: 1000	1: 2000	1: 5000	1: 10 000	1: 25 000	1: 50 000	1: 100 000
WorldWiev-1	S	S	A	X	X	X	X	X
QuickBird	S	S	A	X	X	X	X	X
Ikonos	S	S	A	A	X	X	X	X
KOMPSAT-2	S	S	A	A	X	X	X	X
EROS	S	S	A	A	A	X	X	X
Kosmos KVR 1000	S	S	S	A	A	X	X	X
SPOT 5								
P	S	S	S	A	A	X	X	X
XS	S	S	S	S	A	A	X	X
ALOS								
P	S	S	S	A	A	X	X	X
XS	S	S	S	S	A	A	X	X
Kosmos TK 350	S	S	S	S	A	A	X	X
FORMOSAT - 2								
P	S	S	S	S	A	X	X	X
XS	S	S	S	S	S	A	X	X
IRS								
P	S	S	S	S	A	X	X	X
XS	S	S	S	S	S	S	A	X
JERS	S	S	S	S	A	A	X	X
Landsat ETM+								
P	S	S	S	S	S	A	A	X
XS	S	S	S	S	S	S	A	A
TERRA (ASTER)								
P	S	S	S	S	S	A	A	X
XS	S	S	S	S	S	S	A	A

X	main source material
A	auxiliary source material
S	supplementary source material

Tab. 3 Satellite data suitability for topographic / thematic maps and databases preparation

Taking into the consideration the spatial resolution and cartographic rules of precision it is possible to distinguish 6 groups of satellite data/products, suitable to be used like main source material for:

1. reference 1: 5 000 or 1: 10 000 scale maps or data layers (WorldWiev-1, QuickBird, Ikonos, KOMPSAT-2);
2. detailed 1: 25 000 scale maps or data layers (EROS, Kosmos KVR 1000);
3. 1: 25 000 – 1: 50 000 scale maps or data layers (SPOT, ALOS, FORMOSAT – 2);
4. 1: 25 000 – 1: 100 000 scale maps or data layers (IRS);
5. 1: 50 000 scale maps or data layers (Kosmos TK 350, JERS);
6. 1: 100 000 scale maps or data layers (Landsat TM, Landsat ETM+, TERRA - ASTER).

Taking into the consideration available spectral ranges and thematic scope of forest information which can be received from them, it is possible to distinguish 6 groups of satellite data/products of:

1. Excellent suitability for thematic mapping in medium and little scales (SPOT 4 and 5, Landsat TM and ETM+, TERRA – ASTER);
2. Excellent suitability for thematic mapping in big scales (QuickBird, Ikonos, KOMPSAT-2);
3. Good suitability for thematic mapping, using SAR data (Envisat);
4. Relatively good suitability for thematic mapping (ALOS, FORMOSAT – 2);
5. Useful for thematic mapping (ERS ATSR, IRS),
6. Useful in certain conditions (Landsat MSS[35], JERS 1, NOAA[36]

In the case of environmental research, related to the forestry, the excellent source of information can be SPOT 4 and 5, Landsat TM and ETM+ data. Very useful information can also be provided by QuickBird, Ikonos, KOMPSAT, Envisat, ERS, IRS and in certain conditions NOAA data.
The best source for risk management research, related to the forestry, are Envisat, Radarsat, QuickBird, Ikonos and SPOT data. Useful data can provide also ERS, IRS, NOAA.

Currently it is possible to distinguish two main groups of methods of acquisition of the information from satellite data:

1. of visual interpretation;
2. of numerical processing.

The first group of methods employs in the same time criteria of radiometry, shape, texture, area, proximity and environmental knowledge of remote sensing specialist. Despite the considerable development of expert systems, this kind of acquisition of information is still very difficult to automation. This group of methods allow to avoid the classification errors, caused by presence of ‘mixels’ inside the clusters. It is possible to define classes which can have the similar spectral response (e.g. clear cuts and natural grassland, coniferous forest and dwarf mountain pine[37], exposed soils and rocks or concrete). It allow also to carry out the quantitative and qualitative generalization during interpretation, which can reduce the excess data and to emphasize the essential information. Because of these merits this group of methods is still used, even in the case of big projects (e.g. CORINE Land Cover). It constitutes also one of the steps of supervised classification. The main inconvenience of these methods is risk of the incompatibility of results of interpretation and generalization.

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[35] historical or multitemporal research
[36] Day-by-day big area monitoring
[37] Pinus mugo

The second group of methods includes:

- pixel oriented solutions;
- object oriented solutions.

The most popular pixel oriented solutions are:

- supervised and unsupervised classifications;
- creation of neochannels;
- stratification;
- aggregation.

The most frequently employed object solutions are object classifications.

The **unsupervised classification** is carried out automatically, using natural grouping algorithms. Its general rule is to identify the cluster centers(1), than assign each vector to nearest cluster center (2), to calculate means of new clusters (3), to verify, if the new means are identical with previous (4). If it is thru, it is possible to compute separability information (5). If it is false, the next step is to set cluster centers equal to new means (6) and go to assign each vector to nearest cluster center (P. H. Swain, S. M. Davis, 1978). The most commonly used algorithms are still ISODATA (Iterative Self-Organizing Data Analysis Technique), K-means algorithm, RGB clustering. It is also possible to use the neuronal network solutions and machine learning algorithms (e.g. F. Albanese, M. Caprioli, E. Tarantino, 2005)

The **supervised classification** is carried out under control of the remote sensing specialist. Its general rule is to select the training fields representative for all classes of legend by of visual interpretation (1), to verify its homogeneity (2) and to carry out the classification, using the training fields (3). It is possible to use the traditional ‘two-values’ logic or ‘fuzzy’ logic.

The **‘two-values’ logic classification** consists in the intensity analysis of pixels (in selected channels) and creation of clusters. Than the intensity for each cluster is compared with intensity of training fields (Ciołkosz, A., Kęsik, A., 1989). In the case of conformity, the class description is attributed to the pixel. Result of ‘two-values’ logic classification is map of the classes.

The ‘fuzzy’ logic assumes, that there exist sets in which affiliation of an element to set is controversial. The fuzzy set specified in the x space (containing all interesting us entities) is a function specified in x space, having values included in the [0,1] interval, in contrast to the regular set, the values of which belong to a double elementary set $\{0,1\}$. (L.A. Zadeha, 1965). The **‘fuzzy’ logic classification** consists in the analysis of relations of pixels with classes using criteria of threshold values (e.g. provided by method of minimal distance, theory of Bayes modified by incertitude index, theory of Demster - Shafer) or proposed by user. The result of ‘fuzzy’ logic classification are maps of probability of belongings of the pixels to the classes (A. Jakomulska, 1998). This kind of results can be used like auxiliary source material for forest GIS analyses.

The class differentiation can consist in terrain / environment knowledge, the spectral distance criterion as well as parametrical or non-parametrical decision rules.

The most frequently used **non-parametrical decision rules** are: linear functions, Fix-Hodges method, baricentric method, k - close neighbours method. Application of the linear function rule consist in division of the multispectral data space into the classes using the parts of the straight line (F. Bonn, G Rochon, 1992). The main inconvenience of this method are big areas of rejections. The Fix-Hodges method employs as a class differentiation function the Mahalanobis function $D_i(P) = -1/2(X - M_i)tA_i^{-1}(X - M_i)$ (T.M. Lillesand, R.W. Kiefer, 1979). In the case of baricentric method the class differentiation function is Euclidean distance

$D_i(P) = (X - M_i)^t (X - M_i)$. The k - close neighbours method employs as a class differentiation function equation d(a,b) = IIa – bII – if between k - close neighbours there are majority of points which belongs to one group, this pixel is attributed to the class which belongs to this group.

The most frequently used **parametrical decision rules** are: generalized hypercubes method, Gauss hypothesis method and Bayes method.

The **maximum likelihood (Gauss hypothesis) method** is based on assumption of natural distribution of classes. Object of examination are means M_i and matrices of the covariance Q_i of each C_i class. The probability for x measurement and C_i class is described by equation:

$$p(x / C_i) = \frac{1}{[2\pi Q_i^2]^{1/2}} \exp[\frac{-(x - M_i)^2}{2Q_i^2}]$$

If each class has *à priori* $p(C_i)$ probability, the maximum probability rule is signaling that x is belonging to C_i class, when $p(x/C_i)\ p(C_i)$ is a maximum. The x measurement is attributed C_i class, if $p(x/C_i) > p(x/C_j)$. Introduction of *à priori* probability for each class allow use them in provisional land use model, which is used to carry out the classification. The maximum likelihood (Gauss hypothesis) method allow to avoid the negative results of excessively approached test field estimation. In situation, where it exists the false classification risk of objects which have the similar spectral response, but one of the object is more representative, the application of the maximum likelihood method allow to achieve the considerable improvement of classification results. The maximum likelihood (Gauss hypothesis) method can guarantee a big accuracy of object recognition (Ciołkosz, A., Kęsik, A., 1989). The results of this kind of classification can be used as a main source material for creation of raster data layers for forest GIS analyses.

The **generalized hypercubes method** is a modification of hypercubes classifcation method. In this method each C_i class is modeled by $[m_{ij}, M_{ij}]$ values interval in each of j of n channel. The point x = $(x_1, \ldots, x_n)$ is belonging to i class if for n considered channels x_j is belonging to $[m_{ij}, M_{ij}]$ interval. When Z is a function of belongings to E, described by equations:

Z (x, E) = 1, if $x \in E$
Z (x, E) = 0, if $x \notin E$,

the final value of x in relation to C_i class is described by equation:

$$s = \mathrm{Min}_{j=1}{}^{n} Z(x_i, [m_{ij}, M_{ij}])$$

This value is equal 1 or 0.

In the case of the generalized hypercubes method the Z is extended to the clusters described by class histograms in each of channels, with assumption that:

Z (x, E) = probability of belongins x to E.

Distribution of possibilities is approximated by distribution of probability, what allow to analyse the frequency of histograms in each of channels. The final value of x in relation to C_i class is described by equation:

$$s = \mathrm{Min}_{j=1}{}^{n} h_{ij}(x_j)$$

This method is very similar to Bayes classification, but is much faster. However, it is worth to mention, that this method is less precise (in terms of entities recognition) than maximum likelihood (Gauss hypothesis) method (Ciołkosz, A., Kęsik, A., 1989). It allow to obtain the more generalized results, which can be used (together with the maximum likelihood method) as a auxiliary source material for creation of raster data layers for GIS analyses.

The Bayes method is build on assumption, that if the probability of existence of $P(C_i)$ class and $P(C_j)$ class is the same and the possibility of its classification is depending of $p(x/C_i)$, the total $P(x/C_i)$ and $P(C_i)$ probability is depending of $p(x/C_i)$ $p(C_i)$. The classification of pixel to the class is depending of occurrence *à posteriori* probability. This probability is equal a ratio of quotient of probability of occurrence and probability à priori of occurrence to sum of analogical quotient for examined classes.

$$p(C_i/x) = p(x/C_i)p(C_i)/p(x)$$

$$p(x) = \sum_i p(x/Ci)p(Ci)$$

The decisive rule is:

if

$$p(C_i/x) > p(C_j/x)$$

than $x \in$ i class

In practice *à posteriori* probability is rarely taken into consideration because of its big power. This probability is taken into the consideration in the cases, when the interpreter is knowing very well the classified area.

In the case of **'fuzzy' logic classification** the most frequ**ently parametrical decision rules** are method of minimal distance, theory of Bayes modified by incertitude index and theory of Demster – Shafer.

The first method employs assumption, that mean value of class response is 1, when value distance of examined pixel related to the mean response value is minimal. Together with value distance growth, the probability of belonging the pixel to this class is decreasing. The zero value is fixed arbitrarily.

The second method is very similar to the 'standard' Bayes classification method. The main difference concerns application of the incertitude index:

$$N = 1 - \frac{max - \frac{sum}{n}}{1 - \frac{1}{n}}$$

where:

max – maximal value of belongings for examined pixel

sum – sum of all belongings of examined pixel

n – number of class

The Dempster – Shafer method is a modified version of Bayes theory. It admit certain degree of uncertainty, admitting that it exists the information about all classes spectral responses. Lack of prove concerning the hypothesis isn't a prove to its rejection. This method employs three parameters – of belief, plausibility and belief interval (which is difference between them. The belief is equivalent to the à posteriori probability Bayes theory, while plausibility is a complement of all belongings probabilities for all classes. For A class its equation is as follow:

$$W_A = 1 - [p(C_i x)_B + p(C_i x)_C]$$

Difference between belief and plausibility is a classification uncertainty measure.

The fuzzy logic satellite data classifications were employed succesfully by A. Jakomulska (2004) and A. Ołdak (1994) for creation of pH soils maps and by A. Jakomulska (2004) for Tatra mountains alpine vegetation classification.

The results of satellite data classifications are raster maps. According to the satellite data and products providers license regulations the copyrights of results of classifications belongs to its authors.

The second group of information acquisition methods from satellite data and products is creation of neochannels (e.g. by calculation of Normalized Difference Vegetation Index – NDVI, Green Vegetation Index – GVI, index of brightness, age of vegetation index) or its generalization (e.g. Principal Components Analysis). This kind of methods can provide detailed data on health and sanitary stand of forests, tree species, which can be used like a source materials for supervised classification. The works of C. Bardinet, J. M. Monget (1978), M. Poisson, of "Dupont" group (1979), P. Oliva, A. Dagorne [38], G. Selleron, (1983), S. Rimbert (1984), D. Dukaczewski et al.(1993), D. Dukaczewski (1994) has proved, that Principal Component Analysis carried out with multitemporal satellite data can be very useful for detailed detection of land use changes. This kind of results can be used like a source materials for multitemporal supervised classifications. The results of calculation of the indexes according to the satellite data providers rules, are value added products. The results of 'classic' Principal Components Analysis calculation can be treated like a standard value added products, while the modified Principal Components Analysis – like a author's product.

The main goal of stratification of image is distinction of homogeneous zones, which can be used like a numeric masks or like a source material for supervised classifications (C. Hallum, 1993). The results of stratification can be treated like a author's product.

Data aggregation consists in data generalization and to relate its to grid system. This kind of data were used for spatial analysis e.g. in Sweden (O. Eklund 1977), Poland (A. Ciołkosz, 1990, A. Ciołkosz et al. 1987; M. Baranowski, 1990a, 1990b, Z. Poławski,1989), and USA (C. Hallum, 1993). The results of data aggregation can be treated like a author's product.

The **object classifications** are relatively new solution, which have become more common in the end of 2000 with appear of eCognition software. In this software the fractal Net Evolution segmentation procedure is used (M. Baatz, A. Schäpe, 1999), which uses elements of theory of fractals and neuron networks. The first step of segmentation is analysis of isolated pixels, which are then aggregated into the objects, employing the homogeneity criterion. To avoid aggregation of two different objects the degree of fitting was defined:

$$h = \sqrt{\sum_n (f_{1n} - f_{2n})^2}$$

where:

h - degree of fitting

n – number of dimension of the space of features

f_1, f_2 - values of the first and second object

The degree of fitting is standardized:

[38] M. Brunet (1987)

$$h = \sqrt{\sum_n \left(\frac{f_{1n} - f_{2n}}{\sigma_{fb}}\right)^2}$$

The decision about aggregation of two objects can be taken using the difference of standardized degree of fitting:

$$h_{diff} = h_m - \frac{h_1 + h_2}{2}$$

where:

h_m - degree of fitting after hypothetical aggregation

h_1, h_2 - degree of fitting of first and second object

User can define not only the spectral channels employed into the classification but also its weight. The next stage is scale parameter and the homogeneity criterion (defined by colour and shape. The criterion of shape includes also parameters of smoothness and coherence.
The result of object classifications is a vector map, which can be imported into the GIS database. It is also possible to classify the other raster (e.g. results of pixel supervised satellite data classifications) or vector products (e.g. data layers). The object classification can be used succesfully to classify the very high resolution satellite data, what allow to avoid the data noise effect (S. Lewiński, 2007). This method allow to use more than spectral data like a source material for classification. In the case of forest area classification it is possible to use e.g. both spectral data and texture, which allow to better forest identification (P. Wężyk, R. de Kok, G. Zajączkowski, 2004; P. Wężyk, P. Bednarczyk, 2005). Using the spectral data and edge filtering functions, it is possible to identify forest succession areas (P. Wężyk, R. de Kok., K. Kozioł, 2006). Application of the criterion of spectral characteristics and criterion shape, can allow (potentially) to distinguish the clear cuttings and old burnings zones or blowdown areas of automatically

1.2.1. FOREST TYPE AND FOREST STRUCTURE IDENTIFICATION

Forest type and forest structure identification can be carried out employing combination of satellite channels, satellite data indexes, results of Principal Component Analysis and satellite data classification.

It was mentioned above that the most useful source of forest information are available in green, red, near infrared and short-wave infrared ranges of spectrum (0,5 µm - 1,3 µm, 1,5 µm - 1,79 µm and 2 - 2,4 µm). The broadleaf forest spatial extent can be delineated with big precision using RGB (red, green, blue) combinations of :

- near infrared and two SWIR channels (e.g. Landsat: TM4, TM 5, TM7);
- red, near infrared and SWIR channels (e.g. Landsat: TM3, TM4, TM5 as well as SPOT 5: XS2, XS3, XS4, ASTER or IRS: 2, 3, 4);
- near infrared, red, green channels (e.g. in the case of Landsat: TM4, TM3, TM2, or SPOT 2, 3, 4, 5: XS3, XS2, XS1, ASTER: 3, 2, 1, and QuickBird, Ikonos, KOMPSAT, FORMOSAT: 4, 3, 2).

The coniferous forests spatial extent can be delineated precisely using RGB combinations of:

- near infrared, second SWIR and blue channels (Landsat: TM4, TM7, TM1);
- first SWIR, near infrared, blue channels (Landsat: TM5, TM4, TM1);

The most fundamental for forest information acquisition is near infrared (0,76 – 0,90 µm), first SWIR (1,55 – 1,75 µm) and second SWIR (2,08 – 2,35 µm) data availability. This kind of data are recently available only in case of two (relatively) small resolution satellites – Landsat 5 and Terra – ASTER. In this situation many users, which are interested in data suitable for forest research have a tendency to use the high or very high resolution satellite data using RGB combinations which are suitable for all land use:

- near infrared, first SWIR, red spectrum channels (Landsat: TM4, TM5, TM3, SPOT 4 or 5: XS3, XS4, XS2, ASTER or IRS: 3, 4, 2);
- red, infrared, green (Landsat TM3, TM4, TM2, SPOT 1, 2, 3: XS2, XS3, XS1, QuickBird, Ikonos, KOMPSAT, Formosat: 3, 4, 2, ASTER, IRS: 2, 3, 1).

Using this 'universal', standard 'false colour" combination it is possible to detect coniferous and broadleaved forests of different percentage of damage, coniferous and broadleaf young tree growth, logging areas, bushes, marshes, peat bog, dwarf mountain pine, alpine vegetation, as well as agriculture, antropogenic, and hydrographic classes[39].
All these combinations can be employed as a source material for supervised monodate classifications.

Little spectral shift of acquired data can provoke inconveniences when two (or more) scenes from different satellites were used for data classification or index. In this situation, it is necessary to standardize the satellite data. For example, using SPOT and Landsat TM or ETM+ data it is possible to standardize the relevant channels, as follows:

[39] D. Dukaczewski, (2000) using SPOT and Landsat TM and ETM+ data was able to distinguish in Izerskie / Jizerské Mountains up to 6 stages of destruction of broadleaf forest, 11 stages of coniferous forest, 4 stages of destruction of dwarf mountain pine and 4 stages of young tree growth. The total number of detected land use classes was 107

$$D_i(HRV) = \frac{D_i(TM)}{a_i}$$

According to G. Guyot and X. F. Gu (1994) the mean coefficients of direct proportions between the green, red and near infrared SPOT HRV and Landsat TM (or ETM+) data are as follows:

Parameters	Spectral ranges		
	green	red	near infrared
Numerical values DC_i	0. 580	0. 844	1. 084
Satellite level reflectance ρ^*_i	1. 020	0. 942	1. 003
Earth level reflectance ρ_i	1. 135	0. 939	1. 034

Tab. 4 The mean coefficients of direct proportions between the green, red, near infrared SPOT and Landsat TM or ETM+ data

According to values of coefficients, the TM (or ETM+) sensors are less sensible in green and red range of spectrum, than SPOT HRV, while in the case of near infrared range the sensivity is comparable. This imply that the correct delimitation of coniferous forests is much difficult using TM2 and TM3 channels, than applying XS1 and XS2 SPOT channels.
Lack of compliance between the spectral ranges can be, paradoxically, an additional source of information. Combined usage of non-standardized HRV and TM (or ETM+) can be useful to detect the areas of exposed soil and sparsely vegetated area (G. Guyot and X. F. Gu, 1994).

The 'universal' standard false colours monodate composition, according to the satellite data providers rules, are data providers copywrigted product. The other monodate and multidate compositions are value added products.

It is worth to mention, that auxiliary source of materials for forest type and forest structure identification can be SAR data. Unlike the classification of optical data, the classification of data from SAR exploits differences in macro structure between stands of different species, age or density (K. J., Ranson, G., Sun, 1994; S. S., Saatchi, E., Rignot,1997; T., Castel et al., 2002)

Satellite data indexes, which are most frequently employed for forest type and forest structure identification are: Biomass Index, Normalized Difference Vegetation Index (NDVI), Green Vegetation Index (GVI), Age Vegetation Index (AST), Coniferous Trees Index (IPR).

The **Biomass Index** is a simple relation of near infrared to red channel:

$$VI = \frac{IR}{R}$$

This index is employed to detect the vegetation areas (and its changes in the case of multitemporal data). It can be used to produce the masks of vegetation areas or antropogenized areas for supervised classifications.

The **Normalized Difference Vegetation Index (NDVI)** was developed by to highline the diversity of vegetation as well as to facilitate it detection and monitoring (C.V. Tucker, 1977). This index is a relation of the difference between near infrared channel and red channel values and a sum near infrared channel and red channel values :

$$NDVI = \frac{IR - R}{IR + R}$$

where: $0 \leq NDVI \leq 1$

The NDVI values are comprised between +1 (for the areas of big presence of chlorophyll) till the close to 0 in the case of exposed soils. For better visualisation of NDVI it a good idea to stretch the contrast till 256 hues. It is also recommended introduce the numerical mask at level of $x \geq 35$, to eliminate the areas of water bodies. This index can be used like a auxiliary source material for preparation of supervised classification training areas. It can be also employed with multitemporal data for detection of vegetation dynamics (fig. 7)

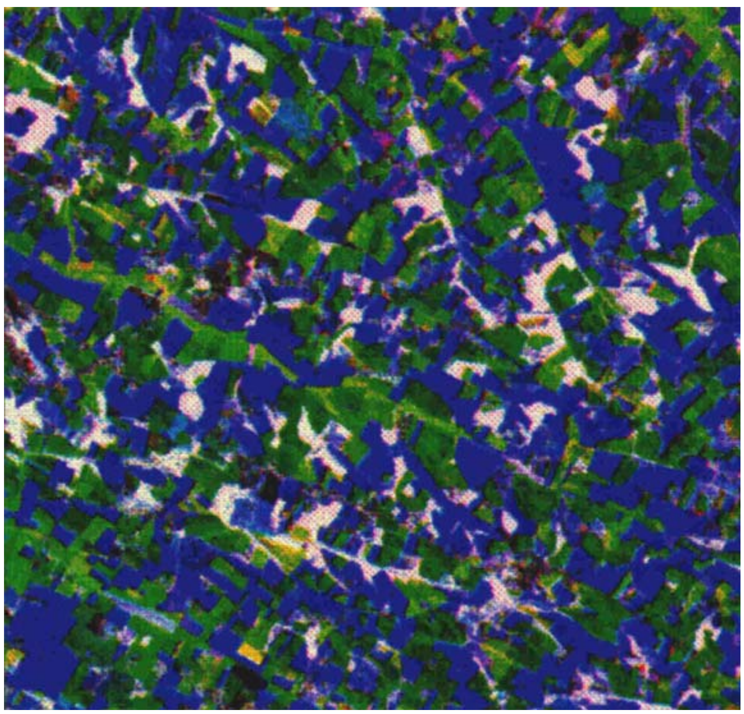

Fig. 7. Multitemporal NDVI (22.05.1986 blue, 22.07.1986 green, 23.09.1986, red), Loragais region (D. Dukaczewski et al., 1993)

The **NDVI modified index** – used for detection of coniferous forests (Nemani et al., 1993):

$$NDVI_c = \frac{SWIR1 - R}{SWIR1 + R}\left(1 - \frac{NIR - NIR_{min}}{NIR_{max} - NIR_{min}}\right)$$

The **Advanced Vegetation Index -** used for highlight differences in canopy density:

$$AVI = [(IR + 1)(256 - R)(IR - R)]^{\frac{1}{3}}$$

AVI = 0, if IR < R

The **Green Vegetation Index – GVI** is employed to estimate the age of the vegetation (J.A. Howard, 1991; K. Chiao, 1991).

$$GVI = - 0.29 \text{ (green)} - 0.56\text{(red)} + 0.60 \text{ (near infrared)} + 0.49 \text{ (SWIR 1)}$$

The **Age Vegetation Index - AST** (B.Lienard, 1986) is a modified version of NDVI. It exist two versions of this index:

for broadleaf vegetation:

$$AST_b = \frac{IR - R}{IR + R} \text{ x } 100$$

and for coniferous vegetation:

$$AS_C = IR - R$$

The **Coniferous Trees Inde**x - IPR (ibid.) has a form of equation:

$$IPR = \frac{IR - SWIR\ 1}{IR + SWIR1}$$

Satellite data indexes can be used like source material for a auxiliary source materials for preparation of supervised classification training areas or like a thematic layers for GIS analyses.
The level of detailness of these indexes is depending on the spatial resolution of satellite data. In the case of medium and low resolution satellites the received information concerns the clusters of forest areas. In the case of high resolution data it corresponds to the groups of trees and bushes, while in the case of very high resolution data the level it corresponds to individual trees and bushes.
The standard versions of these indexes, according to the satellite data providers rules, are standard value added products. The other multidate or modified versions of indexes are author value added products.

The goal of **Principal Component Analysis -** PCA is extraction of synthesis of information from many channels without risk of considerable loss. This method consists in calculation of new axis of data, taking into the consideration the correlations between the channels and facilitating of diversification of dominates types of information. The general principal Component Analysis formule is:

$$\lambda(u,v)\ A(m, n,; u, v) = \sum_{m=0}^{N-1}\sum_{n=0}^{N-1} K(m, n; m_l n_l) A(m_l, n_l; u, v)$$

The Principal Component Analysis can be carried out using the monodate or multidate data. The second solution can be very useful for detection of land use changes (S. Rimbert. 1985), especially in urban and suburban zones (D. Dukaczewski, et al., 1993) (fig. 8). In the case of forest land use changes this solution seems to be more 'fragile', due to the risk of over-generalisation (fig.9).

The Principal Component Analysis can be used like source material for a auxiliary source materials for preparation of supervised classification training areas or lake a material for object classification.

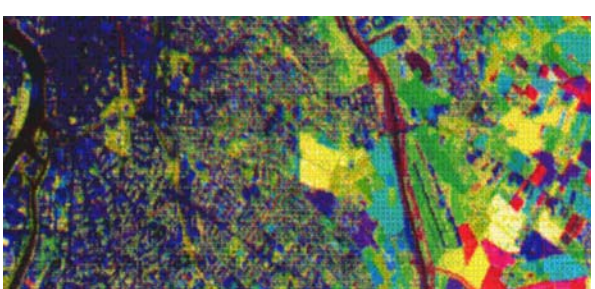

Fig. 8. The multitemporal Principal Component Analysis of Toulouse region (1990 – 1993) versus multitemporal supervised classification (1990 – 1993) (D. Dukaczewski, M. del Rosario Sepúlveda Guillén, J. ,Li, 1993)

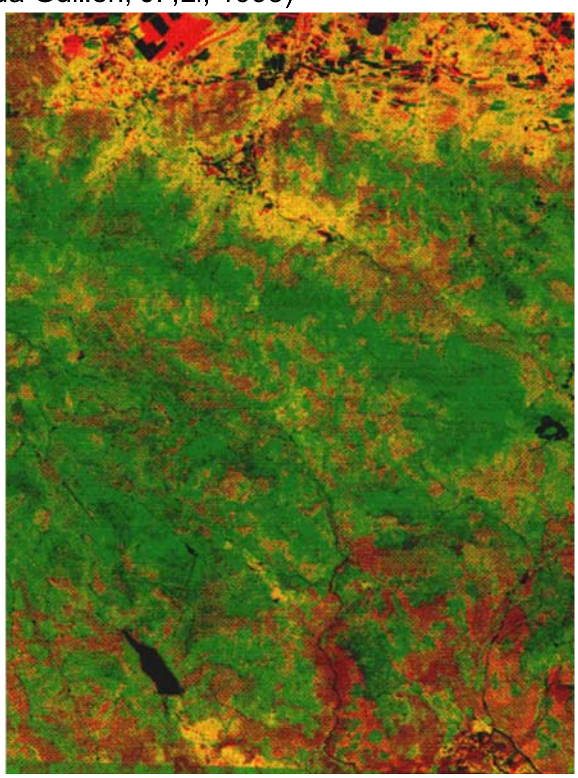

Fig. 9. The multitemporal Principal Component Analysis of Izerskie Mountains (1986 – 1990; red – PCA neochannel 2 1986, green – PCA neochannel 2 1990 (D. Dukaczewski, 1994)

Analysing the spectral responses of the forests in selected channels, neochannels and its numerical values (tab. 5, tab. 6), RGB channels monodate or multidate combinations it is possible to create the training areas for supervised monodate or multidate satellite data classifications. Its results are forest type and forest structure identification raster maps of resolution (and level of detailness) similar to spatial resolution of used satellite data and related statistics. There are no problems with identification of broadleaved and coniferous forests, impaired forests, dying forests, deforestations, burnt areas, logging areas, alpine vegetation. In many cases it is also possible to identify the forest species, even in the case of less resolution data (e.g. beech, poplar, oak, pine). The young forest growth can be sometimes confused with broadleaved forests and dwarf mountain pine – with young coniferous forests. It is difficult to classify automatically the peat bogs and swamps. The dying coniferous forest can be confused with dead coniferous forest, broadleaf forest with impaired broadleaf forest (10 %), meadows with mountain meadows. It is very difficult to get the information about the forest age class. This kind of information can be deducted indirectly, using information about the density of tree canopy.

In the case of very high resolution data (QuickBird, Ikonos, KOMPSAT-2, future WorldView-2) the classified information can concern each tree and bush. The cluster (point) cuts (more frequent during last decade in Poland) can be better classified. Recently it is possible to identify and to classify forest species (Tomppo, E., 1991; J. A. N. Van Aardt, R.H. Wynne, 2001; F. Kayitakire, C. Fancy, P. Defourny, 2002; J. Zawadzki, C.J. Ciszewski, R.C. Lowe, M. Zasada, 2002) and their damage zones (K. Kozioł, P. Wężyk, 2005). However, it is also important to note, that high spatial resolution sometimes doesn't facilitate spectral-based classification (S.E. Franklin, et al., 2000). To avoid the data noise effect many searchers carry out thematic data aggregation before launching the classification process (D. Kristóf, et al., 2002, J. Vijnant, T. Steenberghen, 2004). In this situation good alternative seems to be to employs the object satellite data classification.

The accuracy with which forest types are mapped using remote sensing data can be also enhanced by using inter-annual multitemporal data. Classification of inter-annual multitemporal data sets exploit the temporal change in spectral response from different forest types as a result of phenological activity and enable this within a classification procedure (M.A. Spanner et al., 1990; B. Duchemin et al., 1999; J. R. Schriever, R. G. Congalton, 1995). The classification accuracy may also be increased through the use of contextual and ancilliary information, such as historical land use information (D. Dukaczewski, 2000; V. Brůna, K. Křováková, 2006).

Sometimes, if the spectral responses of classified entities (and related numerical values) are very similar (e. g. deforestation areas with presence of graminaceous formations and mountain meadows) or the classes are difficult to describe in the terms of homogenous spectral response (e.g. thinned canopy forest, shape differences between the old burnt zones and logging areas) it is necessary to carry out the visual on screen interpretation. This solution, which result is vector map was used succesfully in the case of many international projects (e.g. CORINE Land Cover level 3 1990 project, CLC 2000 project, CLC 2005 project, CORINE Land Cover level 4 1995 Czech Republic, Slovakia, Hungary and Poland pilot project), as well as in many national and regional projects.

In many cases, to carry out a detailed forest type and forest structure identification map it seems to be good idea to use the results of supervised classification like a one of the main source materials for specialised visual classification or object classification.

Class	SPOT channels and neochannels numerical values				
	XS1	XS2	XS3	PCA 1	PCA 2
Cultivation area	86 - 109	20 - 24	37 - 41	200 - 210	255
Exposed soils	57 - 63	51 - 60	58 - 72	238 - 255	0 - 49
Meadows	72 - 112	20 - 25	35 - 38	158 - 168	255
Mountain meadow	57 - 66	26 - 28	39 - 40	155 - 168	254 - 255
Pastures	53 - 60	39 - 40	47 - 48	150 - 159	160 - 168
Antropogenized area	42 - 61	30 - 36	44 - 50	248 - 255	0 - 32
Young forest growth	48 - 51	21 - 25	34 - 36	116 - 123	175 - 183
Broadleaf forest	47 - 54	20 - 21	34 - 35	118 - 127	166 - 193
Impaired broadleaf forest (10 %)	38 - 41	20 - 21	31 - 33	105 - 112	144 - 158
Impaired coniferous forest (10 %)	39 - 44	16 - 17	26 - 27	89 - 100	139 - 151
Impaired coniferous forest (10 - 50 %)	31 - 34	17 - 18	27 - 28	76 - 85	121 - 139
Dying coniferous forest	31 - 35	20 - 21	31 - 32	88 - 96	81 - 87
Dead coniferous forest	24 - 31	20 - 21	30 - 32	86 - 90	79 - 85
Coniferous trees remains	29 - 34	25 - 27	34 - 36	97 - 107	79 - 82
Total deforestations of coniferous forests with presence of graminaceous formations	37 - 41	29 - 31	38 - 40	141 - 155	99 - 101
Total deforestations of coniferous forests with presence of trees remains	45 - 49	34 - 35	43 - 44	131 - 144	88 - 87
Total deforestations of young forest growth	54 - 61	42 - 43	45 - 49	218 - 227	152 - 169
Peat bog	58 - 67	38 - 41	45 - 50	190 - 196	110 - 116
Water	12 - 26	13 - 22	26 - 35	49 - 51	69 - 73

Tab. 5 SPOT channels and neochannels numerical values example. Izerskie Mountains (D. Dukaczewski 2000)

Class	Landsat TM channels and neochannels numerical values									
	TM1	TM2	TM3	TM4	TM5	TM6	TM7	PCA 1	PCA 2	PCA 3
Cultivation area	84-86	37-40	45-49	68-75	89-97	141-142	48-59	254-255	48-74	46-105
Exposed soils	76-78	33-35	40-42	47-49	88-97	143-144	45-47	246-252	9-33	4-29
Meadows	71-74	27-28	25-26	94 - 103	66-70	130-132	18-20	184-190	200-233	255
Mountain meadow	63-65	25-27	24-26	60-69	70-81	140-141	23-30	171-191	179-236	152-172
Pastures	69-72	26-31	28-30	66-72	76-82	138-142	27-30	177-190	106-138	157-180
Antropogenized area	85-90	48-53	46-53	31-49	78-54	144-145	54-63	204-255	0-4	2-65
Young forest growth	61-64	22-24	18-20	48-52	35-37	130-132	9-11	107-109	90-114	173-185
Broadleaf forest	65-67	24-26	20-22	33-40	34-39	132-134	11-17	113-120	91-111	167-196
Impaired coniferous forest (10 %)	59-62	21-23	19-21	39-44	23-27	130-132	7-9	97-107	78-88	146-168
Impaired coniferous forest (10 - 50 %)	54-57	17-19	15-18	37-39	17-20	127-129	5-7	47-54	98-112	112-129
Dying coniferous forest	58-60	24-25	18-20	33-35	25-27	123-126	10-12	107-120	80-93	152-161
Dead coniferous forest	56-58	20-22	17-20	38-44	45-50	127-129	16-20	86-91	61-77	117-132
Coniferous trees remains	53-56	20-21	19-20	40-43	42-46	126-128	15-17	104-110	135-160	77-96
Total deforestations of coniferous forests with presence of graminaceous formations	57-60	23-25	21-25	66-70	62-68	133	22-40	142-153	196-207	112-152
Total deforestations of coniferous forests with presence of trees remains	58-60	24-25	21-23	58-62	59-60	131-133	20-40	128-139	167-180	108-135
Total deforestations of young forest growth	59-63	24-26	27-29	65-68	71-74	136-137	23-27	159-170	196-219	125-149
Water	60-62	19-20	15-17	11-13	3-6	116-118	0-4	49-54	0-14	107-114

Tab. 6 Landsat TM channels and neochannels numerical values example. Izerskie Mountains (D. Dukaczewski 2000)

1.2.2. FOREST SANITARY STAND AND CONDITION

The sanitary stand and health condition is a function of an harmony of trees species with environment, especially soil conditions, water regime, air pollutants, biotic and antropogenic agents. The satellite remote sensing can provide relatively rich and standardized information about forest sanitary stand itself, as well as about a big part of factors which can influence it.

1.2.2.1. FOREST SANITARY STAND

Forest sanitary stand and health condition information can be acquired using spectral information available in the satellite channels data combinations and indexes. These data, together with results of terrain verifications, thematic surveys (available even for the part of classified area) can be used like a main source material for satellite data classification.

The channel – by channel acquisition of forest sanitary stand information seems to be difficult (tab. 5, tab. 6). Better idea is to employ the channels data combinations.
The coniferous impaired forests extent can be delineated with big precision using RGB combination of:

- near infrared, first SWIR, red spectrum channels (Landsat: TM4, TM5, TM3, SPOT 4 or 5: XS3, XS4, XS2, ASTER or IRS: 3, 4, 2).

The broadleaf impaired forests and young tree growth spatial extent can be detected and delineated using RGB combination of:

- first SWIR, near infrared, red spectrum channels (Landsat: TM5, TM4, TM3, SPOT 4 or 5: XS4, XS3, XS2, ASTER or IRS: 4, 3, 2).

New logging zones are very well visible at RGB combination of:

- red, green, infrared spectrum channels (Landsat: TM3, TM2, TM4, SPOT: XS2, XS1, XS3, QuickBird, Ikonos, KOMPSAT, IRS, Formosat, ASTER: 3, 2, 4).

The deforestation areas can be surveyed using the combination of:

- red, near infrared and first SWIR channel (Landsat:TM3, TM4, TM5, SPOT 4, SPOT 5: XS2, XS3, XS4, IRS: 2, 3, 4);

The young forest growth are detectable using the combination of:

- green, red, near infrared channel (Landsat: TM2, TM3, TM4, SPOT 1, 2, 3, 4, 5: XS1, XS2, XS3, IRS, ASTER, ALOS: 1, 2, 3, QuickBird, Ikonos, KOMPSAT, Formosat, ALOS: 2, 3, 4);
- red, near infrared and 1 SWIR channel (Landsat:TM3, TM4, TM5, SPOT 4, SPOT 5: XS2, XS3, XS4, IRS, ASTER: 2, 3, 4);
- red, near infrared and 2 SWIR channel (Landsat:TM3, TM4, TM7, ASTER: 2, 3, 7);

The spatial extent of exposed soils can be surveyed using:

- red, 1 SWIR 2 SWIR, channel (Landsat:TM3, TM5, TM7, ASTER: 2, 4, 7).

It is also possible to use the combinations of satellite channels for forest changes detection. In the case of detection of coniferous forest sanitary stand changes it is possible to use a couple of near infrared channels (of different dates) and first SWIR channel of first date (T2 IR, T2 SWIR1, T1 IR) (fig. 10) or a couple of first SWIR channel data (of different dates) and a near infrared channel of first date (T2 SWIR1, T2 IR, T1 SWIR1).

Fig. 10. Detection of coniferous forest sanitary stand changes (1990 IR, 1990 SWIR1, 1986 IR), Izerskie Mountains (D. Dukaczewski, 1994)

The broadleaf forest sanitary stand changes can be detected with a RGB combinations of: first SWIR and a couple of infrared channels of both dates (T2 SWIR, T1 IR, T2IR) (fig. 11).
To detect new logging areas and new deforestations it is possible to employ two green channels (of different dates) and red channel of first date (T2 G, T2 R, T1 G)
or a couple of red channel data and green channel data of first date (T1 R, T2 R, T1 G).
For detection of meadows, pastures and alpine vegetation changes it is possible to use a couple of red channels and one green channel of first date (T2 R, T1 R, T2 G). (fig 12).

Fig. 11. Detection of broadleaf forest sanitary stand changes (1990 SWIR, 1886 IR, 1990IR), Izerskie Mountains (D. Dukaczewski, 1994)

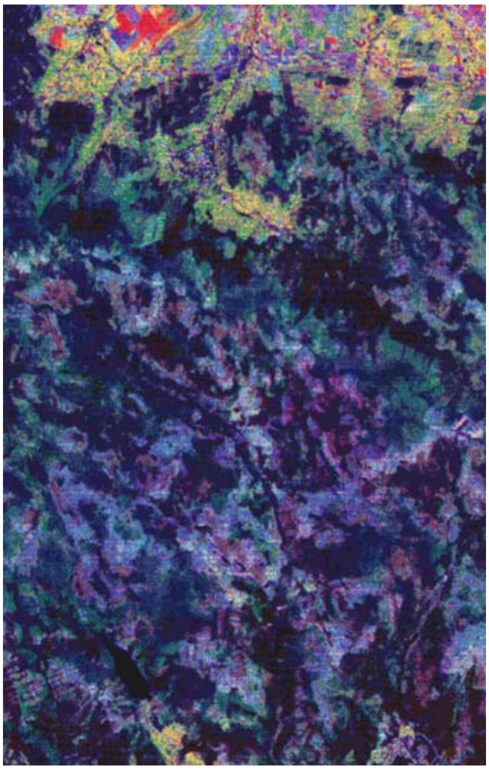

Fig. 12. Detection of detection of meadows and pastures vegetation changes (1990 R, 1986 R,1990 G), Izerskie Mountains (D. Dukaczewski, 1994)

Forest sanitary stand and health condition information can be also acquired using spectral information available in the satellite 'false colour' combination:

- near infrared, first SWIR, red spectrum channels (Landsat: TM4, TM5, TM3, SPOT 4 or 5: XS3, XS4, XS2, ASTER or IRS: 3, 4, 2);
- red, infrared, green (Landsat TM3, TM4, TM2, SPOT 1, 2, 3: XS2, XS3, XS1, QuickBird, Ikonos, KOMPSAT, Formosat: 3, 4, 2, ASTER, IRS: 2, 3, 1).

All these combinations can be employed as a source material for training areas of supervised multidate classifications.

It is possible to acquire information about the forest sanitary stand and health condition using index of destruction.

Index of destruction WU is a quotient of first SWIR and IR channel:

$$WU = \frac{SWIR1}{IR}$$

This index was elaborated for spruces stands. However, research have reveal that it can be employed also in the case of other coniferous species. This index can provide information about the water deficit in needles.

The forest sanitary stand may be also described by some others satellite data indexes, like Biomass Index, Normalized Difference Vegetation Index (NDVI), Green Vegetation Index (GVI), Age Vegetation Index (AST). All these indexes can be used like a source material for preparation of training areas of supervised mono- or multidate classifications, material for object classifications or like a thematic layers for GIS analyses.

It is also possible to distinguish the age of the forest stand, using Canopy Shadow Index:

$$SI = \sqrt[3]{(256 - B)(256 - V)(256 - R)}$$

where:

B – blue channel reflectance,
V – green channel reflectance,
R – red channel reflectance.

The crown arrangement in the forest stand leads to shadow pattern affecting the spectral responses. The young even aged stands have low canopy shadow index, compared to the mature natural forest stand (M. Saei Jamalabad, and A. A. Abkar, 2004).

P.N. Churchill and N. A. Keech (1984) have revealed, that SAR C and X bands can be used for delimitation of the zones of impaired forests. According to Way et al. (1990) X band SAR data can provide information about the slight frost, hoar frost and destructions of trees by a cap of snow, as well as canopy melting snow. This kind of data can be used for big area, homogenous forest monitoring.

The key variable, which could describe the forest sanitary stand could be LAI. This variable is required to drive forest simulation models (F.M. Danson, S.E. Plummer, 1995). LAI was earlier estimated for agricultural crops (P. J. Curran, 1983). The considerable effort has been expended in developing remote sensing techniques to map this variable (S.W. Running et al., 1989; T. Zawiła – Niedźwiecki et al., 1993; J. Liu et al., 1997; R. H. Waring, S. Running, 1998; N. S. Lucas et al., 2000, T. Manninen et al., 2005, M. Kalacska et al., 2005). Recent research has sought to increase the accuracy of estimation of forest LAI, using optical remote sensing data, in two ways. The first is related to employment of the SWIR data. The team of R. Nemani (1993) found that incorporating a Landsat TM first SWIR waveband with red and infrared normalized the effect of variable canopy cover on the relationship with LAI. Then, the research of team of D.S. Boyd (1999) revealed that correcting the SWIR data of NOAA / AVHRR for thermal emission to derive SWIR reflectance, increased the strength of the relationship between radiation acquired in SWIR and total forest biomass, over that obtained using the NDVI. The use of **SWIR reflectance**, alone or within the **VI3 vegetation index**:

$$VI3 = \frac{NIR - SWIR}{NIR + SWIR}$$

proved the strongest relationship with total forest biomass.
Using this solution it was possible to estimate of the LAI of the boreal forest of Canada (D. Boyd, T.E. Wicks, P.J. Curran, 2000).
The second way to increase the estimation of forest LAI has focused on hyperspectral data. The calculation of first or second derivatives of the canopy may suppress the effects of variation in understorey reflectance and allow more accurate estimation of LAI (P. Gong, R. Pu, R.J. Miller, 1992). Correlation between the red-edge position (around 720 nm) and forest LAI are stronger than those with single wavebands (F.M. Danson, S.E. Plummer, 1995). Application of this solution have become wholly possible with launch of Terra satellite with MERIS, MODIS instruments.

Many research reveal positive relationships between SAR data and forest above-ground biomass (e.g. T. Le Toan, T.A. Beaudoin, J. Riom, D. Guyon, 1992; J. R. Baker et al., 1994). According to K.J. Ranson et al., (1997) the SIR C band data can be employed to map above-ground woody biomass of boreal forests. However, the use of SAR C band data is limited to differentiate between very low biomass (e.g. of clear cut) and forests, in dry weather condition (C. F. C. da Yanasse et al., 1997). Better solution is to use L band SAR data of HV and HH polarization.

Recently project on carbon balance in tree species, using NOAA, Terra – ASTER, QuickBird and Ikonos data, is carried (M. Chirrek, P. Strzeliński, A. Wencel, T. Zawiła-Niedźwiecki, M. Zasada, A. Jagodziński, 2007).

Other key problem is application of remote sensing for determination of the relationships between forest canopy biochemicals and rates and patterns of biochemical cycling. The foliar nitrogen content of forest vegetation in conjunction with LAI is closely related to photosynthetic capacity and nitrogen uptake (H. L. Gholz, 1982). The ratio of leaf lignin to leaf nitrogen is related to rates of litter decomposition. Its measurement, which is a key step toward mapping the spatial characteristics of forest nutrient cycles, became possible with the new generation of hyperspectral field spectroradiometers and spectrometers. With recent development of acquisition of hyperspectral data by MERIS and MODIS instruments of Terra satellite, the remote sensing have became the most effective technique for estimating forest biochemical information.

1.2.2.2. SOIL CONDITIONS

However studies on forest soil conditions have important meaning for general inventory of Carpathians forests the remote sensing passive techniques can provide the appropriate data only for exposed soils. The information about soil conditions can be deducted indirectly, by modelling. In this case the remote sensing data can be used like a main source material for creation of very precise Digital Terrain Models (DTM) and Digital Elevation Models (DEM). It can be used also for creation or updating of detailed geomorphological maps (e.g. V. Loghin, 2005, E. Wołk-Musiał, B. Zagajewski, 2000).

In the case of exposed or partial exposed soils it is possible to calculate soils indexes:

Index of brightness IB[40] , which allow to detect the level of exposition of soils, and to distinguish between dry and humid soils. This index have a strong, direct correlation with erosion risk zones and landslides zones (high values), and opposite correlation with deposition areas (low values). The Index of brightness has a form:

$$IB = \sqrt{(B^2 + V^2} + R^2)$$

where:

B – blue channel reflectance,
V – green channel reflectance,
R – red channel reflectance.

Index of Porosity – IP[41] of soils has a form:

$$IP = (R^2 + IR^2)^{\frac{1}{2}}$$

where:

R – red channel reflectance,
IR – near infrared channel reflectance.

Bare Soil Index - BI:

$$BIO = \frac{(SWIR1 + R) - (IR + B)}{(SWIR1 + R) + (IR + B)}$$

BI = BIO * 100 + 100

[40] French:l' Indice de Brillance
[41] French l' Indice de Rugosité

Redness Index - RI[42] (R. Escadafal, M. Pouget, 1987), which has a form:

$$RI = \frac{R - V}{R + V}$$

where:

V – green channel reflectance,
R – red channel reflectance.

Coloratrion Index - IC[43] (ibid.), of form:

$$IC = \frac{R - B}{R}$$

where:

R – red channel reflectance,
B – blue channel reflectance.

Index of Form (R. Escadafal, 1994):

$$IF_{VIS} = \frac{2R - V - B}{V - B}$$

where:

R – red channel reflectance,
B – blue channel reflectance,
V – green channel reflectance.

Redness Index, Coloration Index and Index of Form are used to describe the type of mineral soil composition. They are also employed to detect the soil degradation (corresponding to changes of its structure) in multi-year studies.

Soil Adjusted Vegetation Index - SAVI (A. R. Huete, 1988) has a form:

$$SAVI = [\frac{IR - R}{IR + R + L}](1 + L)$$

where:

R – red channel reflectance,
IR – near infrared channel reflectance,
L – brightness reduction constant (0 for exposed soils, 0.5 for intermediary vegetation coverage, 0.25 for dense vegetation).

This index is used to calculate LAI for partially vegetated soils.

Transformed Soil Adjusted Vegetation Index – TSAVI (F. Baret et al., 1989):

$$TSAVI = a\frac{(IR - aR - b)}{(R + aIR - ab)}$$

where:

R – red channel reflectance,
IR – near infrared channel reflectance,
a, b – exposed soils vector coefficients

[42] French l' Indice de Rougeur
[43] French l' Indice de Coloration

This index is used to calculate LAI for partially vegetated soils.
All these indexes can be used like a source material for supervised classifications, or like a thematic layers for GIS analyses. Very interesting tool for soil degradation is object classification, which can employ the same time spectral and textural parameters (T. Schmid, M. Koch, J. Gumuzzio, 2000)

According to A. Chanzy (1994), the SAR C band HH polarization data of low incidence (7° – 17°) can be used for estimation of soil humidity. This kind of information could be used like a source material for creation of thematic layers for GIS analyses and soil monitoring. Using SAR data, it is also possible to elaborate differential interferogram, which can be employed for detection and surveying of Carpathians landslides.

Remote sensing can provide also information about presence of minerals in soils. Ratio of red an blue channel reflectance can allow information about the concentration of the iron oxide. First and second SWIR ratio can bring information about the presence of clay formations.

In the case of soils covered by vegetation, remote sensing can provide detailed information about the type and species of vegetation, which can be used in soil modelling.

1.2.2.3. WATER REGIME

In the case of research on water regime, the contribution of remote sensing concerns the static and dynamic environmental conditions, the water itself, and its relations. The spectral (or spectral and textural) analysis can provide a detailed information about land use, forest type, species and state of health of vegetation, as well as DTM / DEM and soil information of the area of hydrological basin. Civil remote sensing can also be a source of detailed and up-to-date information about the water bodies (till 0.61 m), soil humidity and soil moisture and detailed weather conditions / weather forecast.

Part of the satellites, which acquired the blue range channel data (Landsat, QuickBird, Ikonos, KOMPSAT, Formosat can provide detailed data on inland water quality.

The NOAA sensors data can be used for snow monitoring, weather conditions (and forecast of snowfall, rainfall, risk of flood). The NOAA AVHRR data are employed for detailed real evapotranspiration survey (K. Dąbrowska – Zielińska, 1989; B. Seguin, D. Courault, M. Guérif, 1994; A. Vidal, 1989), which can be used for agricultural grain production operational forecast (K. Dąbrowska – Zielińska, 1994).

The ERS C band data can be used for survey of exposed soil moisture (K. Dąbrowska – Zielińska, et al. 1994). Using backscatering coefficients σ° from ERS SAR C band (VV polarization) data, LAI coefficient (from optical satellite data) ıt is also possible to survey the soil moisture under the vegetation (M. Gruszczyńska, K. Dąbrowska –Zielińska, 2004). The ERS C band data of VV polarization can be also used for mapping the flooded area extent, even in very poor weather condition (e.g. application for the survey of Odra river flood in 1997).

Using the ratio of first and second SWIR, ratio of red and blue channel reflectance or ratio of near infrared and red channel reflectance it is possible to detect the presence of hydrothermal sources.

1.2.2.4. AIR POLLUTANTS

The remote sensing satellite data are used for detailed meteorological analysis and forecasts. Meteosat satellite is acquiring data on albedo (0.4 – 1.1 µm), surface temperatures (10.5 – 12.5 µm), steam (5.8 – 7.3 µm). The information about the temperatures is also acquired by NOAA – AVHRR – 3 instrument (channel 4: 10.3 – 11.3 µm and 5 11.5 – 12.5 µm). These data are used for precipitation and temperature forecast. Other channels data can be used for detection of fog (channel 3 of NOAA – AVHRR) and winds. The spatial resolution of these data is relatively small (1 km).

The TOVS (Tiros Operational Vertical Sounder) working on board of NOAA satellite provides data for Earth's atmosphere temperature profile with 2 K precision. The TOVS and Meteosat ATOVS instrument provides data concerning the presence of rare and pollutant gases:

$$NO, NO_2, N_2O, CO, CO_2, CH_4, HNO_3, SO_2$$

A part of them is detected indirectly, during process of atmospheric corrections (N.T. O'Neil et al., 1991).

The optical remote sensing satellites provides some data, which can be used for air pollutants modelling. The winter scenes can be used for detection of dust deposition at the agriculture field areas. Some scenes can include the jets or clouds of industrial steam. Unfortunately, it is not possible to detect the presence of pollutant gases.

The Landsat, TM / ETM+, ASTER and MODIS instruments can provide information about the underground coal fires. The TES algorithm, developed by the ASTER team, can extract temperature and emissivity (A.R. Gillespie, et al., 1999), using multispectral thermal data. The RCM (Reference Channel Method) and NEM (Normalized Emissivity Method) can be used along with ASTER thermal data to extract the thermal anomalies due to the coalfires and to calculate the CO_2 concentration (P. Gangopadhyay, F. van der Meer, P. van Dijk, 2005).

1.2.2.5. BIOTIC AGENTS

One of the reason of the forest damages are biotic agents (insect pests, phytopathogenic microorganisms, wild animals). The scale of these damages is depending on the forests resistance on biotic, abiotic and antropogenic hazards. According to PIOŚ (1994), during 1970 – 1992 period, in Polish forests was possible to identify about 50 species of dangerous insect and 25 phytopathogenic microorganisms.

According to E. Wiśniewska, T. Zawiła Niedźwiecki (2004) the strongest correlation between the data of forest defoliation reports concerning i**nsect pests** and satellite data can be find in the case of near infrared, first SWIR and second SWIR satellite data (available only in the case of Landsat TM / ETM+ and ASTER data), as well as in the case of Index of destruction WU:

$$WU = \frac{SWIR1}{IR}$$

1.2.2.6. ANTROPOGENIC FACTORS

The most significant antropogenic factors are ground level air pollution, constructions, fires, and illegal logging.

In the case of the first factor the potential applications of remote sensing data are analogical, like described in the chapter 1.2.2.4.

The impact of constructions (the build up areas, industrial areas, commercial areas, airports, ports, railways, road network and associated areas) and it dynamics can be estimated using multitemporal satellite data, channels combination, indexes and neochannels employed for forest type and forest structure identification, as well as forest sanitary stand and condition. These data can allow to carry out on-screen visual interpretations or supervised pixel classifications. Due to the similarity of spectral response of antropogenic objects exposed soils and rocks, it seems to be a good idea to carry out object classification, including shape and size parameters.

The main method to detect forest fire and survey it range is to use the NDVI index (D. R. Cahoon, B. J. Stocks, J. S. Levine, W. R. Cofer, C. C. Chung, 1992; Z. Li., S. Nadon, J. Cihlar, B. Stocks, 2000) This index can be calculated using data of: QuickBird, Ikonos, KOMPSAT-2, IRS, Formosat, SPOT, Landsat, JERS, ALOS, ASTER, MODIS, Sich-1M and Envisat. The fastest solution to access to the information about the fire extent is to visit the http:/rapidfire.sci.gsfc.nasa.gov, site, where the MODIS images (in degraded format) are available in a few hours after the beginning of fire (A. Röder, S. Bärisch, J. Hill, B. Duguy, J.A. Alloza, R. Vallejo, 2005; A. Hościło, 2005), or to use the NOAA AVHRR data (E.S. Kasischke et al, 1993; IGBP, 1997; .M. Barbosa et al. 1999). It is worth to mention, that A.J. Elmore et al. (2000) have demonstrated limitations of using NDVI in semi-arid areas, and suggested to employ Spectral Mixture Analysis.

1.2.3. WOOD SUPPLY CONTROL

The Carpatian Mountains Countries have a long tradition of wood supply information systems. However, these systems are based on reports. To verify and to update the wood supply information, as well as to detect rapidly the problem zones and areas of illegal logging it is possible to use available vegetation indexes:

- Biomass Index,
- Normalized Difference Vegetation Index (NDVI),
- Green Vegetation Index (GVI),
- Age Vegetation Index (AST),
- Coniferous Trees Index (IPR),

as well as RGB channels combinations of:

- New logging zones (red, green, infrared spectrum channels);
- The deforestation areas (red, near infrared and first SWIR channel);
- The young forest growth (green, red, near infrared channel, or red, near infrared and 1 SWIR channel, or red, near infrared and 2 SWIR channe);
- The spatial extent of exposed soils (red, 1 SWIR 2 SWIR, channel).

It is also possible to acquire information on forest sanitary stand and health condition with index of destruction

VI3 vegetation index:

$$VI3 = \frac{NIR - SWIR}{NIR + SWIR}$$

which can be used for estimation of the LAI.
Using the SAR C band data it is possible to detect the clear cut, independently of weather conditions.

1.2.4. FOREST MANAGEMENT AND FOREST MONITORING

The satellite data and products can be used like a main, auxiliary and supplementary material for updating, control and extension of information used in forest management, forest inventory and forest protection area monitoring.

In the case of forest management, using QuickBird data it is possible to update and control databases and 1: 2 000 and 1: 5 000 scale maps of basic forest divisions (compartiments, partial slots, parts of stands and storeys). Using available indexes, results of visual, authomatic (pixel or either object) classification it is possible to acquire the information about of type of the forest, it sanitary and health stand, tree species. Using QuickBird, Ikonos or KOMPSAT-2 data it is possible to update and control databases and maps of level of detailness, corresponding to 1: 10 000 scale. With available indexes, colour combinations and classifications it is possible to have a information on three species, it sanitary stand, as well as networks of roads, railways, footpaths (including information about its surface, width and related infrastructure). Using SPOT 5 data it is possible to control, update or extend the 1: 25 000 scale maps or databases. In this case it is possible to calculate Biomass Index, Normalized Difference Vegetation Index (NDVI), Green Vegetation Index (GVI), Age Vegetation Index (AST), Coniferous Trees Index (IPR) and to estimate LAI values. These data allow user to acquire the information about of type of the forest, it sanitary and health stand, networks of roads, and railways, selected human and wild animal footpaths. Almost the same information can be generated with ALOS and Formosat data. Using Landsat and Aster data it is possible to generate 1: 100 000 scale maps of types of the forest, its sanitary and health state, including information about roads and selected footpaths. In the case of these data it is possible to calculate all indexes, to estimate LAI, as well as to create maps of fire risk categorization. In all cases it is possible to generate the statistics automatically.

In the case of forest inventory all multispectral satellite data can provide information about the forest area, forest type, forest structure, forest damage, damage risk, forest regeneration, forest road network, watercourses. Only in the case of ASTER and Landsat data it is possible to acquire information about the forest production and fire risk categorization. Information about site condition, ecological stability is available only in the case of SPOT, ASTER and Landsat data. Information about the tree species can be generated only with QuickBird, Ikonos and KOMPSAT data. These satellites can provide also full information about the watercourses, forest road network and all related infrastructure.

In the case of monitoring all multispectral satellite data can provide up-to-date, standardized information on forest range and type, forest structure, forest damage, forest damage risk, deforestation types, clear cuts and point cuts as well as burnt areas. It is possible to acquire momentary information on forest fires and floods. All satellite data can bring us information about the extent of marshes, soil erosion, landslide. In the case of QuickBird, Ikonos, SPOT and KOMPSAT-2 satellites it is possible to acquire stereo scenes, which can be used to generate DTM or DEM. Only in case of Landsat, ASTER and NOAA it is possible to generate information about the evapotranspiration and soil humidity. In the case of QuickBird, Ikonos and KOMPSAT-2 it is possible to classify the full spectral information concerning bushes. Data acquired by these satellites can be also used for detailed monitoring of natural succession.

In the case of forest protection area monitoring all satellites can provide data concerning type of plant cover, tree stand ranges, forest conditions, fire and blowdowns, water bodies, soil erosion, landslides, fires and floods.. It is also possible to detect areas of virgin and very old forests. The data acquired by QuickBird, Ikonos and KOMPSAT-2 can be used for verification of tree, bush and graminaceous protected stands (of limited or difficult access). All satellites data can be useful for identification of anthropogenic threats, related to the tourism (e.g. tourist facilities), local external threats (build-up area, transport network, agricultural areas) and supra-local threats (like industrial areas, damps, industrial plants and mines). All satellite data and data layers can be used like a source material for creation of models. Its advantage is standardization and repeativity.

2. INNOVATIVE APPLICATION OF GIS METHODS FOR GENERAL INVENTORY AND PROTECTION OF CARPATHIAN FORESTS

The first experiments on integration and application of remote sensing data (airborne spectral photos) in GIS were realized in the case of Canadian (National) Geographical Information System (S. R. Johnston, J.G., Roberts, 1971; R. Tomlinson, M.W., Calkins, D. F., Marble, 1977) and Swedish GISA - Geographic Based Information System for County Littera AB, of Stockholm region (O. Eklund, 1977) in the end of the 60-ties. The technological progress of the 70-ties and 80-ties allowed to introduce at the beginnings of the 80-ties the multispectral orthophotos into the GIS databases (e.g. into the SIUTE[44] system, GIS of Survey of Israel[45]).

One of the first application integrating the satellite data into the GIS was Canada's Electronic Atlas (E.M. Siekierska, S.Palko, 1986), experimental system of Pennsylvania State University (J. A. Howard, 1991), IBIS - Image Based Information System Jet Propulsion Laboratory, VGIS - Vermont State GIS. At the beginning of the 90-ties it become possible to create multitemporal GIS, integrating remote sensing products and remote sensing derivate products, used for generation of time-oriented layers of animation system (e.g. D. Dukaczewski, 1994, 2000).

Today the satellite products in form of neochannels, results of visual and automated (pixel and object) classifications and derivates layers are used in many GIS like reference material or source material for spatial analyses.

2.1. TOPOGRAPHIC AND THEMATIC DATABASES

All countries participating in the INTERREG III B CADSES Programme Carpathian Project dispose each own databases, which could be used like a source of data for General Inventory and Protection of Carpathian Forests. It is possible to distinguish few types of these databases:

1. Topographic databases ;
2. Thematic databases:
    - 2a. national parts of international databases ;
    - 2b. national thematic databases ;
    - 2c. regional thematic databases ;
    - 2d. local thematic databases ;
    - 2e departmental thematic databases ;
    - 2f. scientific thematic databases.

According to research, realised in spring of 2007, only five INTERREG III B CADSES countries disposed each own civil topographic databases (tab. 7). Four of them was databases of level of detailness, corresponding to the 1 : 10 000 topographic maps :

- Czech **ZABAGED** – Základní báze geografických dat - Fundamental Base of Geographic Data of Czech Office for Surveying, Mapping and Cadastre / Land Survey Office - Zeměměřický Úřad;
- Polish **TBD** – Topograficzna Baza Danych - Polish Topographic Database of Head Office of Geodesy and Cartography - Główny Urząd Geodezji i Kartografii;
- Hungarian **DTA_10** – Database of 1: 10 000 digital topographic maps of Hungarian Institute of Geodesy, Cartography and Remote Sensing (FÖMI – Földmérési és Távérzékelési Intérzet);

[44] E. Felletti, 1987
[45] R. Adler, 1987

* Slovak **ZB GIS** database of Geodesy, Cartography and Cadastre Authority of the Slovak Republic (Úrad geodézie, kartografie a katastra Slovenskej Republiky).

Scale	Country / *territory*																												
	Austria	Belgium	Croatia	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Spain	Netherland	Ireland	Island	Lithuania	Luxembourg	Latvia	Malta	Norway	Portugal	Poland	Slovenia	Slovakia	Switzerland	Sweden	Hungary	Great Britain	***Northern Ireland***	Italy
1: 500													(●)																
1: 1 000													(●)											●					
1: 1 250																											(○)	(○)	
1: 2 500													(●)														(○)	(○)	
1: 5 000			●										●			●		●	●			(●)							
1: 10 000		●		●	●	●	●	●	●			●			●					●	●		●		●	●	○	○	
1: 20 000						●	●									●													
1: 25 000			●		●						●											●		●					●
1: 50 000	●	●			●	●		●	●	●	●	●	●	●	●		●			●			●		●			●	●
1: 100 000							●	●									●								●	●			
1: 200 000	●										●				●														
1: 210 000																												●	
1: 250 000		●					●		●	●		●	●								●				●		●		●
1: 450 000													●																
1: 500 000	●							●		●	●									●	●								●

Tab. 7. Civil topographic databases in EU and other EEA countries and autonomic regions. (D. Dukaczewski, E. Bielecka, J. Bac-Bronowicz, 2007)

Each of these databases has each own specificity. The most extended thematically was Slovak ZB-GIS (11 level first class objects, 56 second class object, 154 level third class object, 218 attribute groups and 1306 attributes). Czech ZABAGED and Polish TBD was databases of average scope of thematic information.

In the case of Polish TBD, the number of forest related objects was 12[46], in Czech ZABAGED - 7[47], while in Slovak ZB-GIS – 17 (plus 10 attributes concerning tree species). The most rich forest information of all EU and EEA countries 1: 10 000 civil topographic databases contains Finnish Maastotietokanta (Topographic Database) of Maanmittauslaitos – National Land Survey of Finland (D. Dukaczewski, E. Bielecka, J. Bac-Bronowicz, 2007).

All countries INTERREG III B CADSES, except the Ukraine, have participate in CORINE Land Cover Project level 3. In these database (1990, 2000 and 2005) there are 5 forest classes[48]. Czech Republic, Slovakia, Poland and Hungary have participated in CORINE Land Cover level 4 experiment. In this case number of forest classes was 18[49].All these countries and Serbia (I.Nestorov, D. Protic, G. Nikolic, 2007) are vitally interested to complete this kind of database. Poland, Czech Republic, Slovakia and Ukraine was participate in MapBSR database project. The MapBSR database covers almost all territory of Poland and Baltic Sea Bassin part of Czech Republic, Slovakia and Ukraine.

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[46] forest, grove, other tree – covered area, bush, dwarf mountain pine, line of trees, tree, group of trees, hedge, line of bushes, group of bushes, group of dwarf mountain pine, forest section

[47] forest area with trees, forest area with bushes, forest area with dwarf mountain pine, tree, group of trees, hedge, line of trees

[48] broad - leaved forest, coniferous forests, mixed forest, moors and health land, transitional woodland - scrub

[49] 3.1.1.1. poplar plantations, 3.1.1.2.other broad - leaved forests with continous canopy, 3.1.1.3. other broad - leaved forests with discontinous canopy,3.1.2.1. coniferous forests with continous canopy, 3.1.2.2. coniferous forests with discontinous canopy, 3.1.3.1. mixed forests created by alternation by trees with continous canopy, 3.1.3.2. mixed forests created by alternation by trees with discontinous canopy, 3.1.3.3. mixed forests created by alternation by stands with continous canopy, 3.1.3.4. mixed forests created by alternation by stands with discontinous canopy, 3.2.1.1. natural grassland prevailingly without trees and shrubs, 3.2.1.2. natural grassland prevailingly with trees and shrubs, 3.2.2.1. heathlands and moorlands, 3.2.2.2. dwarf pine, 3.2.4.1. young stands after cutting and / or clear cut, 3.2.4.2. natural young stands, 3.2.4.3. bushy woodlands, 3.2.4.4. forest nurseries, 3.2.4.5. damaged forest,

All countries dispose each own departmental thematic databases. In Poland, Czech Republic, Slovakia, Austria and Hungary it exists well developed forest databases. In Czech Republic, this kind of data are available through Czech Mobile Forestry Geodata Infrastructure (J. Fryml, K. Charvat, A. Sida, 2002). In Bulgaria the works on national forest database was in 2006 at the stage of pilot projects (Assenova, M., Dobrichov, I., 2006). In Ukraine the forest database is in stage of project preparation.

To avoid the problem of lack of interoperability between all systems including the forest information in each country, it is at least necessary to elaborate the national systems of common identifiers. It is also necessary to have access to metadata about these databases. This problem will be resolved with accomplishment of INSPIRE directive recommendations.

One of the essential question of General Inventory and Protection of Carpathian Forests is elaboration of methodology of access to the up-to date, rich and standardized data, which could be a main, auxiliary and supplementary source material for updating, control, standardization and development of forest information. Such a data can be remote sensing data and derived GIS products.

2.2. POTENTIAL APPLICATIONS OF GIS METHODS

2.2.1. FOREST TYPE AND FOREST STRUCTURE IDENTIFICATION

As it was demonstrated above, using multispectral satellite data it is possible to identify with big precision forest type and forest structure. With the advent of the very high resolution satellite data, it became also possible to identify the tree species, their damage zones and to calculate their coefficients of density (K. Kozioł, P. Wężyk, 2005). In this case the satellite data are the main and auxiliary source material. Using the low resolution data it is also possible to create the model of forest spatial distribution, carrying out the object classification of satellite data (K. Ostapowicz, 2005) and object analysis of results of such classification and GIS layers data.

In the case of retrospective forest land use analysis it is necessary to elaborate also the archival airborne photographs and archival maps. Such a analyses were carried out for land use changes of Izerskie Mountains in 1767 – 1994 period by D. Dukaczewski (2000), using ‘reference – retrospective’ method, allowing to receive the time – oriented layers of similar level of detailness. The spatio-temporal GIS analyses of forest type and forest structure changes were also carried out for Polish part of Carpathians Mountanins e.g. by B. Woś (2005) for selected communes of Beskidy Mountains during 1935 – 1999 period, by E. Bielecka (1986) for Tatra subalpine forests, by E. Bielecka, W. Fedorowicz – Jackowski, E. Witkowska (1994) for upper line of the Carpathians forests, by P. Kardaś (2000) for Magurski National Park during 1937 – 1999 period, by M. Łuniweski (1999) for Ujście Gorlickie commune during 1952 – 1999 period, by P. Wężyk and M. Guzik (2004) for Kasprowy Wierch mountain range in Tatra Mountains during 1965 – 1999 period, by J. Kozak and M. Troll (1994) for Beskid Sądecki Mountains in 1981 – 1992 period.

Although, like in the case of multispectral high resolution airborne photographs, using very high resolution satellite data it is not possible to obtain all parameters, demanded in forest mapping instruction, the use of remote sensing standardized source material can allow to speed up the process of updating and control of detailed forest maps, as well as to homogenize its level of reliability. The remote sensing data can be used together with inventory data to carry out stratified estimation of forest species, forest stand density, total volume, volume per tree species, stand age and tree height using the k-nearest neighbours method. This kind of analyses were carried out e.g. to complete the Finnish Multi-Source National Forest Inventory (E. Tomppo, 1990, 1991) and to update the Swedish National Forest Inventory (LIFE 00 ENV/S/000861, WP 2 Report, 2002). The similar works were made by H. Franco-Lopez, A.R. Ek, M.E. Bauer (2001) and R.E. McRoberts, M. D. Nelson, D. G. Wendt (2002).

The result of such a classification can be used to carry out a GIS analysis of choice and optimization of the method of timber transport. By reclassifying the raster result using object classification it is possible to get the vector map of tree species. By buffering the network of the roads with distance of maximal possible transport of each tree species it is possible to detect areas, where the installation of cable is necessary. Taking into the consideration the DTM information and slope map, it is possible to reduce the area of potential cable installation. The next stage could be an analysis of the possibilities of clearings, necessary for installation of the cable transport devices.

The result of tree species classification can be also employed in GIS environment for estimation of NDVI of different species and to valorisation analysis of the site.

The layer of tree species can be used also for fragmentation of forest area before the calculation of the Age Vegetation Index – AST.

The detailed layer of tree species, taking into the consideration the gaps between the crowns, together with DTM, layer of the slopes and layer of the exposition of the slopes can be used for estimation of lighting conditions, which could be of fundamental importance for precise localisation of the zones exposed to the risk of insect pests.

The detailed layer of tree species can be used also (like a 'historical' reference source material) for estimation of losses caused by fire, flood (detected with the ERS C band data of VV polarization) and illegal logging.

Using this layer together with result of X band SAR data processings can provide information about the slight frost, hoar frost and destructions of tree species in site by a cap of snow, as well as canopy melting snow.

Finally, the layers of Biomass Index and the Normalized Difference Vegetation Index (NDVI) can be used to create the masks, which (together with DTM) can be employed for advanced analyses of conditions of depositions of the air pollutants.

2.2.2. FOREST SANITARY STAND AND CONDITION

2.2.2.1. FOREST SANITARY STAND

Multiple methods of detection of impaired forest, elaborated by remote sensing, allow to gain access to detailed information about the forest sanitary stand. The layers concerning the state of health of forests, elaborated by pixel or object classification (according to the information gained of indexes and channel combinations) can be used for analysis of the intensity and reasons of deforestation. D. Dukaczewski (2000), using land use layers of Izerskie Mountains (for 1767 – 1994 period), elaborated with old maps, airborne photographs and Landsat TM, ETM+ and SPOT data) and layers of the land use and sanitary stand of forest (for the 1976 – 1994) has create two animations of general and detailed level. Observing the variability of agriculture and forest land use it was possible to detect the problem areas. For these zones (about 8 % of the study area) it was carried out the spatial analysis, using DTM, layers of slopes, soils, geology, erosion risks and exposition. It was possible to detect 5 types of combination of deforestation reasons. This kind of information and related issues, can be used in forest management.

Recently carried forest damage monitoring project in Hungary[50] is using ENVISAT MERIS and IRS-P6 AWiFS data (Cartography in Hungary. ICA/ACI National Report, 2007).

To avoid problems with perception of many visual variables of animation (D. Dukaczewski, 2005b) it is possible do aggregate the temporal layers information to dynamic, animated grid (G. Andrienko, N. Andrienko, I. Denisovich, 2004).

The layers of forest sanitary stand can be used (together with DTM) like a mask for advanced models of air pollutants deposition, like in the case of Czech – Polish BTGIS project (E. Bielecka, 1997).

[50] Utilization of ESA Data under Category-1 scheme" ESA EO CAT-1 3949

Using layers of forest sanitary stand and health condition it is also possible to carry out the cellular automata – based analysis of possible changes in the future, as described by T. M. Centeno, 1998; J. Weimar (1998) or T. Toffoli, N. Margolus (1998). This kind of analyses were carried e.g. by C. Jianquan (2002), I. Blecić, A. Cecchini, P. Prastracos, G. A. Trunfio (2004), A. Zamyatin, N. Markov (2004, 2005).

Other possible solution is to employ the fuzzy logic analysis of sequence of satellite data, as it was experimented by T.M. Centeno and G. Selleron (2001).

In certain situation, for presentation of the dynamics of monitored phenomena it is necessary to generate the virtual images of the phenomenon, representing its spatial reference at ideal times of observation, when no real time is available. For these purposes, it is possible to use the method of fuzzy logic to generate virtual images on the basis of available images taken before and after the ideal date (G. Bordogna et. al., 2004).

2.2.2.2. SOIL CONDITIONS

In many GIS analysis it is necessary to dispose the information about the erosion risk. There are few methods of it estimation. In remote sensing analysis it is possible to calculate Erosion Delivery Ratio – DR:

$$DR = 10(r/\lambda^*)$$

where:

r – altitude difference between the agricultural pixel and water or talweg pixel,
λ* - horizontal distance between these pixels.

However this kind of ratio can be used generally in the case agricultural land use, it is also possible to employ it for deforestated areas, without harbaceous vegetation, when the value of index of brightness is relatively high.

For erosion monitoring of exposed soils it is also possible to use Redness Index – RI, Coloratrion Index – IC, Index of Form. For erosion of the partly vegetated soils (e.g. of alpine level) it is possible to use the Soil Adjusted Vegetation Index - SAVI (A. R. Huete, 1988), or Transformed Soil Adjusted Vegetation Index – TSAVI (F. Baret, et al., 1989), which can be used also for calculate LAI. The mining related soils erosion and degradation risks analyses were carried out in Poland, using neurotical networks (S. Gruszczyński, 1999).

The landslide risk areas can be estimated using DTM, soil, hydrography, land use / land cover layers and tectonical photolineaments analyse. Using SAR data, it is also possible to elaborate differential interferogram, which can be employed for detection and surveying of landslides (Pratti, C. et al. 1992). This kind of work was carried out e.g. by Z. Perski (2001).

The results of research of A. Chanzy (1994) on the SAR C band HH polarization data of low incidence (7° – 17°) suitability for estimation of soil humidity are still not operational in the case of satellite data. The sole satellite, working in C band with HH polarization (Envisat) have no possibility of beam incidence change. In this situation, the solution is to use the ERS C band data for survey of exposed soil moisture or to use backscatering coefficients σ° from ERS SAR C band (VV polarization) data for vegetated soils. This kind of information can provide emergency information about the water saturation of soils (e.g. in effect of long rainfall). These analyses were carried out e.g. in Poland (M. Gruszczyńska, K. Dąbrowska – Zielińska, 2004; E. Bielecka, A. Ciołkosz, 2000).

In 2005 the Czech Ministry of environment launched a project for mapping in GIS various kinds of hazards and also risks (e.g. land slides, floods waste and combined hazards have also been considered e.g. flooding of waste etc). The same time the other hazard mapping has also been carried out by insurance companies (P. Kubíček, K. Staněk, 2006).

The Vegetation Index and brightness temperature can be used for estimation of drought detection (F. N. Kogan, 1994). Using day-by-day NOAA data as well as VCI[51] and TCI[52] indexes, it is possible to detect the drought risk (K. Dąbrowska – Zielińska, F. N. Kogan, A. Ciołkosz, M. Gruszczyńska, U. Rączka, W. Kowalik, R. Jankowski, 1998) and, in the case of arable lands, to estimate the crop production (K. Dąbrowska – Zielińska, A. Ciołkosz, W. Kowalik, M. Gruszczyńska, 2001).

The lithological GIS analyses and modelling using SAR data were carried out e.g. by H. Marcak (2001). Using the remote sensing data and geostatic method analysis it is possible to identify the Pb / Zn mineral deposits (W. Mastej, 2001). The potential functions of remote sensing data interpretation together with geostatistical functions can be used for GIS analyses and modelling of oil and gas reserves prospection (as in the case of J. Kotlarczyk, et al, 1999).

2.2.2.3. WATER REGIME

As it was signalized in point 1.2.2.3. the remote sensing can provide a very useful information for modelling of water regime. It is also possible to generate the flood risk and flood maps. In the case of flood risk maps or systems there are few solutions. In all of them it is necessary to dispose the DTM (which can be generated using QuickBird, Ikonos SPOT or KOMPSAT data). Part of authors tend to create the flood risk map using map of 'highest losses' (J. P. Torterot, P. A. Roche, 1993), or map of the freqency of inondations (G. Oberlin, P. Lambert, 1991), or combination of land use maps, maximum damage maps, inondation maps, together with real damage maps, which allow to generate the map of risk of flood (W. Vanneuville et. al, 2005). It is also possible to use a DTM, slope layers, land use maps for many time states and map of rugosity (generated with appropriate index), soil moisture layers, as well as information about the mean multi-year high rainfall. This last solution was used to create flood susceptibility analysis of Odra river valley (A. Ciołkosz, E. Bielecka, 1998; E. Bielecka, A. Ciołkosz, 2000). The similar solution is used by EADS Astrium together with Météo France for flash flood early warning (A. de Saint Vincent, 2005). The ISTAR early warning flood risk systems are based on very detailed DEM (taking into the consideration the rugosity differences) and multi-temporal archival flood and meteorological data (N. Pisot, 2005). The M3Flood system, using remote sensing generated DEM, imports real-time data from hydro-thermo-pluviometric sensors network, together with meteorological forecast, radar and optical sensor satellite data. Taking into account these data and hydraulic internal models it provide 24 h forecast on selected river section (M. Erena Arraba, F. Toledano, L. Tireli, S. Montesinos, P. Garcia, S. Mazzeo, L. Fernandez, J. P. Cox, 2005).

In the case of minute map of state of flood, it is necessary to dispose the ERS C band data (for an exposed soils and surveying the flooded areas) and backscatering coefficients $\sigma°$ from ERS SAR C band (VV polarization) data, LAI coefficient (from optical satellite data) to survey the soil moisture under the vegetation (M. Gruszczyńska, K. Dąbrowska –Zielińska, 2004). B. Hejmanowska and S. Mularz (2000) have used for soil moisture estimation the ERS SAR C band (VV polarization) data together with Landsat TM data. These analyses were carried out for Odra and Vistula river bassins.

The remote sensing data and old topographic maps derived land use and land cover layers for many time stages, the geological and pedological layers, as well as DTM can be used for creation of soil conditions and soil erosion database, which can be used for flood modelling. Such a database was created this way for Odra river bassin in JRC in Inspra (S. Białousz, J. Chmiel, K. Osińska, J. Pluto – Kossakowska, 2000). Using airborne

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[51] $VCI = 100\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$

[52] $TCI = 100\frac{BT_{max} - BT}{BT_{max} - BT_{min}}$,

where: BT - radiative temperature of vegetation photographs, generated DTM and DEM, as well as detailed land use / land cover layers it was created in IGIK (in coopertation with Tecsult Inc. of Canada and BlomInfo A/S of Denmark) the flood risk warning system for Vistula, Odra, Warta, Przemsza, Raba, Dunajec, Skawa, Nida, Wisłoka, Wisłok, San, Osłoboga, Nysa Kłodzka, Oława, Ślęża, Bystrzyca, Kaczawa, Bóbr, Kwisa, Nysa Łużycka and Prosna river (R. Kaczyński, 2000).

The Landsat TM and SAR C band data cartographic as well as material were used to carry out GIS analysis of identification and delimitation of flood risk areas in Bucharest region (M. C. Potcoava, 2000).

In 2005 the Czech Ministry of environment launched a project for mapping in GIS various kinds of hazards (e.g. floods risks and combined hazards). The Czech Hydrometeorological Institute (CHMI), which is responsible for flood warning have began after 1997 to re-organize its forecasting and warning service by creating a mutually inter-connected system of a Central Forecasting Office (CFO) and six regional forecasting offices (RFOs) at the Institute's regional branches. All RFOs include a hydrological and a meteorological sections forming a fully integrated forecasting and warning system, based on a multi-sensor observation input (precipitation, river flow, data from the WMO Global Telecommunication System (GTS), which uses also remote sensing data. (P. Kubíček, K. Staněk, 2006).

The FÖMI-ESA PECS[53] project "The integrated utilization of ESA ENVISAT data in regional flood/waterlog or drought monitoring and impact assessment (2004-2007)" aims at the further development of the previous R+D activities of FÖMI-ESA Prodex[54] program (2000-2004). It monitored these disasters at regional level employing multi-source satellite data set (NOAA AVHRR, SPOT VEGETATION, IRS WiFS, Landsat TM and IRS LISS) including also ENVISAT (MERIS) data (Cartography in Hungary. ICA/ACI National Report, 2007).

The SAR C band data of VV polarization can be used for mapping the flooded area extent, even in very poor weather condition (e.g. application for the survey of Odra river flood in 1997). This kind of up-to-date data can be employed (together with land use maps, elaborated using optical satellites data) for GIS fast analysis of loss and surveying of accessibility conditions.

Using the land use layer, including information about the forest sanitary stand, layer of distances of open water bodies, layer of soils, layer of erosion risk and layer of slopes it is possible delineate the critical areas of water pollution (E. Bielecka, 1997).

The problem of flood risk is one of the main issues of EURORISK[55] programme (a part of the GMES European programme) started since 2003.

2.2.2.4. AIR POLLUTANTS

Big part of air pollutants is hardly mapped with satellite data. In this situation, these data are used generally for prepare additionally data for modelling, while the main source of data are measurements of the state air quality network stations. The optical high resolution satellite data can be used to prepare detailed and up-to-date land use masks and DTM or DEM's, which can be employed for creation of models for analyses of pollutants transport and deposition. This kind of analysis were carried out e.g. by Czech GISAT and Polish IGiK in the case of Black Triange GIS. The results was maps of SO_2 and NO_x deposition in the northern part of Czech Republic, south-east Saxony and Jelenia Góra and Wałbrzych regions in Poland (E. Bielecka, 1997).

[53] PECS= Plan for European Co-operating States
[54] Prodex= Scientific Experiment Development Programme
[55] with participation of JRC, ESA, ECMWF, EUMETNET, Sweden (SRSA, SMHI), Great Britain (Met Office), Germany (Infoterra, RfG), France (DD SC/CIVIPOL, Météo France, CNES, EADS Astrium, SERTIT), Italy (DPC, INGV, UNIFI, IRPI, Telespazio), Spain (INSA), Portugal, Netherland, Switzerland, Norway, Finland, Czech Republic, Hungary, Greece, Turkey

The analysis of space distribution and modelling of deposition and concentration of heavy metals (taking into the consideration e.g. the source distance, land cover and land use, relief, lithology and pedology) was carried out in Poland by J. Magiera and K. Foryciarz, (2000). The heavy metals soil concentration analyses, using environmental monitoring data processed with linear and non-linear geostatistical methods, were carried out e.g. by B. Namysłowska – Wilczyńska and A. Wilczyński (2000).

The analysis of influence of massive fires and CO and CO_2 production on boreal forest was carried out e.g. by B.J. Stocks, B.S. Lee and D.C. Martell (1996).

2.2.2.5. BIOTIC AGENTS

As it was mentioned in chapter 1.2.2.5., one of the most efficient way of detection of the insect pests, using satellite data is to use the near infrared, first SWIR and second SWIR satellite data or the Index of Destruction WU. These layers can be superposed over the DTM with detailed land use cover or forest inventory made with QuickBird, Ikonos or KOMPSAT-2 data. Using the layer of slopes and exposition it will be possible to localise the crown gaps and openings, sensible for pest gradation.

The near infrared, first SWIR and second SWIR satellite data and/or the Index of Destruction WU can be also employed to carry out the multitemporal geostatical analysis of gradation phenomena (J. Mozgawa, W. Tracz, G., Kamińska, A. Kolk, L. Sukovata, 2007).

In the case of the FŐMI 2004 – 2006 mapping of the forest damage caused by gypsy moth in Hungary was the very high (IKONOS) and medium resolution (mainly IRS-P6 AWiFS) satellite data were used (Cartography in Hungary. ICA/ACI National Report, 2007).

Strong correlation of defoliation with presence of hytopathogenic microorganisms can allow to carry out the similar geostatic analyses.

In the case of defoliation caused by animals, it is also possible to use the near infrared, first SWIR and second SWIR satellite data and/or the Index of Destruction, however it seems to be good idea to carry out the analysis inside the buffer around the network of animal footpaths, detected with very high resolution data. This kind of solution was used by Franck Vidal of CIMA (CNRS – URA 366) in Toulouse for estimation of the deer headage in the eastern Pyrenees. The results of this analysis can be also very useful for modelling of migration corridors for animals.

2.2.2.6. ANTROPOGENIC FACTORS

Ground level air pollution can be estimated by modelling. The use of the remote sensing data will be reduced to provide up-to-date and standardised information about the land use / land cover and DTM.

In the case of construction factor, the satellite data can provide the information about the antropogenized areas and DTM. The remote sensing derived information on land use changes, forest land cover changes, industry activities and tourism can be used to carry out analyses of antropogenic factors. Such a analyses were carried out e.g. by B. Błach (1998) for Osławica bassin in Beskid Niski (Carpathians) Mountains.

There are many methods dealing with fires and burnt areas based on satellite data (J. M. C. Pereira, et al., 1999):

- supervised classifications,
- vegetation index image differencing,
- single-date vegetation index thesholding,
- multi temporal regression analysis,
- fuzzy multiple thesholding,
- spectral unmixing,
- time series analysis.

It is also possible to make an on-screen interpretation or to carry out the object classification, using criteria of spectral response and shape.
The results of these processing can be used like a emergency maps or thematic layers for GIS analyses. In few countries this kind of data are included into the Forest Fire Monitoring Systems (Z. Li, et al, 1997; A. Podolskaja, D. Ershov, 2006). Calculating NDVI, TNDVI and hydrothermal index (employing first SWIR and TIR channel) for forest and superposing received layers it is possible to create the map of fire risk forest categorization (M. Mycke-Dominko, 2003). The detailed prediction of wind driven forest fire can be modelled using fuzzy logic and cellular automata solutions, inspired by works of M. Mraz, N. Zimic, J. Virant (1996).

2.2.3. WOOD SUPPLY CONTROL

The wood supply control information is a part of databases of forest GIS in Poland, Czech Republic, Slovakia, Austria, Hungary and Bulgaria.

The problem of updating the wood supply information and detection of illegal logging, can be solved essentially by creation of layers of Biomass Index, NDVI and VI3 vegetation index: These data together with auxiliary layers of GVI, AST and IPR and results of supervised pixel classification or (better) object classification of forest types ans well as archive forest classifications (or forest inventory data) can provide exhaustive cartographical and statistical information.

The problem of remote sensing and GIS analyses of biomass production was object of studies of e.g. Z. Fazakas, M. Nilsson, H. Olsson (1999). The GIS analyses using satellite data concerning forest stock volume and maximum logging estimation were carried out by Z. Xianwen, Y. Kaixian, B. Yingzhi, (1990) and A. Rikimaru, Y. Utsuki, S. Yamashita (1998).

2.2.4. FOREST MANAGEMENT AND FOREST MONITORING

In the case of the forest management, forest inventory, forest monitoring and forest protection area monitoring almost all indexes, neochannels and results of satellite classifications should be integrated into the GIS databases. To avoid the problem of data format incompatibility, it is necessary to convert the satellite data into the vector form, or to use the hybrid GIS systems. Another solution is to carry out the object classifications and object GIS analysis.

In the case of forest management, forest inventory, forest monitoring systems and forest protection area monitoring it is necessary to elaborate the procedures of database update and data control. It is also necessary to elaborate the rules and procedures of data analysis, data exchange and elaborate the system of metadata. Very interesting solution is system designed to facilitate the exploration of time-series of remote sensing data, which allows studying the behavior of dynamic phenomena, events and evolution of phenomena over time (U. Turdukulov, M.-J. Kraak, 2005; L. Martinez, M. Joaniquet, V. Palà, R. Arbiol, 2005).

The problem of forest inventory updating using remote sensing data and GIS analyses was studied e.g. by O. Hagner (1990), G. Ståhl, (1992). The method of forest canopy density estimation (using Advanced Vegetiation Index and Bare Soil Index for vegetation density modelling, as well as Shadow Index and Thermal Index for estimation of age and total forest volume) was elaborated in Japan (A. Rikimaru, 1996; A. Rikimaru, S. Miyatake, 1997). This method was used to elaborate a semi-expert system (A. Rikimaru, 1999). The similar solution was applied in Iran by M. Saei Jamalabad and A. A. Abkar (2004). The detailed analysis (concerning e.g. estimation of forest species, forest stand density, total volume, volume per tree species, stand age and tree height) using the k-nearest neighbours method (employing field inventory data, optical satellite images, DTM and digital map data) were carried out in Finland by E. Tomppo (1990, 1991), T. Tokola, J. Pitkänen, S.Partinen, E. Muinonen, (1996) and in Sweden (LIFE 00 ENV/S/000861, WP 2 Report, 2002[56]). Later the similar solution were applied in China, New Zealand, Norway, Germany, Ireland, Great Britain (D. McInerney, 2005) as well as in USA and Canada (H. Franco-Lopez, A.R. Ek, M.E. Bauer, 2001; R.E. McRoberts, M. D. Nelson, D. G. Wendt, 2002).

The data and informations provided by analyses carried out in forest inventories can be employed in forest GIS. The first fully operational forestry GIS, supporting complex forest management and forest monitoring, was probably French National Forest Inventory – L'Inventaire Forestier National (Fichiers et Banques de Données, 1974). Today many INTERREG III B CADSES countries dispose each own systems. In Poland it is co called SILP – State Forest GIS (http:/www.lasypanstwowe.gov.pl/sip). In Czech Republic this kind of data are available through Czech Mobile Forestry Geodata Infrastructure (J. Fryml, K. Charvat, A. Sida, 2002). Forest GIS supporting forest management and forest monitoring are functioning also in Slovakia, Hungary, Austria. In Bulgaria the works on national forest database was in 2006 at the stage of pilot projects (M. Assenova, I. Dobrichov, 2006). In Ukraine the forest database is in stage of project preparation.

The data available in forest GIS and informations resulting of forst GIS analyses can be used for environmental modelling. The GIS model of age structure and atmospheric carbon exchange for managed forest in Great Britain was developed by P. M. L. Drezet and S. Quegan (2005), using previous works of R. Milne, K. Hargreaves and M. Murray (2000).

The results of forest GIS analyses as well as new satellite data derived informations can be used in forest monitoring. The northern – central part of Carpathians (Niepołomicka Forest) was one of the three forest areas chosen like a demonstration sites for the Forest Environmental Monitoring and Management System (FOREMMS) project (P. Wężyk, 2004).The FOREMMS is handling monitoring on three levels: local, up to 30 000 km² and the whole Europe. Level 1 areas will be monitored by ground measurement forest inventory (supported by geoinformation technology), sensors providing point information and airborne sensors. Level 2 and 3 areas will be monitored using the satellite data (Landsat, SPOT, MODIS, NOAA). There will be one or two databases located in each country and all databases will cover whole European forest area. Level 1 data will be used to carry out local monitoring measurements, to generate the thematic maps of forest GIS, to generate the DTM. Level 2 data will be used to calculate NDVI, carry out the classifications, to model the space – temporal changes. Level 3 data will be employed to calculate LAI and NDVI for fire risk monitoring, to survey the forest parameters (type of forest, biomass and defoliation) and to carry out the modelling of carbon circulation in ecosystem.

The remote sensing data derived land use and land cover maps, together with information of forest inventories, nature protection inventories and results of field surveys can be used to analysis of potential areas of new protected areas (A. Linsenbarth, 1997; 2000a, 2000b). Interesting analysis concerning the possibilities of Carpathian Euroregion forest protection areas databases satellite data supply was presented by I. Drelich (2000). According to her, the forest protected areas monitoring will includes information on the environmental state of protected areas, including: relief (fluvial and glacial relief, kras relief, soil erosion and landslides data, as well as eolian processes data), water relations (data concerning water bodies and wetlands, river valleys development, floods), vegetation cover (types of vegetation, tree stand ranges, forest sanitary stand, fire and blowdowns risk), antropogenized areas (build-up areas, tourist facilities). It will includes also information on protected areas threats, including: local risks, threats related to tourism (tourist facilities and traffic assessment), external risks (concerning urban and rural built-up areas, road and rail networks, agricultural areas, logging), and supra – local risks (industrial pollution, damps sites and mines activities).

Using remote sensing derived information about the types of relief, types of surfacial sediments, land cover and land use, it is possible to distinguish types of landscape units (E.

[56] using also neural networks

Bielecka, 1989; A. Richling, J. Solon, 1996; A. Hernik, 1998) which are very useful for environmental modelling and forest monitoring. Using SAR data, rather than land use / land cover classes, it is possible to classify such a landscape units. In the case of study of K. Błażejewska (2004) for middle part of Polish Carpathians sections it was possible to distinguish 37 landscape units classes, integrating complex information about the relief characteristics, lithology, soils, forest and other land uses classes.

CONCLUSIONS

After over 35 years of development, the civil remote sensing data have become one of the most efficient source of rich, detailed, standardized and repeatable material for GIS analyses. It can provide products, which can be employed at all 3 level of forest information.

They can be used for forest type and forest structure identification, analysis of forest sanitary stand and condition (including also soil conditions, water regime, air pollutants, biotic agents and antropogenic factors), as well as to update and expand wood supply control supply, and provide the detailed data for forest management and forest monitoring.

The thematic scope, the credibility of provided information and optimization of it transfer can justify the application of the remote sensing data and products in General Inventory of Carpathian Forests.

Recent development of GIS technologies enabled the easiest integration of remote sensing satellite data and products and its derivates, as well as its employment into the spatial and time analyses.

The advent of object - oriented analyses solutions in GIS and in remote sensing have create the new possibilities concerning the detection, inventarisation and mapping of forest information and its employment in complex environmental modelling.

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