APPLICATION OF REMOTELY SENSED AND COLLATERAL DATA FOR MONITORING, MODELLING AND CARBON STOCK ESTIMATION OF THE POLISH FORESTS

P. Turos [a]

[a] GEOSYSTEMS Polska, 00-375 Warszawa, ul. Smolna 38/5, Poland - przemysław.turos@geosystems.pl

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ABSTRACT:

National Greenhouse Gas Reporting is an essential requirement of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The reporting demands information that is usually not provided by most National Forest Inventories or that is not available from other sources. The service offered for the Ministry of the Environment gain is to provide critical environmental information for the effective implementation of the UNFCCC/KP reporting. The service combines EO-derived data with in-situ information derived from a sample-based forest inventory. EO data are used to acquire an information about the forested land current status and it's changes during the monitoring period. EO based derived maps complement statistics from national forest inventories conducted terrestrially. Using EO data in combination with a field inventory increases the accuracy and efficiency while reducing of costs and the margin of error.

1. KYOTO PROTOCOL

Information on carbon content in tree stand as well as its changes in relation to the base year 1990 (1988 for Poland) together with information on the emission are basic components of the national reports delivered annually by Polish Ministry of the Environment in compliance with Kyoto Protocol (KP). Reliable and objective information on forest area changes is significant for the emission limits, which in case of its incomplete exploitation is the subject of trade to other countries (emission trade). The 17th World Climate Conference (COP17) of the United Nations Framework Convention on Climate Changes (UNFCCC), which took place in Durban (RPA) on 9th of December 2011, decided to prolong binding force of Kyoto Protocol for a further 5 years (above 2012) and suggested the plan of actions until 2020.

2. SATELLITE OBSERVATIONS IN EUROPEAN UNION

Data delivered from Earth observation satellite systems in conjunction with ground monitoring data are reliable and precise source of environmental information. Dynamic changes of the Earth caused by human activities and natural phenomenon require information about current synoptic conditions. European Commission along with European Space Agency run two broad ranged programs in the field of satellite technologies. First one, named Galileo aims to create pan-European system of global positioning, the second one- Global Monitoring of Environment and Security (GMES) is focused on the applications of Earth Observations. The research and development stage of GMES, which started in 1998, will move into the operational phase in 2013. Active participation in the research and development stage as well as in the implementation and operational phase of this initiative, gives an opportunity to use rich, constantly extending archive of satellite data held by European Space Agency together with numerous applications and other related products. The membership of Poland in ESA, which is predicted by Polish negotiators for a half of 2012, gives a possibility of participation in construction and implementation of satellite segment of GMES, which is currently running as the Sentinel constellation. Due to the reasons mentioned above the activation of Poland in GMES program as well as full exploitation of its potential by Polish institutions responsible for environmental protection and public safety is crucial.

One of the activities executed at the research and development stage of GMES was action of the international consortium, which has been developing tasks of GMES Service Element Forest Monitoring (GSE FM), and was accomplished in 2009. The aim of the consortium was to propose to central level of national administration a portfolio of services based on satellite imageries, which would support implementation of forest ecosystems protection policies. GEOSYSTEMS Polska started the cooperation within a scope of GSE FM in 2004. The first stage was oriented on strategy analyses and information needs in the European forestry sector, among the others in relation to global policy of environmental protection and implementation of UNFCCC requirements. Basing on the achievements of the aforementioned stage the pilot project for Poland was organised. It was limited to two forest districts and aimed to collect basic information on forests by remote sensing methods. Pilot project enabled GEOSYSTEMS Polska for fully operational integration within the framework of the consortium (setting the procedures of products standardisation and evaluation of their quality) as well as to familiarise the user with the final portfolio of the GSE FM services. The support of the greenhouse gasses reporting required by Kyoto Protocol was selected as the most interesting.

3. FOREST MONITORING FOR KYOTO PROTOCOL REPORTING PURPOSES

Due to the opportunities given by five-years program, Plan for European Cooperating States (PECS), which precedes entering ESA, GEOSYSTEMS Polska completed the first, in European scale, implementation of services based on GSE FE portfolio for the area of the whole country. The aim of the project was to deliver to the Polish Ministry of the Environment (which is responsible for reporting) data about forest volume, biomass and carbon stock of Polish forest in the base year of the KP (for Poland - 1988) and nowadays. The innovativeness of the service relies on application of advanced research methods of the environment, which are based on satellite imageries, and their integration with the data acquired from ground inventory. It was crucial to assign one procedure to the forest under the State Forests National Forest Holding administration and to the forests under other ownerships as it will ensure the integrity of estimation of the forest area for the whole country. It is worth to highlight that the project characterised by the pilot project features was developed for the area of whole country and it enables to assess the value of this methodology in operational stage.

3.1 Production of Satellite Maps

The area of Poland (312 685 km2) was covered by a set of forest maps from two time periods. Basing on these maps as well as on in-situ data the statistical information was derived. It was decided to produce maps for the year 1990, even though that according to the Kyoto Protocol the 1988 was chosen as the base year for Poland. As a current state the year 2006 was selected. In both cases the choice was justified by the availability of the satellite data.

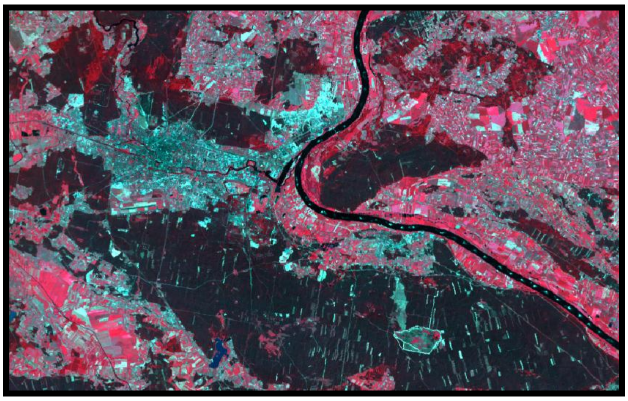

Figure 1. Satellite orthomosaic (IR,R,G composition) 1990. Neighbourhood of Bydgoszcz, Poland

The imageries covering the area of the whole country in two considered years (tolerance of +/-1 year) have been selected from ESA archive. All scenes were acquired between April and September. Since the data acquisition took place during the vegetation period the classification and interpretation of the forest extent and basic types of the forests were enabled. For a year 1990 29 of Landsat-5 TM imageries of 28,5m resolution were used and for a year 2006 27 imageries from IRS-P6 LISS-III scanner and 41 from SPOT-4 HRVIR and SPOT-5 HRG transformed to the resolution of 25m were used. All imageries were delivered as orthophotos. They were used for a production of the forest thematic maps as well as orthomosaics, which later were used as a backdrop data (orthomosaic 1990 - Figure 1., orthomosaic 2006 – Figure 2.)

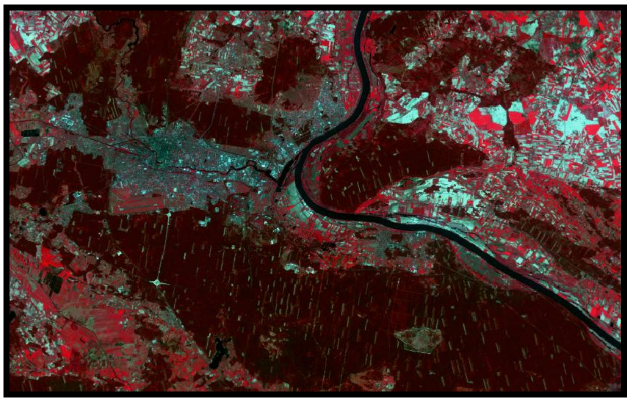

Figure 2. Satellite orthomosaic (IR,R,G composition) 2006. Neighbourhood of Bydgoszcz, Poland

3.2 Production of Thematic Maps

The production of the forest area extent map for a year 1990, the forest type map for a year 2006 and the map of forest area changes may be considered as one multistage process. Imageries classification for the year 1990 was not held independently, but in relation to the results from the year 2006. The map of changes depicts differences between both maps. Such approach ensured the geometrical coherence and enabled the recording of meaningful changes in forest areas. On the other hand the method combing the object classification (advanced automatic method of image analysis, significantly expediting the obtainment of final results) with visual interpretation (manual edition of the automatically delivered results enabling their control and improvement) ensured high accuracy of thematic maps.

Object classification (performed in eCognition environment) of the scenes from the year 2006 lead to production of dozens of separate vector databases holding forest borders and information about forest species type: coniferous forest, deciduous forest and mixed forest. As a data enabling reliable selection of the test samples, for a samples being a basis of the supervised classification of the image, the information on the stand composition from the State Forest Information System was used. The database describes the Forest Numerical Map. This data was made available for a purposes of the project by General Directorate of the State Forests. The application of this information enabled the identification of the representative deciduous forest areas (>75% of deciduous species) and coniferous forest areas (>75% coniferous species) and mixed forest areas on satellite imagery. Except of these categories the map covered non-forest land. For each scene several test samples for a classification purposes were chosen. The same data source was used for a purpose of map accuracy estimation. However, in this case the selection of samples was separated to avoid the overlapping with samples used in the stage of classification.

Vector format simplified the correction process of the automatic classification. The result of the manual correction, joining the single databases created for each scene and transformation to raster format was the map of forest types for the year 2006

(Figure 3.). The resolution of all produced thematic maps was equal to 25m and minimum mapping unit was equal to 0,5ha.

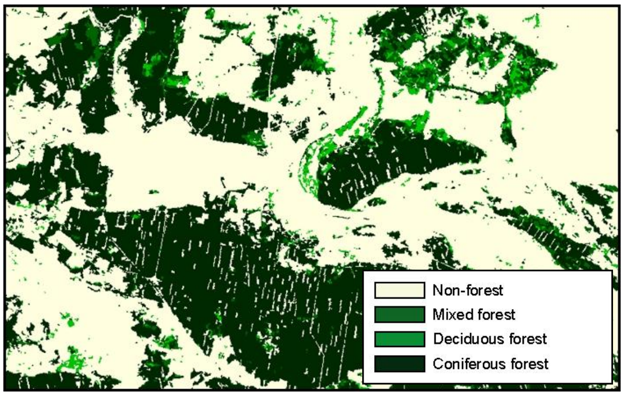

Figure 3. Subset of Forest Types Map 2006. Neighbourhood of Bydgoszcz, Poland

In the next stage maps of the forest types for 2006 were used for the detection of forest area changes between 1990 and 2006. The map for 1990 was created by combining the already existing map for a year 2006 with analysis of the Landsat TM orthophotos. This stage was also performed with use of the eCogniction software, but in this case, both stages: automatic classification and visual improvement were performed in this tool only in raster format. All scenes from Landsat TM were classified with help of the forest map from 2006. The forested areas and non-forest areas in 2006 were classified separately. In case when the chosen area was described as a forested in 1990 and non-forest in 2006 the change was classified as deforestation, while in opposite case the change was identified as re-/afforestation. The map of the forest area changes between 1990 and 2006 included four categories: forest with no changes, non-forest area without changes, re-/afforestation and deforestation. The visual enhancement was performed in dedicated tool developed in eCogniction environment. The tool included functions and procedures essential for the improvement of the accuracy of the forested and non-forest areas classification and keeping the integrity of the thematic maps. The tool mentioned above also simplified the exclusion of the changes detection in the areas of disjunctive geometry of othophotos.

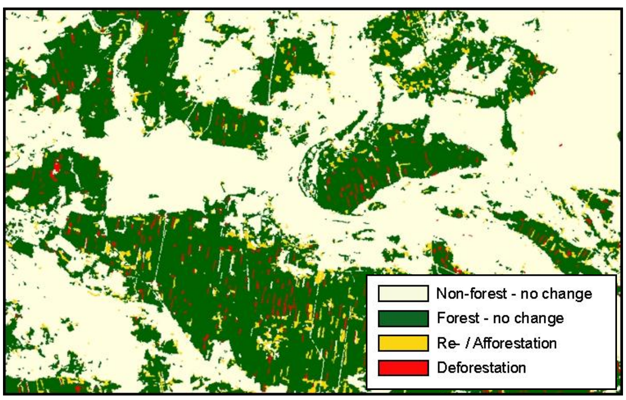

Figure 4. Subset of Forest Changes Map 1990-2006. Neighbourhood of Bydgoszcz, Poland

Except the changes detection map production this process delivered the forest area map for the year 1990. Forest area map from 1990 (Figure 4.) depicted two categories: forested areas, non-forest areas, while the change detection map between 1990 and 2006 (Figure 5.) held four categories: forest with no changes, non-forest areas without changes, re-/afforestation and deforestation. Estimation of the accuracy of the change detection map between 1990 and 2006 was achieved by using the set of 86 orthorectified historic imageries acquired for the area of whole country between 1987 and 1993. For each picture 100 of points were randomly generated and through the imagery interpretation all the points were assigned to the one of following categories: forest areas, non-forest areas. The set of this points became the reference data for accuracy estimation.
High (>95%) and satisfactory (>90%) thematic accuracy of the forest maps enabled their application in further stages of the process, which aimed to obtain information about changes of thickness, biomass and combined carbon.

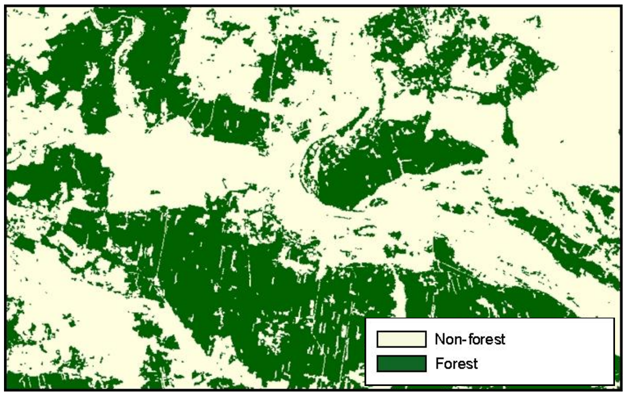

Figure 5. Subset of Forest Area Map 1990. Neighbourhood of Bydgoszcz, Poland

3.3 Modelling of Carbon Stock Change

Thematic maps contained an important information on spatial distribution of forest areas for 1990 and 2006. The forest were divided in tree forest types (considering species content) on the map for 2006 which had a rich source background based of the ground inventory. It facilitated to integrate the data which was captured using different techniques but all in accordance with the Kioto Protocol and to estimate the carbon statistics in tree stands with a high probability. Two main in-situ data sources were used: Digital Forest Map – NML, enhanced with information from the State Forest Information System – SILP, mentioned above as well as a subset from the data base presenting field measurements which were conducted for the needs of Large-Area Forest State Inventory - WISL (acquired between 2005 and 2010). The WISL were made available by the Bureau for Forest Management and Geodesy with the consent of General Directorate of State Forests and Ministry of the Environment. The database mentioned above have other specifics, other applications and they are supplied by other services according to their internal procedures therefore they can be considered as completely autonomous data. The application of two sources facilitated to compare the parallel modelling results. On the basis of both database the sample of points containing information about volume of tree stand (per 1 ha) as well as information of site adherence to one of three forest species types based on forest type map 2006 were prepared.

In the case of the WISL the localization of points was equal with the localization of measuring grid used during the inventory (a set of five test areas in each grid note 4×4km). About 22 000 test areas representing forested habitats were selected. In case of sampling of data from NML/SILP which covers with a layer of polygons areas belonging to the State Forest, the sampling was conducted according to the fixed scheme (grid 4×4km) what gave about 2 200 points on the national level

An identical procedure was conducted based on both in-situ information sources and in a result carbon stock statistics 2006 for tree stands in Poland were generated. As a first step biomass and carbon stock in each from measuring points were evaluated in relation to 1 ha . The values were estimated according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC) included in a document: 2006 the IPCC Guidelines for National Greenhouse Gas Inventories.

For the assessment of above biomass for the points representing 1ha samples of forested areas the information which was inscribed in input data base as well as the Biomass Conversion and Expansion Factors in dependency on type species of forest were used (Biomass Conversion and Expansion Factors – BCEFs, source: 2006 the IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4: Forest Land, Tabele 4.5). Moreover, an information about wood density (Basic Wood Density – D, source: 2006 the IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4: Forest Land, Tabele 4.13) was applied. For the calculation of below-ground biomass a Ratio of Below Ground Biomass to Above-Ground Biomass also in dependency on the species composition was used (soure: 2006 the IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4: Forest Land, Tabele 4.4). The sum of below-ground and above-ground biomass for each test area was a base for an evaluation of carbon stock. For this operation Carbon Fraction factor was applied (Carbon Fraction of Above-Ground Biomass – CF, source: 2006 the IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4: Forest Land, Tabele 4.3). Determination of tree values: volume [m3/ha], biomass [t/ha] and carbon [t/ha] for each point from in-situ data facilitated to integrate the results with satellite maps.

The integration of the satellite maps with the information from the point database (measures of values and an estimation of biomass and carbon) was performed for the purpose of reference of tree stand parameters to forest areas which was classified based on information from imageries. Both forest areas map 2006 and point database included an information about species composition of forest. Three subsets of point database were created. Each of them represented consecutively coniferous, deciduous and mixed forest. These data base includes an information about tree stand parameters and tree masks showing the spatial distribution of the following forest types in the area of Poland on the basis of the map. For each point database three parameters of tree stand were available which values were used as a base of interpolation. As a result of interpolation nine continuous raster layers (three forest types and three tree stand parameters) were created. They represented theoretical, spatial distribution of tree stand parameters within the whole area of Poland in resolution of 25 m (resolution of thematic maps). In the next step the layers were clipped with corresponding forest masks extend from the forest type map. Final result – entire maps of spatial distribution of volume, biomass and carbon stock was achieved by mosaicking of layers of three forest types for each assessed parameters. Complete representation of distribution of forest parameters for all forest types were conducted as a basis for calculation of the estimated amounts of volume, biomass and carbon stock for all forest in Poland.

Project assumed an estimation of change of tree stand parameters within sixteen years which were covered by the monitoring. In the praxis operation was reduced to estimation volume, biomass and stock carbon for the base year 1990. The map for 1990 did not include species related division of forests. Detailed and accessible data from the ground inventory did not exist. Statistically estimated, average timber volume of Polish forests in reference to other property form was published by the Central Statistical Office (GUS) was used instead. GUS published different values of an average stand volume for the forest in ownership of State Forest and forest of other property form. A contemporary ownership structure of forest published by GUS was substantial (approximately 83% - State Forest , 17% - forest of different property form). An approximated, aggregated value of volume for 1990 was achieved by the use of aggregated area of forest 1990 as well as the average volume for the forest of different property form. In turn this value became a basis for estimation of biomass and carbon stock (average values of BCEF, D, R i CF were used).

4. RESULTS AND CONCLUSIONS

In result of the estimated calculations performed by the application of information from the thematic maps, results of in-situ measurements as well as all available statistical data aggregate values of tree stand parameters for the entire Poland for 1990 and 2006 were obtained. These results were referred to the available reference data published by GUS (volume 1990), Ministry of the Environment in the Report about Condition of Forests in Poland 2010 (carbon stock 2006). The results with the reference data and with an estimation error for 1990 and 2006 (two sources of information from ground measurements) are included in the Table 1.

Year	**Forest parameters**	***In-situ source***	**Estimated values**	**Reference data**	**Error**
1990	**Volume[m^3]**	**GUS**	1562200000	1456900000	7,4 %
	Biomass [t]	**GUS**	1277300000	-	-
	Carbon stock [t]	**GUS**	638700000	-	-
2006	**Volume[m^3]**	**SILP**	2285441494	2304000000	-0,81 %
		WISL	2492434486		8,18 %
	Biomass [t]	**SILP**	2083053812	-	-
		WISL	2226736977		-
	Carbon stock [t]	**SILP**	1043808166	968000000	7,83 %
		WISL	1120898512		15,80 %

Table 1. Results of the estimation of tree stand parameters In Poland with a reference data and error values.

The analysis of estimation error for tree parameters enables for optimistic look on using integrated information derived from the satellite observation systems and from the ground inventory. Especially high accuracy of estimation of stem volume for 2006 by use of SILP data is worth to underline.

However the method should be improved and developed in order to eliminate or limit influence of source of error. The

WISL seems to be extraordinary valuable in-situ data source because of its range, scope and methodology. In this case the application of an information about age and structure of tree species could increase the accuracy of calculations and fuller use of IPCC procedures.

The presented method will not replace the previously used information sources about the absorption of atmospheric carbon dioxide by forest ecosystems in the annual cycle of reporting required by the Kyoto Protocol. However in three or five years cycle may become a complement and calibration of the currently used models. Moreover, the maps which were generated in the workflow present value in itself because of display of the dynamics in the environmental changes.

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