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Processing and Utilization of Remote Sensing Data in the Regional Information System (RIS) of Ecological and Productive State of Forest

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Abstract. The paper presents methods of processing and utilization of satellite imagery data in the regional information system (RIS) of ecological and productive state of forest stands. The RIS provides information about actual state of the forest stands, changes of state and productive characteristics. The system is composed of two web applications and covers the area of Western Carpathians, the northern part of Pannonian basin and adjacent parts of surrounding units. Satellite scenes from MODIS Terra, LANDSAT TM and ETM+, SPOT and ASTER are the main data inputs utilized in the RIS.

The evaluation of ecological state of forest is based on the identification of areas with the sings of spruce stand decline and forest windbreaks. Several different approaches to data processing and visualization were tested with concern to make the identification fast and easy even for the less experienced users of the RIS. Combinations of selected bands of Spot and Aster scenes were chosen to identify the sings of spruce stands decline. The resulting satellite composition shows the changes of state of forest in red colours. The main advantage of this time, labor and finance consuming method is fast and clear identification. Resulting satellite scenes were also utilized for the classification of health state of spruce forest. The classification was verified with the field data from 35 terrestrial plots. Visual comparison of two Landsat satellite scenes (from 2007 and 2009) was chosen as the best method for identification of windbreaks. Landsat scenes are available free of charge and they cover the area of interest. Lower resolution and corrupted scenes from Landsat ETM can be accepted due to the low financial costs.

The evaluation of productive state is based on the object oriented approach to data processing and modeling of productivity. MODIS enables to monitor biophysical and structural properties of forest ecosystems as: Normalised vegetation index (NDVI), Enhanced vegetation index (EVI), Leaf area index (LAI), Photosynthetic active radiation absorbed by vegetation (FPAR). Mentioned characteristics are important identifiers of health and ecological status of forest. They are used as the inputs into productivity models or phenological model.

Keywords: remote sensing, satellite scene, ecological and productive state of forest, changes of state of forest

1   Introduction

Satellite mapping of forests together with an assessment of their biophysical and structural properties enable us to deepen our knowledge how forest ecosystems response to global environmental change, how is influenced the carbon cycle, allocation of carbon and productiveness of forest. Scenes from satellites such as Landsat, SPOT and Aster can be utilized for several decades. Opportunities for the further research were greatly improved by the launch of the Moderate Resolution Imaging Spectroradiometers (MODIS) instruments on the Terra platform in 1999 and on Aqua platform in 2002. Wide spectral range (0.4 – 14.5 μm), acquisition in the 36 spectral bands, moderate spatial resolution (250 m - 1 km), free of charge access and near daily global coverage offers the huge opportunity to monitor, quantify, and investigate large scale changes in forest vegetation in response to human actions and climate. The mentioned data are suitable for the development of the Regional Information System (RIS) of ecological and productive state of forest. Because existing MODIS products were

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originally designed for global scale monitoring [13, 6] and their spatial resolution is mostly 1 km, validation of the global MODIS algorithms, their regional based parameterization and creation of products with higher spatial resolution are actual and required issues.

The aim of proposed RIS is to present information about ecological and productive state of forest, based on remote sensing data. The input database of RIS consists predominantly of MODIS and Landsat scenes. The quality of satellite data is sufficient to work with forest compartment as the lowest forest management unit, to which information obtainable from MODIS products can be related. Forest compartment's area (from 5 to 20 ha) approximately corresponds to area of MODIS pixel (6.25 ha in the most important red and infrared bands). If needed, MODIS outputs will be related to higher level of forest ecological or management units i.e. associated forest typological types, forest parts, sub-regions and regions. Nevertheless, ecological and productive state of forest can not be assessed by remote sensing techniques entirely. Despite that, the terms "ecological" and "productive" will be used in this paper to distinguish between two different aspects of proposed RIS.

Spatially the RIS covers whole Slovak territory and surrounding areas (Western Carpatians and northern part of Pannonian basin), what enables better understanding of global changes impact (chemical changes of atmosphere, climate changes) on forests and technically simplifies work with full satellite scene covering selected region (Fig. 1).
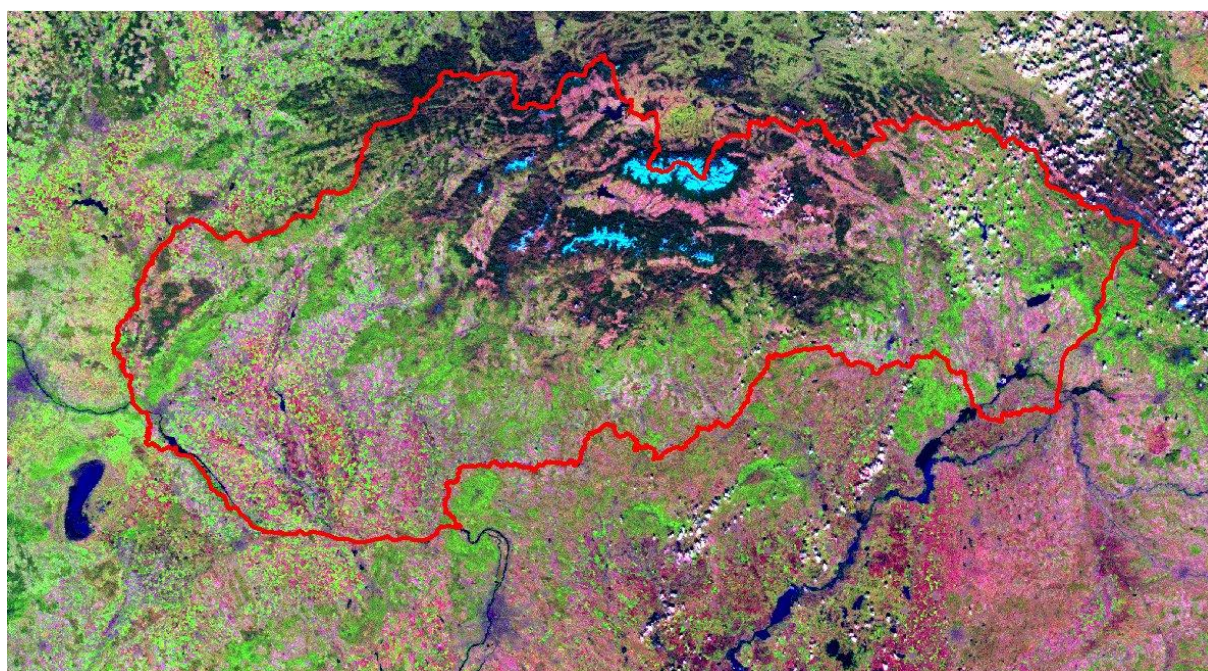

Fig. 1. MODIS scene covering the selected region. Red line – the boundaries of Slovak Republic.

The evaluation of ecological state of forest is based on the identification of areas with the sings of spruce (*Picea abies* L.) stands decline and forest windbreaks. The productive state is assessed by biophysical and productive characteristics of forest ecosystems derived from satellite data from spectroradiometer MODIS, namely: Normalised vegetation index (NDVI), Enhanced vegetation index (EVI), Leaf area index (LAI) and Photosynthetic active radiation absorbed by vegetation (FPAR) [27, 13, 28]; and phonological model [29]. It is proved, that there is close relationship between ecophysiological measurements (NDVI, LAI, FPAR) in the forest stands and reflectance measured by satellite sensors [8, 24, 10]. The data from terrestrial research are used for validation and parameterization of output remote sensing data [5].

The paper presents the proposal of concept of RIS, the comparison of several different approaches to development of specialized tools for management, administration and presentation of information about ecological and productive state of forest. The first results from acquisition, evaluation and calculation of biophysical and productive characteristics of forest ecosystems, derived from satellite data, are also presented.

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2   Material and methods

The material and methods used in this research depend on accessibility of input data and software products. Satellite data with free of charge access were preferred because of their applicability, regional coverage and financial demands. The chosen software products must be accessible to all members of research team.

2.1   The logical and technical structure of RIS

The structure of RIS is optimized to better understand the data processing and acquisition of output information. The end users of RIS should have access to information about ecological and productive state of forest and relevant input data. This led to dividing of RIS into two subsystems, each of them represented to end users by different web map application.
The first subsystem is aimed at evaluation of the ecological state of forest and its changes using the Landsat, SPOT and Aster scenes; the second one is aimed at evaluation of productive state using MODIS data. Each subsystem has its own tools for pre-processing, analyses and presentation of data, included in classical desktop map application (e.g. ArcGIS Desktop) or specially developed in programming languages. The geodatabase is used for data storage and back-up, the presentation is solved by web map applications.

2.2   Software solution

RIS is based on geographical information systems (GIS), which provide plenty of standard tools for work with spatial information [26, 3, 9, 19]. ArcGIS Desktop and ArcGIS Server from ESRI are dominant software environments because they allow operative spatial analyses, multi-user access and safe data storage together with publishing of data over the internet network. Easy and fast development of specialized tools using Python language and their implementation into standard user interface is a big advantage of this software [21, 20]. However, some special analyses are solved using other products, e.g. Erdas Imagine or Idrisi Taiga.
Data storage and back-up is solved via geodatabase [1]. The main difference between classical database and geodatabase (also known as a spatial database) is that the geodatabase records use a geometry data type to represent the geographic location of an object. Database solution provides safe data storage and effective work of several users at the same time with huge amount of data. ESRI Geodatabase (ArcSDE, component of the ArcGIS Server) built upon Microsoft SQL Server was chosen because of robustness and compatibility with other ESRI products.
Specialized software tools were developed for pre-processing and analyses of input data mostly with Python programming language and implemented into RIS map applications [7]. They are also used for automation of processing of huge datasets.
Publishing of output data over the internet is done easily due to chosen software solution and integration of particular ESRI products, which can use the same project file in mxd format for desktop and web map applications.

2.3   Input data

The evaluation of ecological state of forest is based on scenes from satellites Aster (with resolution 15 m), SPOT (10 m) and Landsat 4-5 TM and 7 ETM+ (with resolution 30 and 15 m resp.). The Landsat scenes are provided by USGS free of charge and accessible via GLOVIS application (USGS Global Visualization Viewer, http://glovis.usgs.gov). SPOT and Aster scenes cover area 60x60 km, the cost of one scene is approximately 3000 €. SPOT and Aster have better spatial resolution, but number of spectral channels is lower and processing of scenes is more complicated.
Landsat data cover the whole territory of Slovakia with 6 scenes, with 3 scenes covering 92% of the state territory (Fig. 2). One scene covers area 190x180 km. There are differences in the quality of TM and ETM+ scenes. It is possible to rescale the resolution of ETM+ scenes from 30 to 15 m due to presence of panchromatic channel, but most of the scenes contain strips of missing data (Fig. 3). Only central part of the scene in the satellite path with 21 km width is free of mistakes, but there may be up to 22% of missing data in the scene.
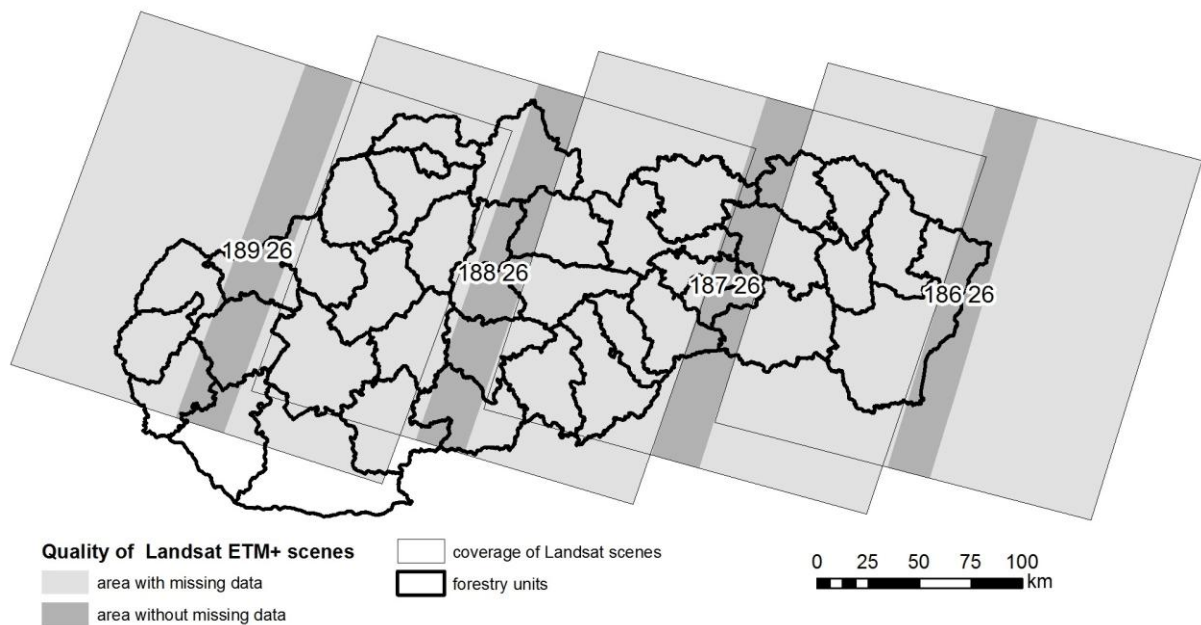
Fig. 2. Landsat scenes covering Slovakia territory and quality of Landsat ETM+
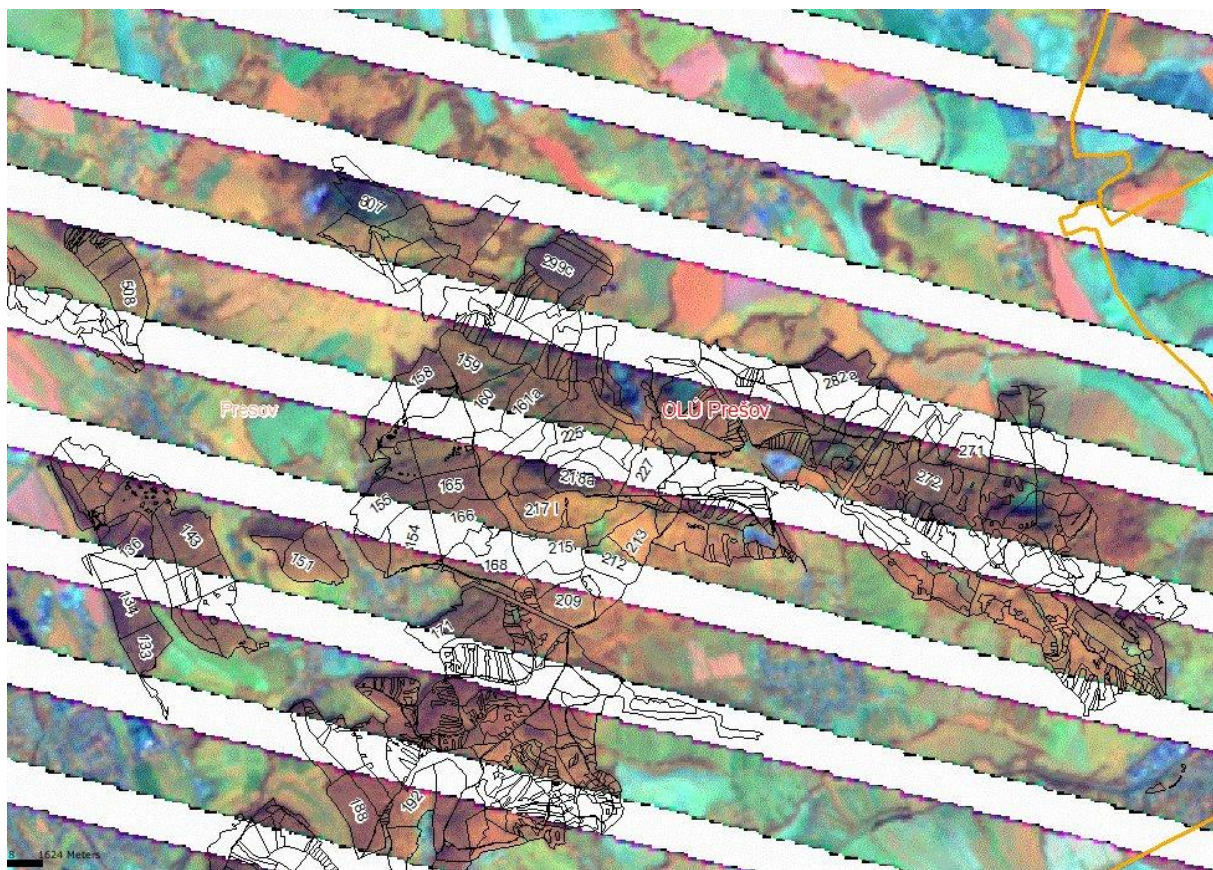

Fig. 3. Missing data in Landsat ETM+ scenes. Black lines – forest compartments.

The subsystem for evaluation of productive state of forest is based on MODIS product MOD09, which represent pre-processed data of surface reflectance with resolution 250 and 500 m. This product has undergone radiometric and atmospheric corrections; it means that absorption and diffusion of radiation in atmosphere were eliminated. Computation of NDVI is based on MOD09 product.

The quality assessment of data is based on the subdataset of quality, which is present in the MODIS products. It defines the quality of computation of pixel values within the product's subdatasets.

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Implementation of quality layer into process of RIS database enables to find potential sources of mistakes.

Global MODIS products (MOD15) with resolution of 1 km – leaf area index (LAI) and photosynthetic active radiation absorbed by vegetation (FPAR) are evaluated by the subdataset of quality (to assess the quality of measurements) and then resampled to 250 m resolution by correlation with NDVI. Product MOD17 (GPP and NPP) is used for comparison of modelled results with resolution 250 m.

The process of downloading and transformation of MODIS data into Krovak projection (S-JTSK) was automated via Python script in ArcGIS Desktop 9.3. The chosen subdatasets are extracted from original HDF files. Spatial resolution of layers is resampled to 250 m. There is still necessity to select the scenes with adequate quality manually. Idrisi Taiga is used for development of phenological model and therefore the data are converted into RST format which is native for IDRISI. Results of the model are converted back into ArcSDE geodatabase.

2.4   Identification of changes of the state of forest

Satellite scenes from SPOT and Aster have to be orthorectified. Then the composition of channels from two subsequent years is created: infrared (year X) – infrared (year X-1) – green (year X-1). This composition shows areas with changed forest stands in red color (Fig. 3). License of the purchased scenes does not allow to publish resulting composition in the full quality, thus the result of the unsupervised classification into 80 (2008-2009) and 256 classes (2007-2008) was used for preparation of web map application. Spatial resolution remained 10 m.

Fig. 4. Changes of the state of forest shown in red color

Processing of Landsat TM scenes is relatively simple; the scenes are transformed into Krovak projection, their contrast and brightness is corrected for easier visual identification of state of forest. Landsat ETM+ scenes are resampled from 30 to 15 m resolution (Pan-sharpening) using standard ESRI method. Strips with missing data can be at least partially removed if there are two overlapping scenes, taken within short period of time (less than 1 month).

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2.5   Modeling of phenophases

Phenology studies periodic plant life cycle events and how these are influenced by seasonal and interannual variations in environment, predominantly in weather and climate. Terrestrial monitoring observations are in progress on 4 monitoring plots. There are monitored phases as follows: onset of greenness, foliation, Lammas shoots, summer coloring, autumn coloring, leaf cast (beginning and the end). Manual on methods and criteria for phenological observations [23] and scale proposed by the Slovak Hydrometeorological Institute [4] was used to evaluate phenophases of selected tree species. Monitoring starts in 1. 4. of each year, with interval of 2 week or less. Each phenophase starts when at least 50% of the trees shows the signs of given phenophase. Duration of phenophase is given by number of days between beginnings of two subsequent phenophases. There are 10 monitored trees on each plot and the plot is also monitored as a whole. Observed tree species are as follows: beech, oak, ash and maple.

Under the modeling of phenology of forest tree species is understood a prediction of main phenological events. Derivation of annual dynamic of Normalized difference vegetation index (NDVI) by using sigmoid curve is solved:

$$v(t) = v_{\min} + v_{amp}(\frac{1}{1+e^{m_1+m_2t}} - \frac{1}{1+e^{m_3+m_4t}}) \qquad \textbf{(1)}$$

Parameters v_{min} and v_{amp} are minimal value and amplitude of vegetation index (NDVI), $m_{1,2,3,4}$ control shape and slope of curve in spring and autumn phase. Phenological curve will be used for determination of beginning of crucial phenological events. They will be determined by derivations and curvatures of the modeled curve. Phenological observations on monitoring plots will be used for verification of hypothesis, that extreme values of curvatures are related to beginnings of phenophases.

2.6   Concept of modeling of primary productivity of forest ecosystems

The basic postulate for modeling of primary production is that relationship exists between absorbed solar energy and productivity [22, 2, 11, 18]. Absorbed photosynthetically active radiation (APAR) is used for estimation of GPP together with respiration in MOD17 algorithms, which are the basis of modeling of gross and net primary production. MOD17 algorithms require input data from 3 sources:

- Specific parameters for each biome are taken from Biome Parameter Look UP Table (BP-LUT). Their values for diurnal and annual algorithms are derived from Biome-BGC (BioGeochemical Cycles) model, which is based on daily meteorological data, geomorphological, pedological and environmental characteristics and specific ecophysiological parameters for biomes.
- Information about incident radiation, including air temperature and relative humidity, are provided by the Data Assimilation Office (DAO), a branch of NASA
- Satellite-derived FPAR

Modeling of gross (GPP) and net primary productivity (NPP) is based on analysis of amount of APAR ($0.4 – 0.7$ µm),

$$APAR = PAR * FPAR \qquad \textbf{(2)}$$

where PAR – flux density of photosynthetically active radiation in $MJ.m^{-2}.day^{-1}$, FPAR – fraction of PAR absorbed by vegetation (between $0 – 1$).

There are some other factors except APAR that influence NPP: concentration of photosynthetic enzymes, structure of forest stand, mean flux density of PAR, costs for maintenance and growth respiration, temperature of forest stand, evapotranspiration, accessibility to soil water and nutrients. Estimation of GPP and NPP using APAR is complicated by these factors and objective parameterization of relationships between GPP, NPP and APAR is seen as a crucial problem. Solution will be based on concept of maximal effectiveness of exploitation of incident radiation, where coefficient of conversion efficiency (ε) [14] is used:

$$GPP = ε * APAR \qquad (3)$$

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The value of ε is biome-specific according to differences in amounts of energy used for respiration and climatic conditions.

Components, modeling intensity of maintenance and grow respirations, will be incorporated into derivation of daily, 8-daily and annual NPP. Yearly NPP will be computed by summation of 8-daily products modified by both types of respiration.

Possibilities of improvement of important input data and map layers are researched because they may be treated as a main source of errors at regional scale. These possibilities are as follows:

- Replacement of meteorological data from DAO by data from Slovak Hydrometeorological Institute. As a result the values of coefficient of conversion efficiency (ε) should be improved.
- Replacement of PAR from NASA database (spatial resolution 1°) by values derived from radiometer AVHRR.
- Improvement of parameters adopted from BPLUT tables
- Improvement of LAI and FPAR. The layers from global products (resolution 1 km) will be replaced by layers with 250 m resolution according to conversion tables [17]. These tables are based on correlation between NDVI and LAI or FPAR.

2.7   Publishing of results on internet network

Due to compatibility of chosen software products the publishing over the internet network is relatively simple process. However, it is crucial from the point of view of end users. Map layers, stored in geodatabase, are organized in desktop map application ArcMap in mxd file format. Visualization of map layers (contrast, color balance, etc.) is optimized, legend is defined and metadata are added within desktop map application. Specialised tools designed for web map application can be added in this step. Final mxd project is directly used by ArcGIS Server to create web map service. Updates of web map application are fast and simple using this technology. Non-spatial information, which can not be added directly into map application, is published on subsidiary RIS web site.

3   Results

Proposed structure of RIS was evolved by gradual development and optimization. RIS compounds of two subsystems aimed at ecological and productive state of forest. Each subsystem has its own tools for data pre-processing, storage, analyses and publication (Fig. 5).
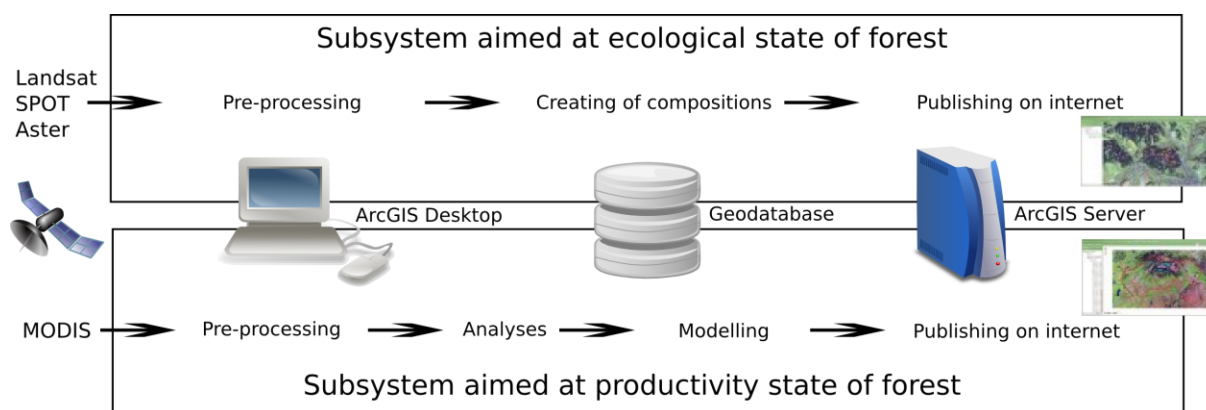

Fig. 5. Structure of regional information system

3.1   Subsystem aimed at ecological state of forest

Two approaches are possible for identification of changes in state of forest. The first is direct identification by composition of satellite scenes from two years. Creating the composition of SPOT and Aster scenes is finance, time and labor consuming, but enables easier identification of changes resulting from spruce decline and windbreaks. Composition will show the areas with change of state in red colors (Fig. 4). Intensity of red color depends on amplitude of change. Forest stands without

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changes are shown in green, green-blue or blue colors. However, accurate identification can still be done only by skilled users. For example, the red color can be found also in areas with cloudiness or if orthorectification was not sufficiently accurate (mostly at the fringe of forest stands). Its important to know, that composition shows only the change and not the state of the forest, it mean that if dead trees were on the same stand on both original scenes, the stand will not be shown in red. Manual for interpretation of the composition was therefore prepared and can be found on subsidiary web page. Mosaic of satellite scenes can be utilized also for evaluation of defoliation of spruce stands, if terrestrial measurements of defoliation are available. Present web map application contains two compositions for central and northern parts of Slovakia, showing the changes within 2007-2008 and 2008-2009 periods.

The second approach, a simple visual comparison of two Landsat scenes, is easier to prepare, but identification of changes may be complicated for unskilled end users and spatial resolution is lower. It is technically possible to add a new scene to the web map application within tens of minutes after it was published by USGS agency. Low costs and full-region coverage are further advantages of Landsat scenes. So far 4 pairs of scenes (2007 – 2009) were prepared for web map application. Scenes contains channels in combination 4/5/3 – near infra-red, mid infra-red and red channel. Strips with missing data in ETM+ scenes were partially removed in areas where two overlapping scenes from short period of time (less than month) were available.

The web map application was already practically tested by government forestry authorities and forest owners as a pilot project (http://www.nlcsk.sk/stales). Besides satellite scenes, the vector layers of forest units were added to enable searching of forest compartments and to improve map readability.

3.2   Subsystem aimed at productivity state of forest

Each MOD09 scene has to undergone quality assessment before the NDVI is computed. The main reason is presence of pixels affected by cloudiness, shadows of clouds and position of satellite. The scenes from 2000-2009 were visually classified into 4 classes according to cloudiness:

- scenes of very high quality – no cloudiness
- scenes of high quality – small part of region covered by cloudiness
- scenes of good quality – larger part of region covered by cloudiness
- scenes of poor quality – region mostly or totally covered by cloudiness

Only scenes of 1st and 2nd class were accepted. Position of satellite was the next criterion for classification. Scenes with nadir lying out of the RIS region were excluded, because their true spatial resolution of 250 m is not guaranteed. As a result the list of 266 days from 2000-2009 with high quality scenes was prepared.

Besides the visual quality assessment, the subdatasets of quality, included in MOD09 products, were analysed. These layers allow quality assessment of measured radiation at pixel level. 16-bit information is used for inclusion or exclusion of the given pixel during computation.

Data needed for verification of LAI and phenophases were acquired from long-term terrestrial measurements on monitoring plots. Vector map layers of forest units with attribute tables were obtained from the database of Forest Research Institute (FRI) of the National Forest Centre of Slovakia.

Daily product with FPAR data is provided by company Geomodel s.r.o. Bratislava, which produce the 15-minutes FPAR data. After the down-scaling and conversion into 8-day cycle this product will be used for further computations.

The output data on productivity of biomass in young spruce and beech stands, acquired from existing research plots of FRI, will be used for calibration and validation in modelling of NPP.

Modeling of phenological phases in forest stands. The curve of NDVI values during 2001-2008 is shown on Fig. 6. Satellite-measured values were computed for stand with prevailing oak (*Quercus cerris* L.) on one monitoring plot in southern Slovakia. The curve respects both basic states of broad-leaves forests, with and without leaves, using 6 parameters.
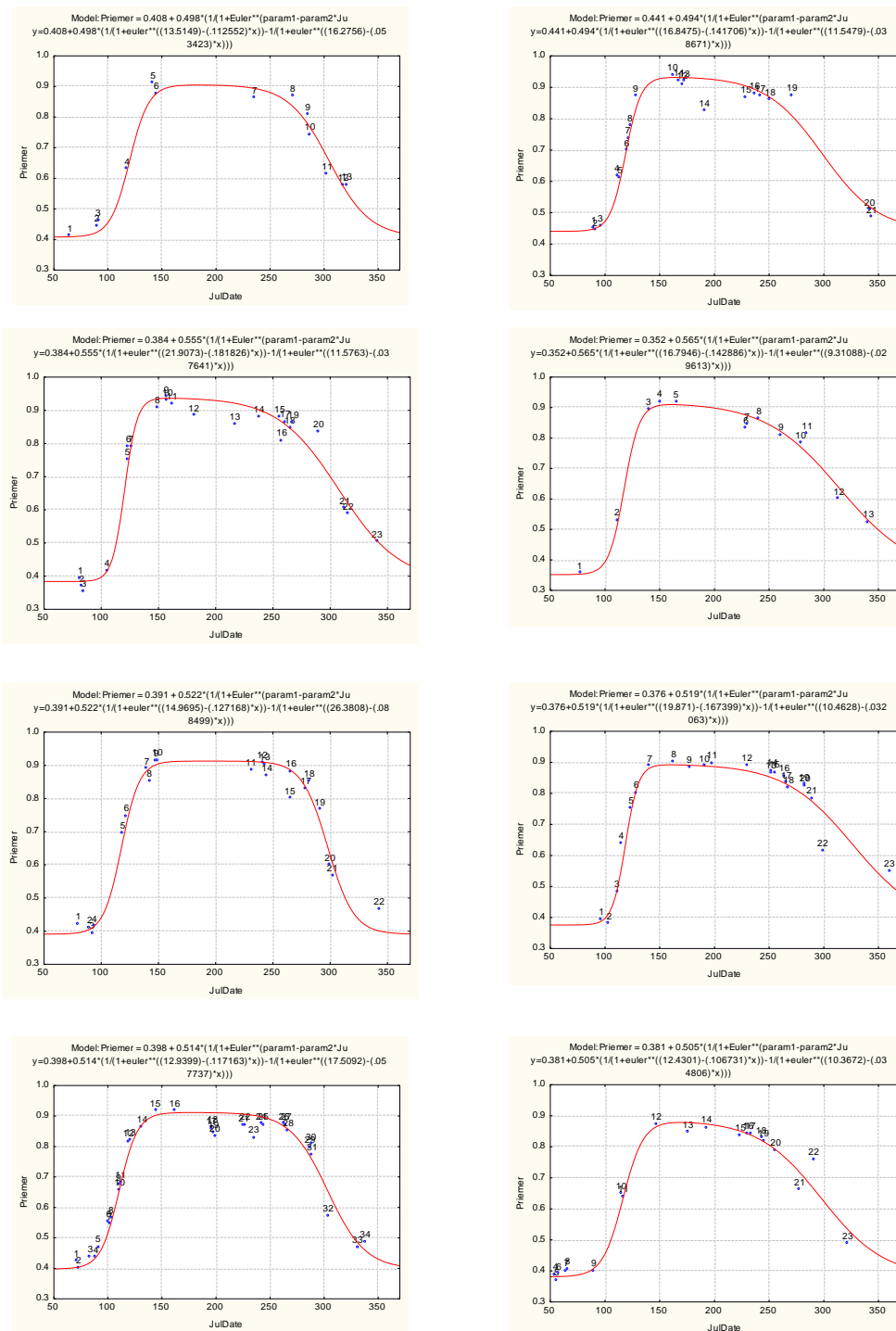
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Fig. 6. NDVI curve based on MODIS (product MOD09) in 2001–2008 for long-term monitoring plot Čifáre, Slovakia. X-axis shows the day of the year (ordinal date), Y-axis the mean value of NDVI based on MODIS data.

Phenological curve is used as a basis for further analyses of relationship between NDVI curve and terrestrially observed phenophases. The aim of analyses is a definition of phenophases using local extremes of NDVI function. After that, evaluation of changes in phenology of forest stands will be possible.

A new software product "Phenological profile" was developed for estimation of parameters of phenological curve, its derivations and curvatures based on NDVI maps (Fig. 7).
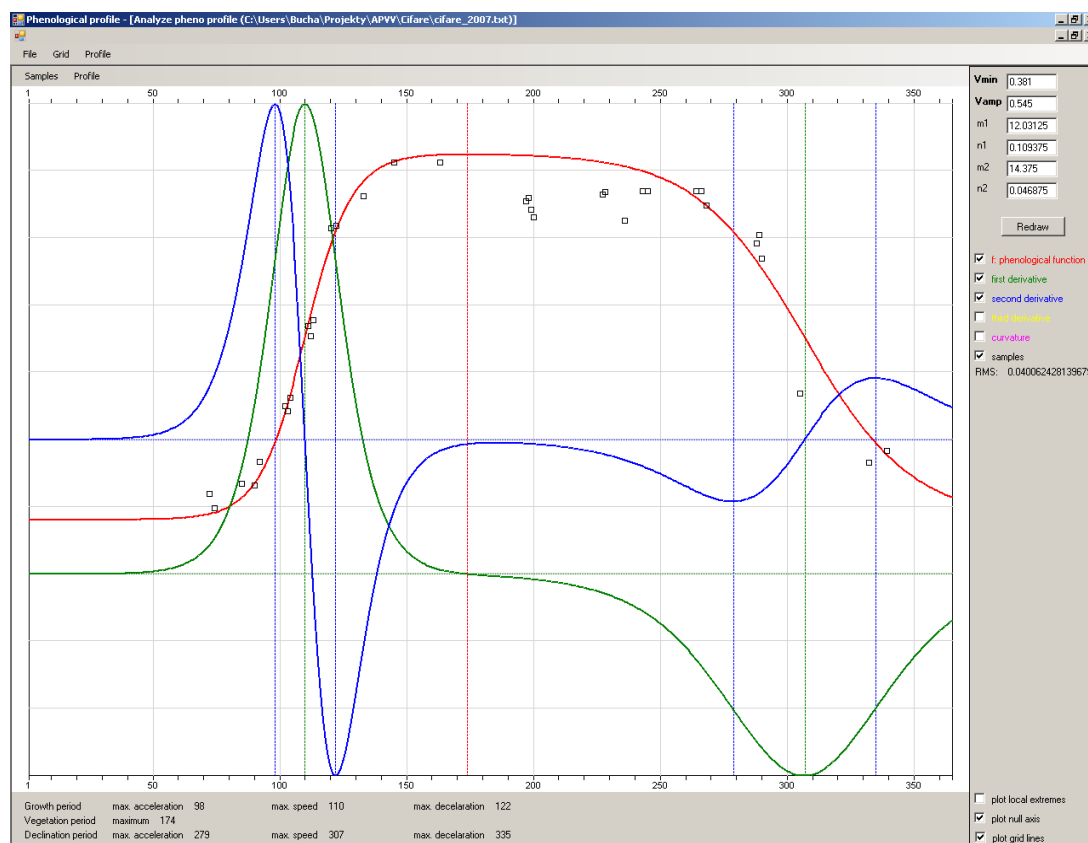
Fig. 6. Modeling of NDVI curve and its derivations

Comparison of terrestrial phenological data and MODIS based NDVI curve shows that NDVI values start to increase approximately 20 days before the begging of budding of *Quercus cerris* is observed. The main reason is the presence of underbrush level in oak stands with dominant bleach thorn (*Prunus spinosa* L.*)* and European privet (*Ligustrum vulgare* L.) which start budding before oaks. Begging of oak foliation is observed at 117th day which is situated after the inflexion point and caused by underbrush level too. The end of foliation at 146th day is near the maximum of NDVI curve. Beginning of autumn yellowing at 283rd day corresponds with minimum of 2nd derivation. The end of the year is again strongly influenced by underbrush level. The further research is needed to evaluate this influence on NDVI curve.

Modeling of productivity of forest ecosystems. Modeling of productivity was started with preparation of knowledge base (Fig. 8) using Netweaver TM software. Knowledge base comprises the information from published papers and MODIS algorithms.

Knowledge base will be applied to input data within EMDS environment, an extension of ArcGIS Desktop, during the next phase of research project.

Partial results of the project are presented on its web site (http://www.nlcsk.sk/satlesys). Map application of the subsystem contains raster layers of MODIS scenes and NDVI, the other thematic layers are added continually.
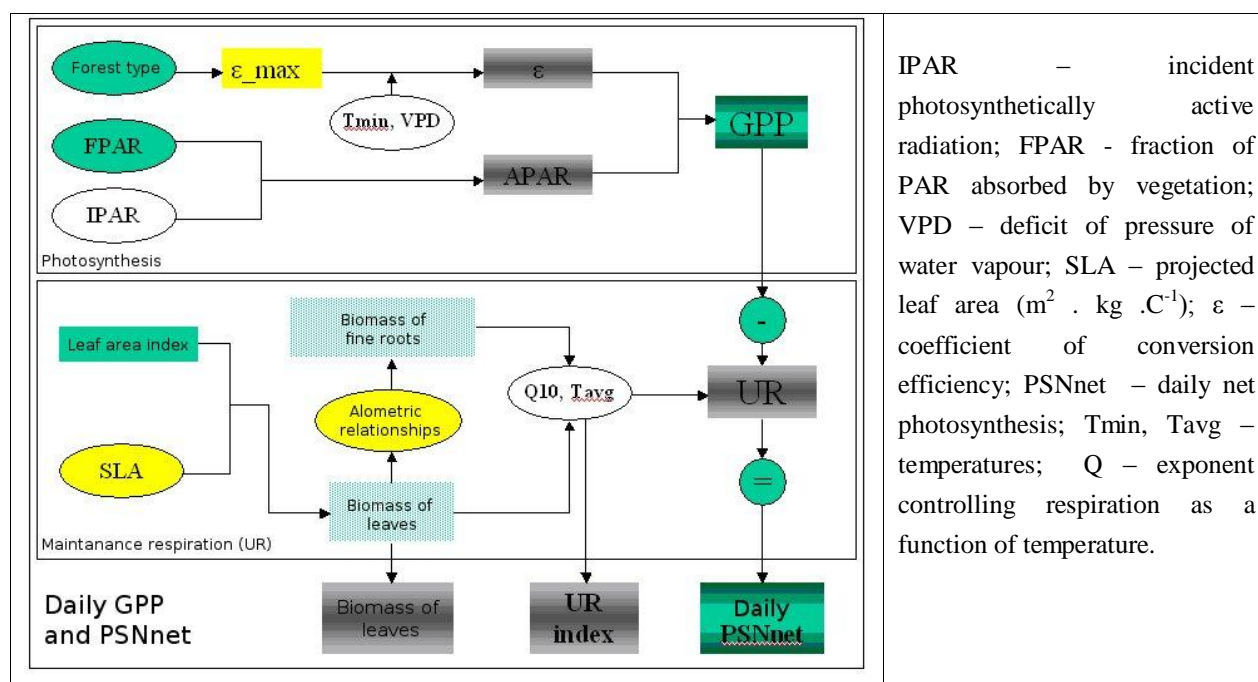
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Fig. 6. Computation of GPP a PSNnet based on MODIS data (green), meteorological data (white), alometric relationships (yellow) and estimations (stipple). Outputs are shaded.

4   Conclusions

The paper presents results from first phase of research project aimed at development of regional information system (RIS) of ecological and productive state of forest.

The process of acquisition, evaluation and calculation of biophysical and productive characteristics of forest ecosystems derived from satellite data from spectroradiometer MODIS is presented. The solved problems are aimed at (i) selection and analysis of MODIS products and their quality, (ii) derivation of annual dynamic of Normalized difference vegetation index (NDVI) by using sigmoid curve, (iii) analyses of the curve course in relation to the observed phenophases and (iv) analyses of possibilities for replacing and refining of input parameters for modeling of primary production of forest ecosystems. Proposed structure of two partial subsystems is a result of practical implementation based on input data utilized in the development of system for continuous evaluation of forest ecosystems response on environment changes. Both subsystems use the same software products from ESRI, enriched by self-developed tools, for data pre-processing, storage and publishing.

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