The Irkutsk Regional Information System for Environmental Protection (IRIS)

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ABSTRACT

The Irkutsk Regional Information System for Environmental Protection (IRIS) assesses the current status and dynamics of the Irkutsk region's forestry environment as influenced by man-made changes and anthropogenic impact. IRIS aims to efficiently share up-to-date and long-term satellite-based Earth Observation (EO) data and socio-economic information within earth science community, regional governance and nature-protecting services to identify environmental impacts that are both economic and socially responsible. IRIS is integrating methods of econometrics, a framework to estimate quantitatively the contribution of specific industrial branches, here the Lumber Industry Complex (LIC) into the economy of Irkutsk Province. Thus, for integrated environmentally-adjusted forest management, tools are necessary which refer to the complexity of the natural resource to be managed and the difficulty to predict the factors or driving forces influencing them. Advanced EO products, image processing techniques embedded in an object-oriented GIS framework, web service technology and open standards as recommended by the Open Geospatial Consortium (OGC^{TM}) help to handle the complex character of the problem. IRIS benefits and contributes to on-going European-Russian cooperation projects and is funded by the European Commission (INCO-CT2006-015110).

Keywords: Forestry, Econometrics, Earth observation, Trend analysis, SAR

1. Introduction

Russian Federation possesses the largest forestry resources in the world, containing about 22% of the world's forest. One of the most wooded regions of Russian Federation is the Irkutsk Province compromising 4.5% of Russian territory. The Irkutsk Province is dominated by typical taiga forest. 81% of the territory is covered by forest, which corresponds to an area of 66.8 million hectares or 9.9% of Russian forested areas. With it the province takes the first place in Russia. The annual gain is estimated to 80 million m^3 timber (Savel'eva et al. 1998, Shvidenko and Nilsson 2003). The proportion of wood processing and pulp and paper industries is about 20% of the industrial production of the region. Thus, the resource potential determines the leading role of the forest complex in industries' structure alongside with fuel and energy, chemical, petrochemical and the nonferrous metallurgy complex. Lumber industries' enterprises thereby are the major ones in many administrative districts.

The Irkutsk Province is political important since its development represents the economic and sustainable growth in the vast rural territories of Siberia. The many years of human impact culminated in heavy industrial development during Soviet times. Large areas are under intensive anthropogenic press, which intends to be substantially increased. Atmospheric pollution by large industrial zones, contamination by untreated waste water effluents and higher run-off loads of nutrients caused by intensified land use and timber logging are pointed out as region's most apparent man-made environmental risks. The high value forests of the Irkutsk Province are also affected by this development and since then information provision for forest protection with respect to natural and human-induced disturbances is needed. Due to common forest fire events as well as intensive human activities such as clear cutting and cultivation the Irkutsk Province is characterized by intensive large area changes of forests.

However, the controlling of forest resources and their active involvement into the economic cycle do not provide the region with proper sustainability and qualitative economic growth. Irkutsk Province, as a typical resource-rich Russian Federation administrative region, suffers much of these capacities and material inputs and, accordingly,

reaches only low levels of added values and low labour productivity in comparison to developed countries. Moreover, the big number of industrial facilities in the territory has resulted in serious ecological consequences: high and very high levels of pollution of the natural environments are stably verifiable in 42 % of Irkutsk Provinces' settlements, which frequently exceed average over Russian Federations indicators (Oblmashinform 2005). Under these conditions, the formation of a qualitative economic growth is not ensured and economic, ecologic and social risks come up. Considering the above mentioned remarks, the issue of an adequate measurement of the region's economy functioning by taking into account a certain number of factors describing the public welfare, is obvious and requires a solution.
The evaluation of the influence of specific industrial branches onto the economic well-being of the society takes a center stage by economists for more than a decade. Special attention is paid to the system problems, such as the reduction of negative impacts of specific productions and industries on the environment or the provision of ecologically sustainable or acceptable functioning of economic systems. There are a lot of disputes on how to better determine and compare levels of public welfare of various regions, areas, countries. In 1946 and for the first time, it was offered by Hicks to solve this problem with the help of the net national product parameter. The researches in this direction were continued by Sollow (1956) or Weitzman (1976, 1999). Criticism came up since the net national product does not take into account the negative aspects of the economy functioning from a society's point of view. It was offered to correct the net national product indicator by values characterizing depletion of natural resources and environmental degradation. New approaches, such as the estimation of an environmentally-adjusted net domestic product (Bartelmus 2001) dealing with the social costs of environmental impacts.

One of the major challenges for an integrative environmental development is the integrated management of natural resources and socio-economic developments in order to secure a sufficient availability of timber. Thus, for an integrated management methodical designs are necessary which refer to the complexity of the resources to be managed and the difficulty to monitor them. A recent, sophisticated approach is to understand landscapes consists in modelling their structures as a fuzzy system composed of complicated, dynamic, stochastic processes. This methodology supports specifically landscape-ecosystem based approaches in which ecosystems of different scales are regarded as primary units for quantification and modelling (Seppelt and Voinov 2002). Satellite-based Earth Observation (EO) platforms are herein the primary data source from which the above mentioned landscape patterns can be assessed. Without a priori information about these patterns, observations made by remote sensing sensors supply an independent and unbiased framework to analyze the land cover at multiple scales (Marceau and Hay 1999, Hay et al. 2003). IRIS' strategy follows an approach that considers spatial, spectral and temporal resolution demands by combining a variety of EO products and is thus in agreement with the suggested key issues by latest landscape research: data acquisition and scaling (Wu and Hobbs 2002). Satellite images are one of the basic sources of information for study of the forest state and land cover monitoring (Wagner et al. 2003, Miles et al. 2003). The multi-band and multi-temporal images from the EO platforms SPOT-Vegetation, TERRA/MODIS as well as ENVISAT/ASAR and ALOS/PALSAR data deliver a wealth of environmental information. Therefore, such remote sensing information is used for environmental studies, risk management and so on. Moreover, the results of these studies serve as a base, core or additional information for creating specific or multipurpose GIS.

It is a methodical challenge to derive sound parameter sets from EO data and to implement spatial tools in large regions and, at least across administrative boundaries. In this context IRIS will profit from recent technological developments, like universal connectivity, new advanced sensors (ALOS-PALSAR, TerraSAR-X), comprehensive analysis environments (GIS, Spatial Data Infrastructures), standards for data, metadata and web services (like OGC), or communication platforms for computer-supported cooperative work (Wikis). One of essential components of IRIS is the implementation of an Open Source GIS system. Open Source technology is a growing field that encourages the free sharing of software, codes and services. The goal of the Open Geospatial Consortium (OGC) is to promote standard open software interfaces. These interfaces will enable geoprocessing so that different geospatial systems are able to communicate with each other.

Within the concept of IRIS, the authors undertake an attempt

- *to assess the current status and dynamics of the province's forests;*
- *by using and efficiently sharing multi-scale up-to-date as well as long-term satellite-based EO data;*
- *to identify human-induced regional as well as global environmental impacts that are both economic and socially responsible;*

- *to estimate quantitatively the contribution of the Lumber Industry Complex into the economy of Irkutsk Province;*
- *to determine how essential is the factor of environmental degradation while estimating and forecasting the Gross Regional Product (GRP).*

This paper is aimed to show the potential of an integration of monetary-based methods of econometric analysis with spatial-explicit and time-invariant methods of geobiophysical measurements from space. Thus, the mathematical model describing the role of the Lumber Industry Complex (LIC) in the generation of the Gross Regional Product (GRP) of Irkutsk Province with consideration to environmental impacts will not discussed in detail. Nevertheless, a description of the initial information for the formation of GRP as well as some conclusions out of the forecasting will be given. To better understand the intrinsic value of both the forest resource and the LIC (and its role in the formation of the GBP) it is important to monitor the region under changing environmental and socio-economic conditions. Thus, more attention is paid to multi-scale EO and image processing, where EO platforms are the primary data source for area-wide, daily, weekly or yearly time-series analyses to better understand the inter-annual variations of the environmental processes and geobiophysical turnovers of forests in the region.

2. Data

What is available from finished and on-going projects? IRIS is a follow-on activity to the EU-funded SIBERIA-II project (Multi-Sensor Concepts for Greenhouse Gas Accounting of Northern Eurasia, EVG2-2001-00008). SIBERIA-II was a joint Russian-European remote sensing project that improved greenhouse gas accounting over a 300 Million ha area in the central Siberian region including the Irkutsk Province. The products which have been generated include regional maps of land cover, fire induced disturbances, phenology, snow depth, snow melt date, onset and duration of freeze and thaw, LAI and others. Most of these products are available for several years and cover the entire SIBERIA-II region.
The GIS database already developed for the Irkutsk region by the Institute for Applied Systems Analysis (IIASA) together with a number of Russian institutions includes a number of layers (landscape, soil, vegetation, forests, utilities), which will effectively used for the goals of the regional information system on environmental protection and anthropogenically-driven risk assessment. However, in order to serve as a basis of IRIS, the GIS is required to be adapted to recent technological standards such as web map services (WMS) and web feature services (WFS).
The 'GMES (Global Monitoring for Environment and Security) Service Element Forest Monitoring' (GSE FM) provides another tool for effective forest monitoring and inventory at regional scale for the Irkutsk region. Reliable and up-to-date information on forest characteristics and changes are required by the State Forest Service of Irkutsk General Survey of Natural Resources (FS of GSNR) in order to fulfil several international and national treaties, for its own forest policy as well as to perform the task of delivering data to the federal level. Specific information needs arise in the area of continuous inventory of forest and forest fund land as a basis for perspective and operative planning, an assessment of changes and trends such as ARD (Afforestation, Reforestation, and Deforestation).
Socio-economic directions and fields of expertise such as the programmes and mechanisms of the development of regions, inter-budget relations in the region, and links in the system "Economy and Environment" as well as all the data for the econometric modelling are covered by the Department of Regional Economic and Social Problems of the Irkutsk Science Centre.

New advanced multi-scale EO data/ products are a necessity. To ensure a continuous, region-wide approach we have chosen spatially medium remote sensing data from Terra/Aqua MODIS and SPOT-4 sensors. These temporally high resolution EO land products time series serve as baseline information for higher resolution images at a more or less particular point in time. So far, IRIS uses the monthly Land Surface Temperature (LST) product (MOD11C3; 1/20 degree or 5km per pixel) and SPOT-4 VEGETATION Seasonal Mosaics (1km) for trend analyses. Up-to-date and spatially high resolution C-band SAR data from ENVISAT-ASAR (25-50 meters) and L-band SAR data from ALOS-PALSAR (6.25 meters) are used for reliable and up-to-date information on forest extent and changes in areas with high dynamics.
The SPOT data source of the time series analysis is based on S-10 standard products from the SPOT-4 Vegetation sensor. The data used in this study is provided by the TerraNorte Information System by the Russian Academy of Science's Space Research Institute (Bartalev 2005). The TerraNorte Information System provides seasonal mosaics

derived by maximum NDVI images of SPOT-VGT S-10 products for the seasons spring (March-May), summer (June-August) and fall (September-November). The time period of the mosaics is from summer 1998 to fall 2005. The MOD11C3 product is composted and averaged from the global daily CMG product (MOD11C1) over a period of 32 days. MOD11C3 time coverage is 2000-2006 on a monthly base with a ground resolution of 1/20 degree. According to the above mentioned NDVI seasons trends for the same time intervals has been calculated.
13 cross-polarised C-Band ENVISAT ASAR APP IS7 scenes were used. The data have been delivered as precision images = pixel spacing 12.5 m x 12.5 m. The scenes have been pre-processed and georeferenced with GAMMA RS Software. Therein, the pixel size has been resampled to 25 m resolution. SRTM C-Band DEM was used as input for ortho-rectification of SAR data with GAMMA RS Software. After a raw registration via orbit parameters a synthetic SAR image, generated from the DEM is cross-correlated with the scene to be ortho-rectified. The accuracy is in the order of one pixel (compared to the DEM).
Until today the data were acquired both at no costs from internet databases and external project agreements or at low cost reproduction fees. Expenses were therefore be minimised. For the future, the University of Jena (as principle investigator on the use in forest environments) is looking forward to major data contingents on spatial very high resolution data (1–15 meters per pixel) from the recently successful launched X-Band SAR sensor TerraSAR-X.

3. Methods

For an integrated environmental management methodical designs are necessary which refer to the complexity of the natural resource to be managed and the difficulty to predict the factors or driving forces influencing them. IRIS focuses on the current status and dynamics of the region's forestry environment as influenced by man-made changes and thus is using econometrics analysis and a multi-scale EO data framework.
Thereby, GRP has been chosen as the major indicator, characterizing the efficiency of the economy functioning. To measure the GRP, econometric models have been applied. Such models usually consist of two parts, estimation equations and defined equations as that the GRP is composed of consumption, investment, and export off import. The most important statistical method to get the estimation equation is regression analysis. Here, the GBP is the independent variable and several factors are the dependent variables in forming the regression equation. In this way the dependency of the LIC's net product from several factors was determined to estimate the contribution of the LIC into the net regional product of Irkutsk Province with consideration of the amount of environmental contaminations. Possible changes in the GRP indicator, related to the inclusion of ecological pollution characteristics into the calculations had been determined, the forecasted LIC's GRP values had been constructed. For this econometrics analysis the following factors have been considered to form the regression model:

- the purchasing power in the LIC (salaries, dividends, allowances and other payments in all enterprises in the province, savings);
- the harm made to the environment while LIC operates;
- major LIC's funds (fixed capital);
- total number of the forest cuttings (obtaining of the major resource for the LIC);
- production of goods made from the forest resource;
- allowable pollution level, established by the State, the excess of this level results in fines and penalties;
- rate of return used in the capitals market (LIBOR rate);
- volumes of the retiring assets in the LIC;
- round woods export;
- LIC products export;
- shadow coefficients of the influence of the indicators presented on the GRP (national income in terms of the benefit should reflect the well being, and should be definitely corrected for the values of the resources depletion, increase of the pollution and increase of the national non-resource wealth, all these is evaluated as the shadows prices);
- the dependency ratio of the pollution from the permissions granted.

Apart from the above mentioned econometrics, IRIS' spatial data base on forest state and extent as well as environmental pollution needs to be developed. Thus, the multi-scale EO framework follows three tasks,

- (1) time-series analyses to better understand the inter-annual variations of the environmental processes and geobiophysical turnovers of forests (MOD11, MOD12, MOD13, MOD17 products);

- (2) the generation of reliable and up-to-date information on forest extent and changes in areas with high dynamics (ASAR,PALSAR, TerraSAR) and
- (3) at a later date the linkage of (1) and (2) in an object-oriented multi-scale framework.

(1) Trend analyses of photosynthetic activity and land surface temperature
Climate and human impact are influencing factors on Irkutsk Province's forest ecosystem fluxes. Thus, to detect significant positive and negative trends in both plants photosynthetic activity (1998 – 2005, Huettig et al. 2006) and land surface temperature (2000–2006), a temporal trend analysis using the ordinary least squares (OLS) regression technique on the basis of a linear regression model as presented by Fuller (1998) and Zhou et al. (2001) was applied on the NDVI/LST dataset. Every pixel value is plotted over time and the linear model fit is calculated by minimizing the sum of the vertical deviations (least squares) from each data point to the line. By applying the linear regression model on satellite time series data it will be possible to detect linear changes of the pixel values over time. These linear variations of the surface reflectance/radiance can be detected either as positive trends (slope b is a positive value) or negative trends (slope value is negative).The slope value thus gives information about the annual increase or decrease of pixel value, here LST/NDVI values. Another parameter taken into account is the coefficient of determination (R^2), which describes how strong the linear relationship is between LST or NDVI change and time. To avoid interpretation errors the trends are analyzed on a confidence level of 95% using standard t-test. The SPOT-VGT NDVI and the MOD11C3 LST datasets were regressed over six respective seven years for the same time interval (seasonal) as well as in a higher resoluted (monthly). Abrupt changes of land surface characteristics like fire events, logging or mining activities can lead to misinterpretations of the regression outputs. The standard t-test to detect step changes within satellite data (De Beurs et al. 2005) has therefore been calculated.

(2) Forest mapping using SAR data
According to the cross- and along-track components of radar images, a strong dependence of radar backscatter to mountain slopes is given. Thus, for forest mapping, radiometric and geometric corrections are necessary. Prerequisite is the availability of precise elevation data. For forestry, the use of low incidence angles enhances the sensitivity to biomass, whereas the use of high incidence angles enhances the discrimination of forest types through interaction with forest structure. The use of cross polarisation improves the discrimination between volume scattering (vegetation) and surface scattering (soil), in this case the forest/non-forest discrimination and the retrieval of low biomass values (forest regeneration, re-growth).
Forest area maps for the Irkutsk Province are generated using cross-polarized ENVISAT-ASAR precision images acquired at large incidence angles (swath 7). For quality control and product verification archived Landsat TM5 and Landsat ETM 7 as well as ground reference data have been used. The acceptability threshold of the thematic mapping accuracy is 90% for forest areas and 85% for forest area changes, respectively. Image processing tasks included in this order:

- Sigma Nought calculation, Ortho-rectification of SAR data, Topographic Normalization, Calculation and Transformation from linear values in dB, Stacking of Landsat ETM 7 data and ASAR data (HV, HH, ratio), Geometric Accuracy Assessment, Segmentation, Classification, Change Detection, Post Classification Processing, Accuracy Assessment.

4. First results and discussion

The role of LIC in the formation of GRP
The econometric analysis conducted allows us to make the following conclusions:

- The statistical dependency of the GRP produced by the LIC from the solvent demand created in the LIC, the pollutions made by the LIC, the cost estimation of the LIC's products, and fixed assets used in the LIC, turned out to be significant under all the factors, thus:
- The solvent demand results in the growth of the province's regional product and is the most significant factor of the growth of the society's wealth.
- The pollutions paid for (enterprises are obliged to pay for the environmental contaminations, which exceed the limited by the state values, as penalties) are the factor positively influencing the well-being of the society. It is explained by the fact, that with an increase of pollutions, the deductions into the budget grow, the production grows.

- The process of the deforestation is organized inefficiently: there is a high share of unaccounted cuttings, a smaller output of the wood products per square meter in comparison to the developed countries, a resource oriented export, a smaller margin profit from the functioning of the production.
- the increase of the quantity of the permissions to pollute results in the fall of the well-being of the society: the growth of the unpaid pollutions, the growth of the uncompensated harm to the environment.
- the GRP values were obtained with consideration of the harm made to the environmental degradation, an inefficiencent use of the resource and a fixed assets usage.

First results from the EO framework

Canopy temperature is among the main determinants of the rate of growth of vegetation. Increasing temperatures are a major stress factor on the composition of vegetative ecotypes and plant (forest) physiology and force the outbreak of insect calamities and forest fires. Moreover, permafrost is influenced with rising risk potentials for infrastructures (slope failures). Time series analyses of 7-year record satellite observation of monthly Terra-MODIS Land Surface Temperature Climate Modelling Grid data (MOD11C3) for the Irkutsk Province were carried out and trends in daytime Land Surface Temperatures were assessed. The slope parameter gives information about the annual increase of pixel values, originally Kelvin. Areas most affected by July surface temperature increase are in the Krasnoyarsk Kray northwest of the Irkutsk Province and in the Republic of Buryatia to the East. Within Irkutsk Province, Zhigalovskij, Mamsko-Chujskij and Chunskij districts show a considerable increase. In comparison to spring or fall, summer season shows regions (see Tab.1) with strong negative (-1.67) as well as positive (1.59) temperature trends. The negative impact results from June (-2.74), the positive one is carried by July (2.54). Seasonal averaging leads to disappearing trend locations.

Table 1: Slope of positive and negative trends for seasonal and monthly LST data for 2000-2006, Irkutsk Province. The trends are analyzed on a confidence level of 95% using standard t-test. Values represent changes in Kelvin.

	Min		Max		Mean		Stdev	
time\trend	positive	negative	positive	negative	positive	negative	positive	negative
spring	0.53	-1.45	0.68	-0.18	0.60	-0.67	0.03	0.13
summer	0.14	-1.67	1.59	-0.12	0.55	-0.74	0.16	0.24
fall	0.14	-0.50	1.37	-0.15	0.70	-0.30	0.16	0.07
June	0.13	-2.74	1.28	-0.16	0.54	-0.75	0.14	0.28
July	0.20	NaN	2.54	NaN	0.94	NaN	0.21	NaN
August	0.16	-1.43	1.89	-0.16	0.95	-0.64	0.34	0.17

Time series analyses of 6-year record satellite observation of seasonal SPOT-VGT mosaics for Northern Eurasia were carried out and trends in vegetation photosynthetic activity were assessed (Hüttig et al. 2006). SPOT-VGT time coverage is 1998-2005 for summer (Jun-Aug) and fall (Sep-Nov), 1999-2005 for spring season (Mar-May), with a ground resolution of 1km. Trends are the increase/decrease of NDVI per year. Significant trend patterns were detected for spring, summer and fall. NDVI trends over the boreal forest ecosystems in spring and fall indicate an onset of vegetation greening and a lengthening of the photosynthetic period. For summer trends (Fig.1), Tundra or disturbed areas show an increase or "greening" of vegetation. Districts most affected are Katangskij, Nizhneudinskij and Ust'-Ilimskij. In contrast, and after excluding impacts like clearcuts, fires or insect outbreaks, there are areas with decreasing photosynthetic activity, also called "browning" of vegetation (Bunn and Goetz 2006). Most notably affected areas are in Ust'-Kutskij, Kirenskij and Bodajbinskij district.

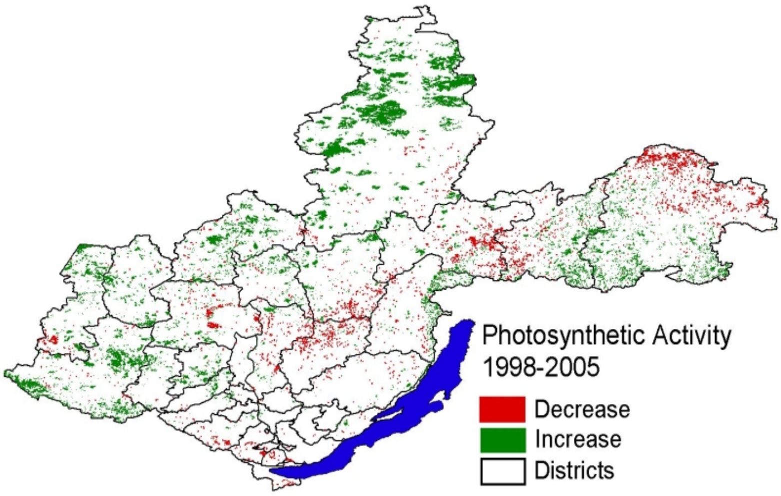

Figure 1: Positive (green) and negative (red) trends of summer NDVI 1998-2005 (trends at 95% confidence level).

Forest mapping is performed from high resolution ENVISAT-ASAR Precision images by analyzing image texture. Because of the fuzzy character of the forest/non-forest classification problem, the integration of an object-oriented multi-scale GIS framework (eCognition^{TM}) considering spatial, spectral and temporal resolution demands has been carried out to reduce operator judgement as source of error in the delineation process. Figure 2 shows a part of the Forest Area Change Map 2000-2006 which is based on a Landsat ETM 7 classification 2000-2002 and the ENVISAT ASAR APP IS7 classification 2006. Moreover, the results of NDVI/LST trend analyses are dislayed. It has to be mentioned that most of the change areas from 'unforested area' to 'forest' (light green) depend on the better detectability of roads, pipelines and smaller clear cuts in Landsat ETM 7 scenes. Especially the detection of roads and pipelines in ASAR scenes depend on the view direction of the sensor and the extension of the object and are therefore not always observable in the SAR data. In some cases, old clear cuts visible in Landsat ETM 7 scenes feature already enough biomass or young forest stands in ASAR APP IS7 scenes that the backscatter signal reaches higher dB values than bare soil or fresh clear cuts and are therefore classified as 'forest' in the SAR data.

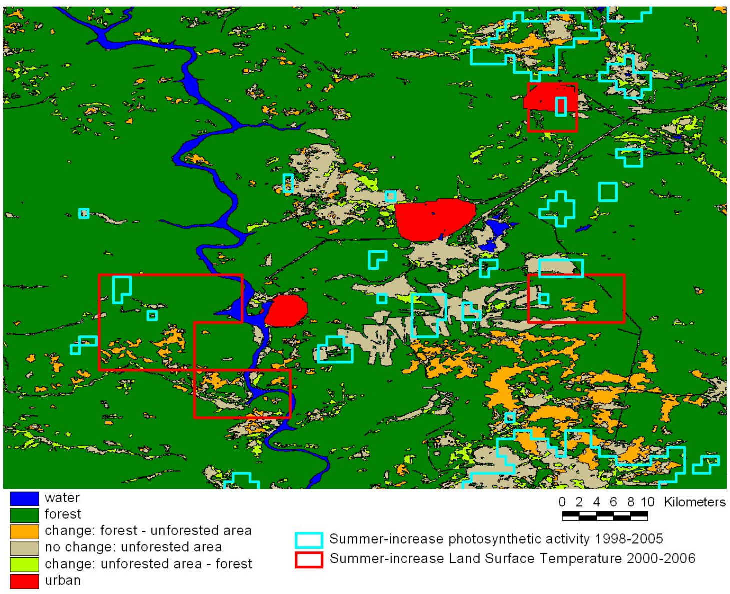

Figure 2: Forest area change map overlaid by results of seasonal trend analysis: summer-increase of photosynthetic activity and summer-increase of LST (Projection: Geographic Lat/Lon).

5. Conclusion

Fast-growing economies and worldwide growing consumer demands have a considerable impact on natural resources and thus on the way Earth Science community addresses the acquisition, storage and analyses of socio-economic and environmental data. Reliable and up-to-date information on land surface characteristics and changes are required by decision makers in order to fulfill several international and national treaties and for its own policy. Satellite-based Earth Observation serve thereby as an independent and unbiased framework to analyze landscape structure and related environmental processes as well as impacts at multiple spatial, temporal and thematic scales. Trend analyses of temporally high resolution EO products with well defined product uncertainties and downstream advanced image processing techniques such as for spatially high resolution SAR (ENVISAT-ASAR) embedded in an object-oriented GIS framework, help to handle the complex character of managing the forest resource. Without the proper implementation of such a multi-scale EO-concept, IRIS is not able to satisfactory solve its major tasks of integrating methods of econometrics. Econometrics can be used as a framework to estimate quantitatively the contribution of the Lumber Industry Complex into the economy of Irkutsk Province, here the formation of the Gross Regional Product. More research in terms of the effective integration of other EO products as well as steps towards the regionalization of the econometric model needs to be done. Another essential component of IRIS is to compound and provide data and knowledge from different scientific domains by using web-based services and open standards as recommended by the Open Geospatial Consortium (OGC^{TM}). For the resulting tools, user community involvement (science, regional governance) is the most challenging objective and remains an ongoing process.

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