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 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. Thus, for integrated environmental 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 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).

1. INTRODUCTION

1.1. Region's impact on global levels

Russia possesses the largest forestry resources in the world, containing about 22% of the world's forest. One of the most wooded regions of Russia is the Irkutsk region compromising 4.5% of Russian territory. The Irkutsk region is dominated by typical taiga forest. 82% of the territory is covered by forest, which corresponds to an area of 71.5 million hectares or 9.9% of Russian forested areas [1]. Over the last decade China's exports of wood products have been fast growing and hence their imports of timber [2]. The high value forests of the Irkutsk region are 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 region is characterized by intensive large area changes of forests.

The Irkutsk region is environmentally important due to its central, indicatory location in the Eurasian boreal zone with pronounced expected climate change [3]. Its ecosystem vulnerability is very high and recovery rate very slow due to the extreme continental climate. For the last centuries a strong Atlantic control has been shown to affect the timing of the ice break-up in Lake Baikal [4]. This observation supports a strong teleconnection between the Central Asian and European weather systems that cause a well-defined atmospheric pattern in the region. These links to the global atmospheric system as well as the necessities of estimating the current carbon balance of Northern Eurasia [5] make the region highly attractive to climate research on a global scale.

1.2. Anthropogenic impact on the local environment

The Irkutsk region is politically 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 – causing electricity demands which are supplied by world's largest hydro-power plant system along the Angara River. 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 today's most apparent man-made environmental risks for Irkutsk region.

In studies of the anthropogenic impact on the environment, an important aspect is the spatial and temporal variability of gaseous pollutants and aerosols in the atmosphere [6]. Numerical simulations allow to reduce the volume of costly and time consuming experimental studies as well as to assess the contribution of local and remote emission sources to the secondary pollution of the regional forestry and soil conditions. It is important here to conduct a risk assessment and determine the potential anthropogenic "signal" among a great variety of photochemical air pollutants and aerosol particles.

Under all these circumstances an issue that must be addressed is the monitoring of the forest resources of the region and the subsequent analyses pertaining to environmental impacts.

1.3. Landscape-Ecosystem approaches

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 fresh water and 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 [7].

1.4. Satellite-based EO is crucial

Satellite-based Earth Observation (EO) platforms are 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 analyse the land cover at multiple scales [8, 9]. 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" [10].

Satellite images are one of the basic sources of information for study of the forest state and land cover monitoring [11, 12]. The multi-band and multi-temporal images from the EO platforms SPOT-Vegetation, TERRA/MODIS, Monitor-E/RDSA, Aura/OMI as well as ENVISAT/ASAR and ALOS/PALSAR data deliver a wealth of environmental information. Therefore, such remote sensing information is often 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.

1.5. Considering recent technological developments

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 (internet, asynchronous JavaScript, mashups), 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.

2. DATA AND METHODS

2.1. 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 region. 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 requires to 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" are covered by the Department of Regional Economic and Social Problems of the Irkutsk Science Centre.

2.2. Additional multi-scale EO data/ products

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 turnovers.

To ensure a continuous, area-wide approach we have chosen spatially low but temporally high resolution atmospheric data from the “Total Ozone Mapping Spectrometer” (TOMS) and the “Ozone Monitoring Instrument” (OMI). Both sensors provide temporal high resolution global information about the total ozone content as well as aerosol distribution of the atmosphere. TOMS/OMI data represent the primary long-term, continuous record of satellite-based observations available for use in monitoring global and regional trends in total ozone and aerosols over the past 25 years.

Spatially medium resolution EO land products such as time series from Terra/Aqua MODIS or SPOT-VGT 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; 5km per pixel) and SPOT-VGT NDVI (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.

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 new X-Band SAR sensor TerraSAR-X.

2.3. Trend analyses using linear regression

To detect significant positive and negative trends in both the SPOT-VGT NDVI mosaics (1998 – 2005) and the MODIS LST products (2000 – 2006), a temporal trend analysis using the ordinary least squares (OLS) regression technique on the basis of a linear regression model ($Y = a + bX + å$) as presented by [13] and [14] is applied on the dataset. 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 each pixel slope of the linear regression (Kelvin) and R^2 values (in %) were extracted. 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.

2.4. SAR data processing

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 our case the forest/non-forest discrimination and the retrieval of low biomass values (forest regeneration, re-growth). In case of forest area/type applications ENVISAT-ASAR AP mode with VV/VH polarisation for swaths IS4-6 can be recommended.

Forest area maps for the Irkutsk region 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 are used. The following products are provided: “Forest Area Map 2005/2006”, “Forest Area Change Map”, “ARD Area Map”, “Burned Area Map”, “Clear Cut Map”. The acceptability threshold of the thematic mapping accuracy is 90% for forest areas and 85% for forest area changes, respectively.

3. RESULTS AND DISCUSSION

3.1. Aerosol Index

TOMS (on Nimbus-7) Aerosol Index monthly means from daily global 1.0° x 1.25° products from January 1980 – December 1992 and OMI TOMS-like (on Aura) Aerosol Index monthly means (Fig. 1) from daily global 0.25° x 0.25° products from August 2004 until now have been processed for IRIS. The spatial and temporal variability of aerosols in the atmosphere are important for studies of the anthropogenic impact on the environment. The data serve as base for numerical simulations, which allow assessing the contribution of local and remote emission sources to the secondary pollution of the regional forestry and soil conditions.

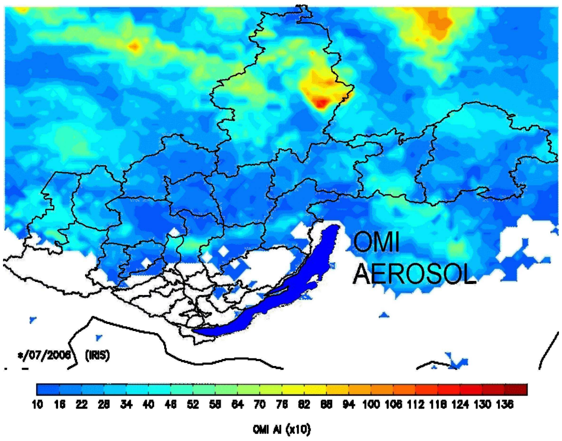

Figure 1 UV Aerosol Index from OMI on Aura: monthly mean July 2006. High AI values due to smoke from forest fires.

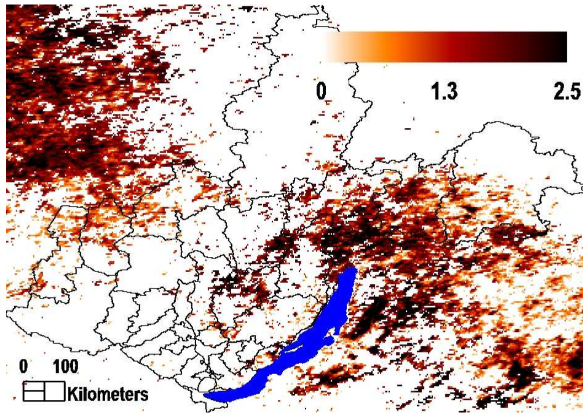

Figure 2 Slope of positive trends for monthly LST data for July (2000-2006). The trends are analyzed on a confidence level of 95% using standard t-test.

3.2. Temperature trends

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 region were carried out and trends in daytime Land Surface Temperatures were assessed. MOD11C3 is simply composited and averaged from the global 8-day CMG product (MOD11C2) over a period of 32 days. MOD11C2 again is composited and averaged from the global daily CMG product (MOD11C1) over a period of 8 days. Science quality status is 'validated' but product accuracy has been estimated using only a small number of independent measurements. MOD11C3 time coverage is 2000-2006 on a monthly base with a ground resolution of 5km. Trends are analyzed on a confidence level of 95% using standard t-test and show the increase/decrease of LST per year. The slope parameter in Fig.2 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 region and in the Republic of Buryatia to the East. Within Irkutsk region, Zhigalovskij, Mamsko-Chujskij and Chunskij districts show a considerable increase. Another parameter taken into account is the coefficient of determination (R^2), which describes how strong the linear relationship is between LST change and time.

3.3. Trends in photosynthetic activity

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 [15]. 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.3), Tundra or disturbed areas show an increase or "greening" of vegetation.

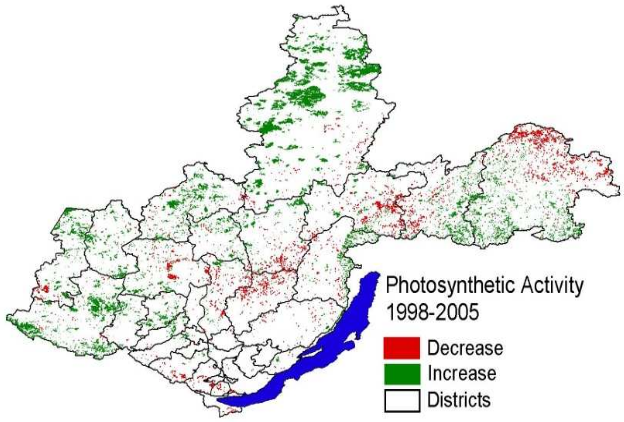

Figure 3 Positive (green) and negative (red) trends of summer NDVI 1998-2005 (trends at 95% confidence level).

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 [16]. Most notably affected areas are in Ust'-Kutskij, Kirenskij and Bodajbinskij district.

3.4. Clearcut delineation

Clearcut delineation is performed from high resolution ALOS-PALSAR Precision images (6.25 m, Fig.4) 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™) considering spatial, spectral and temporal resolution demands has been carried out to reduce operator judgement as source of error in the delineation process.

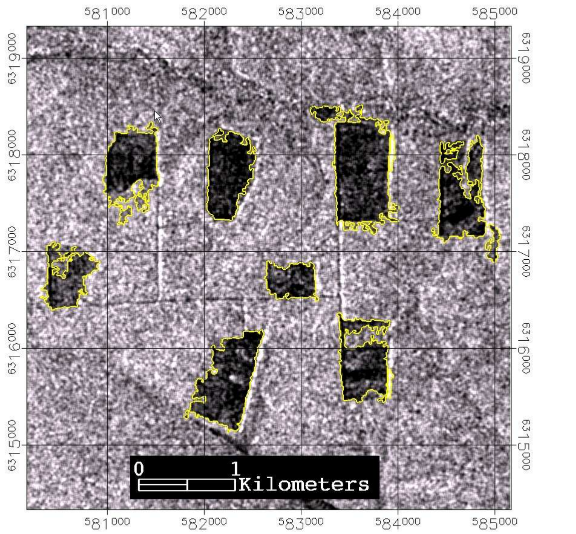

Figure 4 ALOS-PALSAR Precision image from 14th of August 2006 and delineated clearcuts (Projection: UTM Zone 47 North, WGS-84).

3.5. Web service technology

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. Consequently, IRIS’ spatial data base (Fig.5) will be implemented as 3-tier architecture with database server (PostgreSQL), application server (Geoserver or Mapbender Client Suite) and internet browser. PostgreSQL with the PostGIS extension follows the Simple Features for SQL specification from the Open Geospatial Consortium. The application server acts as a OpenGIS-compliant web services layer on top of existing data sources. For a later stage, it is in discussion that the Mapbender Client Suite as a framework for managing spatial data services will be implemented as IRIS Online-GIS. Mapbender provides interfaces not only for displaying and navigating but also for querying OGC Open Web Services. Moreover, Mapbender provides interfaces for user and group administration and management functionality for maps displayed and data served by OGC Open Web Services.

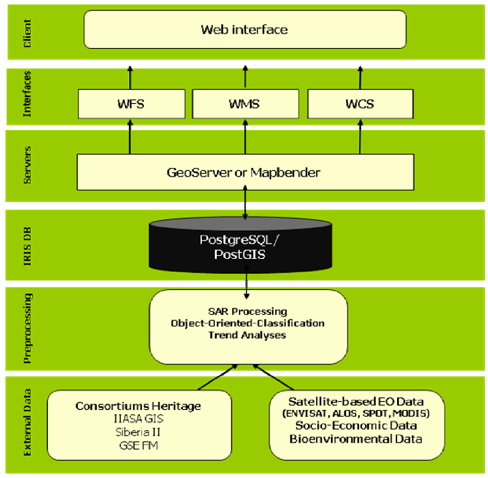

Figure 5 Concept of data representation and dissemination.

4. SUMMARY

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 spatial 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 (EO) serve thereby as an independent and unbiased framework to analyze landscape structure and related environmental processes as well as impacts at multiple 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 (ALOS-PALSAR, ENVISAT-ASAR) embedded in an object-oriented GIS framework, help to handle the complex character of the problem. Without the proper implementation of such a multi-sensor EO-concept, IRIS is not able to satisfactory solve its major tasks. The 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™). For the resulting tools, user community involvement (science, regional governance) is the most challenging objective and remains an ongoing process.

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REFERENCES

1. Shvidenko A., Nilsson S. (2003). A synthesis of the impact of Russian forests on the global carbon budget for 1961-1998. *Tellus* **55B**, 391-415.
2. White, A., Sun, X., Canby, K., Xu, J., Barr, C., Katsigris, E., Bull, G., Cossalter, C., & Nilsson S. (2006). China and the Global Market for Forest Products: Trends, Implications, and Steps to Transform the Trade to Benefit Forests and Livelihoods, Washington D.C.: Forest Trends, Center for International Forestry Research, and Chinese Center for Agricultural Policy.
3. Lapiens, A., Shvidenko, A., Shepaschenko, D. G., Nilsson, S., and Aiyyer, A. (2005). Acclimation of Russian forests to recent changes in climate. *Global Change Biology*, **vol. 11**, pp. 2090-2102.
4. Livingston, D.M. (2000). Ice break-up on southern Lake Baikal and its relationship to local and regional air temperatures in Siberia and to the North Atlantic Oscillation. *Limnology and Oceanography*, **44/6**, 1486-1497.
5. Beer, C., Schmullius, C. & Lucht, W. (2005). Estimating the current carbon balance of Northern Eurasia by incorporating satellite-derived land cover information into a Dynamic Global Vegetation Model. *Geophysical Research Abstracts*, **vol. 7**, 10271.
6. Aloyan A.E. (2000). Mathematical modelling of the interaction of gas species and aerosols in atmospheric dispersive systems. *Russian Journal of Numerical Analysis and Mathematical Modelling*, **15(1-4)**, 211-224.
7. Seppelt, R. & Voinov A. (2002). Optimization methodology for land use patterns using spatially explicit landscape models. *Ecological Modeling*. **151 (2/3)**, 125–142.
8. Marceau, D.J. & Hay G.J. (1999). Contributions of remote sensing to the scale issue. *Canadian Journal of Remote Sensing* **25 (4)**, 357-366.
9. Hay, G.J., Blaschke, T., Marceau, D.J. & Bouchard, A., (2003). A comparison of three image-object methods for the multiscale analysis of landscape structure. *ISPRS Journal of Photogrammetry & Remote Sensing* **57**, 327-345.
10. Wu, J. & Hobbs R. (2002). Key issues and research priorities in landscape ecology. *Landscape Ecology*, **17 (4)**, 355-365.
11. Wagner, W., Luckman, A., Vietmeier, J., Tansey, K., Balzter, H., Schmullius, C., Davidson, M., Gaveau, D., Gluck, M., Le Toan, T., Quegan, S., Shvidenko, A., Wiesmann, A., and Yu, J. J. (2003). Large-scale mapping of boreal forest in SIBERIA using ERS tandem coherence and JERS backscatter data. Remote Sensing of Environment, **vol. 85**, pp. 125-144.
12. Miles V.V., Bobylev, L.P., Maximov, S.V., Johannessen O.M. & Pitulko, V.M. (2003). An approach for assessing boreal forest conditions based on combined use of satellite SAR and multi-spectral data. *International Journal of the Remote Sensing.* **vol. 24**, No. 22, pp. 4447-4466.
13. Fuller, D.O. (1998). Trends in NDVI time series and there relation to rangeland and crop production in Senegal, 1987-1993. *Int. J. of Remote Sensing*, **19**, 10, 2013-2018.
14. Zhou, L. M., Tucker, C. J., Kaufmann, R. K., Slayback, D., Shabanov, N. V., & Myneni, R. B. (2001). Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *J. of Geophys. Res.*, **106**, 16, 20,069-20,083.
15. Hüttich, C., Herold, M., Schmullius, C., Egorov, V. Ego & BARTALEV, S. A. (2006). SPOT-VGT NDVI and NDWI Trends 1998-2005 as indicators of recent land cover change processes in Northern Eurasia. Presented at: 2nd Workshop of the EARSeL Special Interest Group on Land Use and Land Cover, 28-30 September 2006.
16. Bunn, A.G. & Goetz, S.J. (2006). Trends in Satellite-Observed Circumpolar Photosynthetic Activity from 1982 to 2003: The Influence of Seasonality, Cover Type, and Vegetation Density. *Earth Interactions*, **Vol. 10**.