Forest Cover Change in Siberia - Results from the Siberia-II Project

S. Hese [a,*], C. Schmullius [a]

[a] Institute of Geography, Friedrich-Schiller University of Jena, 07743 Jena, Germany - (soeren.hese,c.schmullius)@uni-jena.de

Abstract – In this paper results of an object oriented image analysis approach for forest change detection based on spectral, contextual and object specific attributes are presented. A change detection classification system is developed that derives a change map using 1989 and the status in 2000 for selected forest inventory test territories in Siberia with extensive ground truth information from Russian forest inventory enterprises. Multitemporal Landsat satellite data sets are co-registered and atmosphere corrected. A hierarchical object-based and multi temporal class description is developed and applied to different multitemporal data sets. This work presents the methodology and results of a combination of a direct two-date change detection and a post classification procedure that also uses landuse change information.

Keywords: Forest change, deforestation, Kyoto, SIBERIA-II, object oriented image analysis, change detection.

1. INTRODUCTION

The work on forest cover change detection presented in this paper is part of the EU project SIBERIA-II (Multi-Sensor Concepts for Greenhouse Gas Accounting of Northern Eurasia) (Schmullius and Hese, 2002; Hese et al., 2002; Santoro et al., 2002). The scientific objective of the SIBERIA-II project is to integrate Earth observation and biosphere process models such that full greenhouse gas accounting within a significant part of the biosphere can be quantified. Global estimates of the net carbon flux due to land cover changes are complicated by critical uncertainties like distribution and rate of deforestation and biomass burning, conversions from natural land cover and rate of reforestation and re-growth of deforested or burned land. The Kyoto Protocol (KP) carbon emission inventory is related to land cover changes with respect only to areas directly affected by human action through ARD (Afforestation, Reforestation, Deforestation) (Scole and Qi, 1999).

It is important to differentiate the needs by the KP and by full carbon accounting (FCA). FCA accounts for all possible sources and sinks and not only for those related to ARD under a specific and restricting definition of forest.

Differentiation between natural and human induced forest changes (as required by the KP) is a complex task and asks for an analysis of underlying causes of disturbances. As noted already in Scole and Qi (1999) forest management practices which change growth rates of forests and selective logging are not considered in the KP. Interpretation of the possible causes of forest changes is often impossible with Earth observation. Analysis of contextual and structural information using post classification analysis with contextual GIS analysis systems in multiple scales can however improve the potential of remote sensing for Kyoto ARD mapping. There will however remain restrictions to extract underlying causes of land cover changes with remote sensing. A combination of Earth observation with extensive ground truth and local forest enterprise information to deliver precise information to these questions is essential.

Different forest cover change detection approaches have been proposed in the past. Coppin and Bauer (1994) analyzed vegetation indexes using standardized differencing and selective principal component analysis. 14 change features were generated and the Jeffries-Matusita distance for best minimum separability was used as a measure of best statistical divergence to select the best change feature dataset. Copping and Bauer (1994) concluded that the most promising change features are the standardized difference of brightness, the second principal component of greenness, the second principal component of brightness, the second principal component of the green ratio and the standardized difference of greenness. This pointed towards the Kauth-Thomas brightness and greenness indexes and the green ratio as the vegetation indexes with the most relevant forest cover change information. It was also noted that analysis of change that is beyond the spectral-radiometric information would need the incorporation in a GIS framework with artificial intelligence capabilities. Other studies used direct multi-date classifications or hyper clustering (Leckie et al., 2002), change vector analysis, parcel-based change detection procedures, artificial neural networks (Gopal and Woodcock, 1996), cross-correlation analysis (Koeln and Bissonnette, 2000) and various post classification change detection methods. Important reviews of change detection methods have been published by Singh (1989) and Coppin and Bauer (1996).

The object-based strategy for data classification (Baatz and Schäpe (1999) and Benz et al. (2004)) uses as a first stage a segmentation into different scales of image object primitives according to spatial and spectral features. This segmentation is a bottom up region merging technique starting with one pixel sized objects. In numerous subsequent steps smaller objects are merged into bigger objects (pair wise clustering) minimizing the weighted heterogeneity of resulting objects using the size and a parameter of heterogeneity (local optimization procedure) (Benz et al. 2004). This concept has the advantage to account for contextual information using image objects instead of the pixel based concept used frequently as the basic element in image processing. In a second stage rule-based decisions can be used to classify the multi scale image objects. Class based feature definitions (integrating a post classification analysis) are possible as well as the inheritance of class descriptions to form a class hierarchy. Image processing tasks can be performed using vector shape and vector

* Corresponding author.

characteristics. Results can be also analyzed and presented in vector format (polygons with attributes) instead of the raster cell format. This increases the flexibility of this image processing concept and integrates GIS-like data queries in an attribute database directly into the image processing and analysis approach. New attributes (like object shape or structural characteristics e.g. distance to other objects) can be used on the basis of the vector data format.

Object based image analysis has been used since 1999 for different forest classification approaches. Halounova (2004) used the object oriented approach to classify B&W aerial photos with textural features. Yijun and Hussin (2003) classified tropical deforestation in East Kalimantan using the object oriented approach and Mitri and Gitas (2002) developed an object oriented classification model for burned area mapping. Flanders et al. (2003) tested the object oriented approach for cut block delineation.

Different advantages over pixel-based approaches have been published mainly using very high resolution airborne or orbital Earth observation data. The primary advantage of reducing spectral variability in high spatial resolution data sets (spatial resolution better 1 m) is only one aspect of object oriented image analysis. For the development of change detection procedures new GIS-like analysis concepts are important. Object shape in different scales based on a simplification through vectorisation can be used to differentiate clear cuts from other deforestation processes that do not show specific object shapes with a high rectangular fit (Hese and Schmullius, 2004). Multi-scale object information can be used to increase the classification accuracy of classes that have to be defined using textural information instead of spectral information (e.g. the spectral variability in urban areas is preferably classified using larger objects). Class related classification can be used to build rules for complex neighborhood relations to already classified image objects. This can be used to function as a classification of object structure. Such an approach can be applied e.g. to connect the classification of clear cuts to the classification of linear road objects beyond a parent change class. Transportation is prerequisite for logging activities and can be used as GIS-like context information. Road networks that were created in forested areas are secondary information for the detection of logging processes.

Using the class hierarchy with inheritance of features, simple change – no-change masks can be developed that provide a powerful global (inherited) approach for the adaptation to other data sets.

One drawback of the combined use of post-classification procedures using class related features and direct two-date change detection in one procedure is the complex error propagation logic that can lead to unstable classification results.

2. DATA

Ground truth information from test territories with extensive forest inventory data from forest enterprises in Russia is used for this analysis (on ground forest inventory and planning (FIP) for intensively managed forests). These datasets cover different regions in Siberia (Table A). Multi-temporal Landsat ETM and TM5 data stacks for these areas were acquired from 1989 and 2000 covering areas in the Krasnoyarsky Kray and Irkutsk Oblast (Landsat path and row: 140/20, 141/20, 142/20, 143/20, 135/21, 136/21). To correct for path radiance in multi temporal data atmosphere correction algorithms were employed using algorithms from Richter (1996). Some Landsat TM5 data sets showed a "salt and pepper" effect which appeared randomly at different places in the image geometry and without correlation between the different sensor bands. This noise was corrected using a threshold based selective filter technique that changes the effected pixels to the mean of the surrounding 8 pixel values if a defined threshold is exceeded. Adjacent Landsat scenes were relative corrected to an atmosphere corrected multi temporal master scene using histogram matching techniques to allow the application of training areas and signatures to larger areas. Reprojection to the specific Siberia-II "Albers Equal Area Conical WGS84" projection was performed for all datasets.

Table A: Forest inventory enterprises in Siberia for the forest cover change analysis (IIASA - International Institute for Applied Systems Analysis - GIS ground truth database).

Test Territories	East	North	East	North
Krasnoyarsky Kray				
Bolshe-Murtinsky	91.83	56.83	94.00	57.33
Chunsky	95.17	57.42	98.25	58.08
Irkutsk Oblast				
Primorsky	102.09	55.58	102.56	55.99
Shestakovsky	102.94	56.10	104.51	56.68
Juzhno-Baikalsky	103.08	51.33	104.75	51.83

3. METHOD

The first step in object oriented image analysis is the segmentation into object primitives using a bottom up region merging algorithm. Three different object levels are generated for the forest change detection approach using different thresholds for object merging based on multitemporal data from 1989 and 2000. The class hierarchy that is created is based on the primary segmentation levels. A change and no-change parent class is created using a simple standardized change ratio (Coppin and Bauer, 1994) of the red Landsat band. Clouds, cloud shadows and water objects are classified with the Brightness calculated for Landsat ETM and TM5. These classes are grouped together to form one class and are excluded from the change detection classification process. This is done by inheriting an inverted expression through the change – no-change parent class of the finest segmentation level.

The final forest change classification is done in the segmentation level with the smallest objects. Again a no-change and change "decision tree" is created using a standardized multi temporal change ratio of the red and the green channel. "Forestation on deforested areas" and "Deforestation" is classified using the multitemporal near infrared difference and NDVI thresholds. "Forestation on deforested areas" is defined as deforested in 1989 and reaching an age of 10 years in 2000. Deforestation is defined as not forested in 2000 but in a forest state in 1989. The classification is done using a NIR difference image and NDVI thresholds.

The human induced landuse conversion of agriculture land (that has not been forest before) to forested land is named "Afforestation". For the classification of this specific change class differentiation of urban areas, agricultural used areas and forested areas in 1989 is important. In order to integrate this additional information into the change analysis system class related features are used. Using class related features a landuse change classification can be combined with a forest change mapping approach.

It should be noted that these definition do not follow exactly the definitions for Afforestation, Reforestation and Deforestation. The improvement of ARD classification with Earth observation is still subject of ongoing research using context information to classify human induced changes and differentiate different types of changes with probability estimations. The limitations to derive these class definitions using Earth observation (EO) have already been mentioned in this paper.

4. RESULTS

Results of the forest cover change classification are provided in Table B. Part of the analyzed data was masked due to cloud coverage and not used for the classification (Figure 1). Deforestation and Forestation are between 3 and 5 % of the classified area and the Forestation on "non-forested areas in 1989" can be neglected with below 0.1 %.

Old fire scars and logging activities are not differentiated in this work. Although it is possible to differentiate these change classes using image object shape characteristics this approach has proven to be not stable enough to be used with large datasets and is subject of ongoing research. The analyzed area shows only moderate forest changes. This is however not the case in other regions of Siberia where severe deforestation caused by pollution or fire occurred.

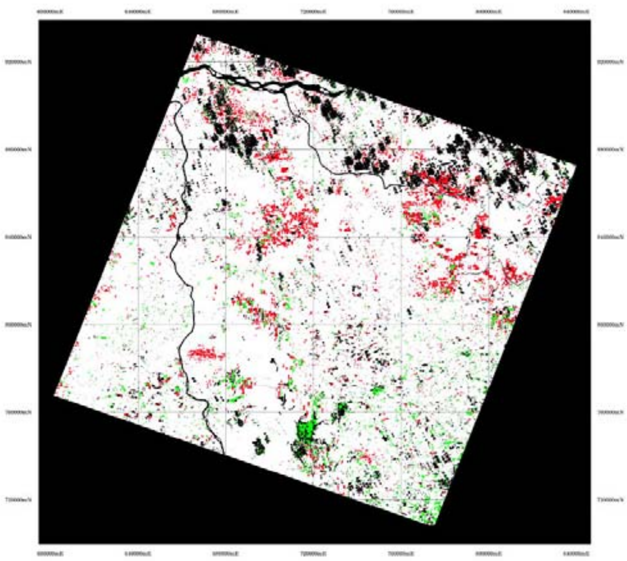

Figure 1: Forest change map (Landsat scene, approximately 180x180 km) with deforested areas (in red), forestation on areas that have been forest before (in green) and forestation on areas that have not been forest before (in cyan) in the south of Siberia (Bolshe Murtinsky) Landsat 142/20. Masked clouded areas, cloud-shadows and water areas appear in black.

Table B: Forest change area statistics for 3 Landsat scenes for the test territories Chunsky and Bolshe Murtinsky.

Class	Area in hectares
Path/Row: 142/20 (Bolshe Murtinsky)	
Deforestation	157668.53
Forestation on deforested land	74761.91
Forestation on non-forest land	1495.68
No change	2669942.00
Masked	178128.33
Path/Row: 143/20 (Bolshe Murtinsky)	
Deforestation	104981.10
Forestation on deforested land	101454.97
Forestation on non-forest land	1931.98
No change	2837849.50
Masked	68684.27
Path/Row: 140/20 (Chunsky)	
Deforestation	134878.34
Forestation on deforested land	124979.38
Forestation on non-forested land	6386.06
No change	2663196.25
Masked	189718.58

5. ACKNOWLEDGEMENTS

This work is part of the project SIBERIA-II which is a shared-cost action financed through the 5th Framework Programme of the European Commission, Environment and Sustainable Development sub-programme, generic activity 7.2: Development of generic Earth Observation Technologies (Contract No. EVG1-CT-2001-00048).

6. REFERENCES

M. Baatz, A. Schäpe, "Object-oriented and multi-scale image analysis in semantic networks, in: proceedings of the 2nd International Symposium: Operationalization of Remote Sensing, 16-20 August, ITC, NL, 1999.

U.C. Benz, P. Hofmann, G. Willhauck, I. Langenfelder, M. Heynen, "Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information", ISPRS Journal of Photogrammetry and Remote Sensing, 58 (2004), 239-258, 2004.

P.R.Coppin, M.E. Bauer,"Processing of Multitemporal Landsat TM Imagery to Optimize Extraction of Forest Cover Change Features", IEEE Transactions on Geoscience and Remote Sensing, Vol. 32, No. 4, July, 1994.

P.R. Coppin, M.E. Bauer, "Digital Change Detection in Forest Ecosystems with Remote Sensing Imagery", Remote Sensing Reviews, 1996, Vol. 13, pp 207-234, 1996.

D. Flanders, M. Hall-Beyer, J. Pereverzoff, "Preliminary evaluation of eCognition object-based software for cut block delineation and feature extraction", *Canadian Journal of Remote Sensing*, Vol. 29, No. 4, pp.441-452, 2003.

S. Gopal, C. Woodcock, "Remote Sensing of Forest Change using Artifical Neural Networks", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 34, no. 2, March 1996.

L. Halounova, "Textural classification of B&W aerial photos for the forest classification", Remote Sensing in Transition, Goossens (ed.), Millpress, Rotterdam, 2004

S. Hese, C. Schmullius, H. Balzter, W. Cramer, F. Gerard, R. Kidd, T. LeToan, W. Lucht, A. Luckman, I. McCallum, S. Nilsson, A. Petrocchi, S. Plummer, S. Quegan, A. Shvidenko, L. Skinner, S. Venevsky, S. Voigt, W. Wagner, U. Wegmüller & A. Wiesmann, "Sensor Systems and Data Products in SIBERIA-II - a Multi-Sensor Approach for Full Greenhouse Gas Accounting in

Siberia", *ForestSAT proceedings*, Edinburgh, 5-9 August 2002, Forest Research, Forestry Commission, 2002.

S. Hese, C. Schmullius, "Approaches to Kyoto Afforestation, Reforestation and Deforestation Mapping in Siberia using Object Oriented Change Detection Methods", GGRS 1st Göttingen GIS and Remote Sensing Days, Göttingen, Germany, 2004.

G. Koeln, J. Bissonnette, "Cross-correlation analysis: mapping landcover change with a historic landcover database and a recent, single date multispectral image", in Proc. 2000 ASPRS Annual Convention, Washington D.C., 2000.

D. Leckie, N. Walsworth, J. Dechka and M. Wulder, "An Investigation of Two Date Unsupervised Classification in the Context of a National Program for Landsat Based Forest Change Mapping", Proceeding of the International Geoscience and Remote Sensing Symposium (IGARSS) and 24th Symposium of the Canadian Remote Sensing Society, June 24-28, Toronto, Canada, 2002.

G.H. Mitri, I.Z. Gitas, "The development of an object-oriented classification model for operational burned area mapping on the Mediterranean island of Thasos using Landsat TM images", Forest Fire Research and Wildlife Fire Safety, Viegas (ed.), Millpress, Rotterdam, 2002.

R. Richter, "A spatially adaptive fast atmospheric correction algorithm", *Intern. Journal of Remote Sensing*, vol. 17, no. 6, 1201-1214, 1996.

M. Santoro, C. Schmullius, L. Eriksson & S. Hese, "The SIBERIA and SIBERIA-II projects: an overview", Proceedings of *SPIE*, vol 4886, SPIE Conf., Crete, Sept. 2002.

C. Schmullius, S. Hese, "SIBERIA-II – an international Multi-Sensor Remote Sensing Project for Full Greenhouse Gas Accounting in the Boreal Region", Proceedings of the *DGPF* annual meeting 2002, Neubrandenburg, 2002.

D. Scole, J. Qi, "Optical remote sensing for monitoring forest and biomass change in the context of the Kyoto Protocol", Workshop Paper 5 , Remote Sensing and the Kyoto Protocol, Workshop Report ISPRS WG VII / 5-6, Michigan USA, October 20-22. 1999.

A. Singh, "Digital change detection techniques using remotely-sensed data", *Int. J. Remote Sensing*, Vol. 10, No. 6, 989-1003, 1989.

C. Yijun, Y.A. Hussin, "Object-oriented classifier for detection Tropical Deforestation using Landsat ETM+ in Berau, East Kalimant, Indonesia", Map Asia Conference 2003.