Supporting a Forest Observation System for Siberia: Earth Observation for Monitoring, Assessing and Providing Forest Resource Information

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Abstract

More than 50 percent of the Russian forest inventory was updated more than 25 years ago. The consequence is that most of the existing forest inventory is outdated. Human and environmental forest disturbances continuously affect changes of forest cover and biomass stocks. The magnitude and extent of ongoing environmental pressures (e.g., forest fragmentation and the impact of global climate change) and the loss rates of particular habitat types is unknown. The aim of the paper is to provide an integrated concept for the monitoring and assessment of forest resources, as demonstrated for Central Siberia in the framework of the ZAPÁS project and the Siberian Earth System Science Cluster (SIB-ESS-C).

Regional and local scale in-situ and multi-agency satellite data were analyzed to generate biomass and forest cover change maps at local scales which were validated with up-to-date forest inventory data. At regional scales a synergy map of land cover and biomass information was developed. Annual PALSAR backscatter data proved to be applicable for local scale forest biomass monitoring and reforestation assessment. The forest resource maps were integrated in a data middleware system to provide Web-based analyses interoperability, data access of multi-scale forest resource maps to local stakeholders, and decision support for regional and local forest management in Central Siberia.

1. Introduction

Biomass is one of the considered Essential Biodiversity and Climate Variables (ECV, EBV[1]). Due to the large-scale distribution of the Siberian Taiga, the systematic monitoring of forest dynamics is challenging. Satellite Earth observation is the only alternative for a frequent monitoring of biomass reduction such as clear cutting, selective logging, fire, insect infestation, afforestation and forest succession processes [2] .

The application of Synthetic Aperture Radar (SAR) systems is a crucial tool for updating obsolete forest inventories and forest regrowth after disturbances [3]–[5]. The development of spatiotemporally more detailed and accurate biomass maps including land use and land cover change information is a pre-condition for more accurate carbon accounting and net primary production assessments. There is also a need for inter-comparison and (cross-) validation assessments of independently derived biomass maps since SAR data are being delivered spatially consistent at continental [6], pan-boreal [7] or global scales[8]. Important research needs have to be addressed for a better implementation of remote sensing-based growing stock volume (GSV) estimates. In particular the implementation of radar-based remote sensing techniques have to be fostered since they are independent from cloud cover and provide biophysical measurements of the three-dimensional structure of the forest (e.g., stem and growing stock volume). Frequent multi-temporal observations of forest biomass have to be envisaged in order to provide temporally consistent assessments of forest change processes. The interoperability of multi-scale forest resource maps has to be improved (e.g., to provide easy Web-based access to maps and forest cover change information and enable interactive analyses tools between locally relevant high resolution maps, regional scale forest resource maps, and frequently updated satellite time series information).

The ZAPÁS initiative [9] particularly aims to overcome existing gaps of inadequate data integration and inter-operability as one of the targeted gaps of the Group on Earth Observations (GEO) [10]. ZAPÁS was chosen as the project acronym because it sounds like the Russian word “Запас”. ZAPÁS is used in forest terminology for growing stock volume or forest stock. The collaborative development of advanced methods and the exchange of earth observation data are fully compliant with the cooperation policy established between the EU and Russia within the ESA-ROSCOSMOS Data Exchange Agreement March 11, 2009.

One of the key perspective goals of the ZAPÁS initiative is to develop and assess integrated concepts for forest resource assessment to (a) provide methods and technical solutions for regional and local forest resource management, and (b) provide multi-scale and multi-product validation results as important information source for the global forest carbon tracking. This paper aims to present results of a multi-source Earth observation forest resource assessment as implemented within the EU-FP7 ZAPÁS project [9], [11] and the Siberian Earth System Science Cluster (SIB-ESS-C [12]).

Based on a synergistic ESA-ROSCOSMOS satellite database, regional and local scale forest resource maps were developed comprising biomass maps, forest cover and disturbance maps, and maps indicating forest regrowth due to agricultural land abandonment. Regional and local scale biomass maps were cross-compared with up-to-date forest inventory data for the local test sites. Examples of assessments of forest cover change dynamics were presented for a selected local test site. The regional and local scale forest resource maps were integrated in the SIBESSC data middleware system. Examples of Web-based exploration tools for forest change (logging, reforestation) were shown to demonstrate the ZAPÁS support for a forest observation system for Siberia.

2. Synergistic ESA-ROSCOSMOS Satellite and in-situ database

Optical and SAR imagery were acquired basically from the European Space Agency (ESA) and the Russian Space Agency (ROSCOSMOS) archives, including the ESA Third Party missions of NASA and the Japan Aerospace Exploration Agency (JAXA). Time series data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were acquired for the generation of an improved Central Siberian land cover map. Regional scale biomass mapping was conducted using hyper-temporal Synthetic Aperture Radar (SAR) imagery from ESA's Environmental Satellite (ENVISAT). A forest inventory (FI) database was generated in high-priority areas selected by Siberian forestry enterprises of Krasnoyarsk Kray and Irkutsk Oblast (Figure 1). By involving recently updated forest inventory data SAR data was used for high resolution biomass, forest cover and disturbance, and forest regrowth mapping. Additionally, optical high resolution imagery was used for validation purposes. An overview of the sensors used in the ZAPÁS project and their specifications was given in [13].

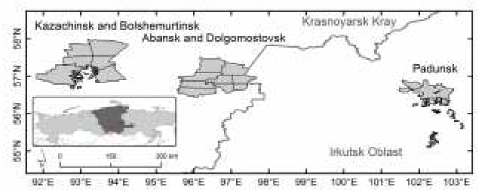

Figure 1: Local test sites of the ZAPÁS project as defined by forest management areas in Krasnoyarsk Kray and Irkutsk Oblast, Central Siberia. Forest inventory data were updated for the local mapping sites covering an area of 2,049,629 hectares.

3. Regional scale forest resource assessment

Land cover – Land cover and a forest species maps with 250-meter spatial resolution (Figure 2) were developed using time series of MODIS spectral reflectance composite images. Various land cover classes were identified based on the dynamics of their biophysical characteristics, which is reflected in their multi-spectral and multi-temporal class signatures [14]. For the classification of MODIS (MOD09A1) data, seasonal composite images were generated and classified using a locally adaptive classification method (LAGMA) [15].

Biomass - A pan-boreal growing stock volume map at 1-kilometer scale was developed using hyper-temporal ENVISAT ASAR ScanSAR backscatter data [4], [7]. Multi-temporal series of (250 images and more) backscatter intensity acquisitions were geo- and terrain-corrected in 1-kilometer pixel spacing. The SAR scenes were tiled in a regular grid of 2–by-2 degree grid cells. Noise and speckle were reduced using a multi-channel approach according to [16]. A detailed description of the SAR processing is given in [7].

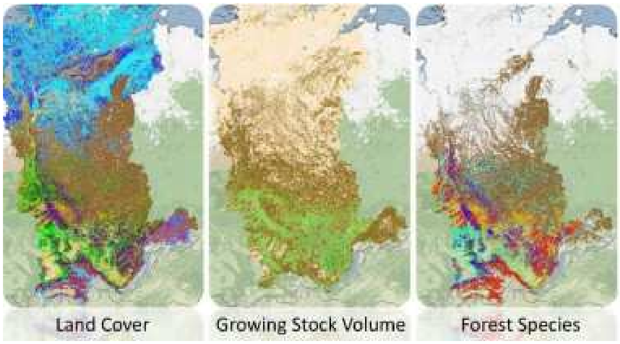

Fig 2: Land cover, growing stock volume and forest species maps for Central Siberia. Legend descriptions and further exploration capabilities were provided in the SIBESSC geoportal. Image Credit: ZAPÁS.

4. Local scale forest resource assessment

An orthorectified dual-polarization mosaic of the Advanced Land Observing Satellite (ALOS) Phased Array type L-band SAR (PALSAR) at 25-meter resolution could be provided through JAXA's Kyoto & Carbon Science Initiative [17]. These annual mosaics covering the time periods of 2007-2010 were used for biomass, forest cover and disturbance, and forest regrowth mapping.

Biomass – using the annual PALSAR mosaics from 2007 to 2010 growing stock volume maps were retrieved based on a supervised random forest regression approach. Non-parametric tree-based ensemble regression techniques are widely used for ecological modelling [18]. Random forest regression models were trained using growing stock information from forest inventory polygons on forest stand level in cubic meters per hectare and the dual-polarized (HH) and cross-polarized (HV) backscatter intensity images as predictors. The models were run for each annual mosaic (Figure 3).

Forest cover and disturbances – the ALOS-PALSAR HH and HV backscatter mosaics and the biomass map for the related year were implemented in three different forest cover and disturbance mapping frameworks. In a first step, an object-based image analyses (OBIA) was developed for a fully automated wall-to-wall mapping of forest disturbance classes in all local test sites for 2007 and 2010. We performed several multi-scale image segmentation runs using eCognition. The result was a segment-based forest cover and disturbance map for the years 2007 and 2010. Another biomass disturbance map product was generated using an image differencing approach applied on the annual growing stock volume maps. A combination of image differencing and standard deviation thresholding resulted into an image mask of disturbed forest areas in terms of loss of biomass. The difference images from 2007 to 2010 were combined in order to derive a biomass disturbance map (2007-2010). An example is shown in Figure 4. The forest cover and disturbance map and the biomass disturbance map are covering all local test sites of the ZAPÁS project in Central Siberia. For further map exploration, see the SIB-ESS-C geoportal .

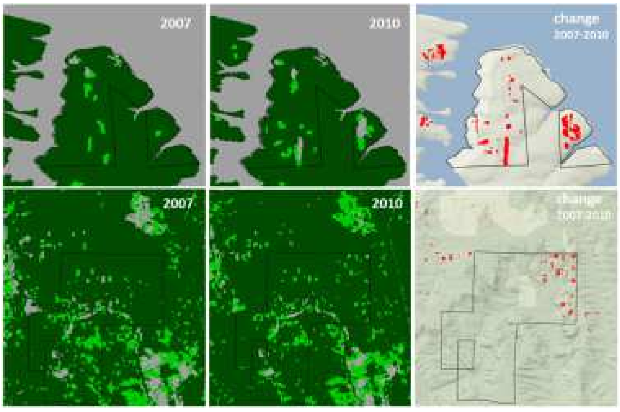

Figure 4: Example of local scale forest cover and change mapping in the Padunsk test site. The forest cover and disturbance classifications for 2007 (right) and 2010 (middle) indicate changed patterns in the forest stages (green = forest, gray = non-forest, light green = forest regrowth). This agrees to the biomass disturbance map (2007 – 2010) on the left where changes are indicated in red. Image Credit:ZAPÁS.

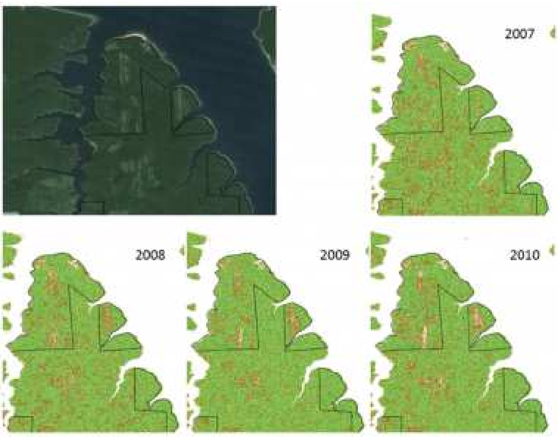

Figure 3: Example of annual growing stock volume mapping (2007- 2010) for parts of the Padunsk test site in the Irkutsk Oblast. The Google Earth image indicates deforestation patterns, as also tracked in the biomass maps.

Abandoned land and forest regrowth mapping – annual ALOS PALSAR backscatter mosaics and the retrieved biomass layers from 2007 to 2010 were integrated in a random forest regression model in order to detect possible afforestation areas due to agricultural abandonment processes or forest regrowth (such as logging and wildfires). An example of continuously increasing biomass levels is shown in Figure 5. These features were used to train the regression model.

6. Assessment of forest cover change dynamics

Landscape metrics [19] were derived to analyze the effect of landscape fragmentation on forest cover distribution and forest area changes. The fragmentation analysis was conducted using the forest cover and disturbance maps of 2007 and 2010. Figure 6 visualizes the change of patch density and area for the classes Forest, Non-Forest, and Forest Regrowth in the Abansk and Dolgomostovsk test site (698,479 ha). Temporal comparisons of the fragmentation indices indicated complex processes of forest regrowth (e.g., on abandoned agricultural fields and former forest fires and logging areas). This is shown by increasing patch density and area in the Forest regrowth class. However, ongoing forest cover loss is indicated by decreasing forest areas and increasing non-forest areas.

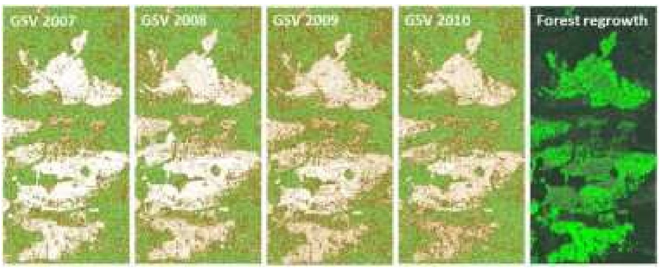

Figure 5: Biomass distributions from 2007 to 2010 indicate recent increasing forest cover on former agricultural areas in the Abansk region. The increasing biomass rates of the annual GSV layers were the input for the mapping of re-growing forest areas. The mapping result is shown in green (right). Image Credit: ZAPAS.

7. Supporting a forest observation system for Siberia

To achieve the overall goal of the ZAPÁS initiative– prototyping and supporting a forest observation system for Siberia using Earth observation data from European and Russian satellite data providers– intelligent data distribution chains are needed. This means that the link between Earth observation data (and related maps) and national and local users has to be designed as fast and easy-to-access as possible. Here, a data processing and integration middleware is proposed as a technical solution to improve interdisciplinary research using multi-source time-series data and forest resource maps, standardized data acquisition, pre-processing, updating and analyses [12]. The Siberian Earth System Science Cluster (SIB-ESS-C) combines various sources of Earth observation data, climate data and analytical tools. The development of this spatial data infrastructure (SDI) was based on the definition of automated and on-demand tools for data searching, ordering and processing, implemented along with standard-compliant Web services. These tools, consisting of a user-friendly download, analysis and interpretation infrastructure, are available within the Siberian Earth System Science Cluster (SIB-ESS-C) geoportal for operational use. The ZAPÁS project is closely linked to the SIB-ESS-C developments and uses its capabilities by integrating local and regional scale forest resource maps and land dynamics analyses tools (Figure 7).

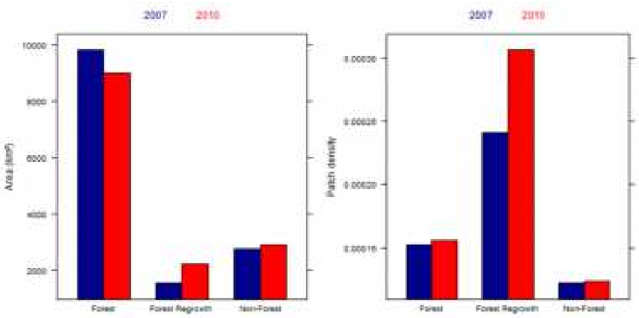

Figure 6: Patch density and area change between 2007 and 2010 for the Padunsk test site in Central Siberia resulted by processes of forest regrowth and logging activities.

After developing regional and local scale forest resource maps, all geo-information products were integrated in the geoportal. The portal was designed as a data middleware infrastructure supporting the so-called multi-concept in Earth observation. In the case of forest resource assessment and monitoring, state and dynamics of forest resources can be assessed for Central Siberia. The complete set forest resource maps related to biomass and forest cover tracking is accessible under www.sibessc.uni-jena.de. The basic functions are explained in a tutorial.

The presented maps and statistics demonstrate ongoing processes of forest reduction and degradation in the Boreal zone. Most of them are of anthropogenic origin [20]. However, forest regeneration processes also are visible. Forest succession is often observed on abandoned agricultural lands due to post-Soviet land use conversions [21]. Understanding, observing and managing Siberian forests is challenging. The capabilities for the implementation of Earth observation techniques in national management bodies was demonstrated using multi-sensor and multi-agency satellite data that have been acquired within the European Union-Russia Space Dialogue. However, the biggest obstacle is data access (including long time series, SAR and optical high resolution maps at different thematic information levels) and maps and related forest cover change statistics. Novel satellite based forest monitoring techniques highlight the potential for the implementation in the operational forest management. Fast and easy-to-use Web-based middleware geoportals are crucial for this process.

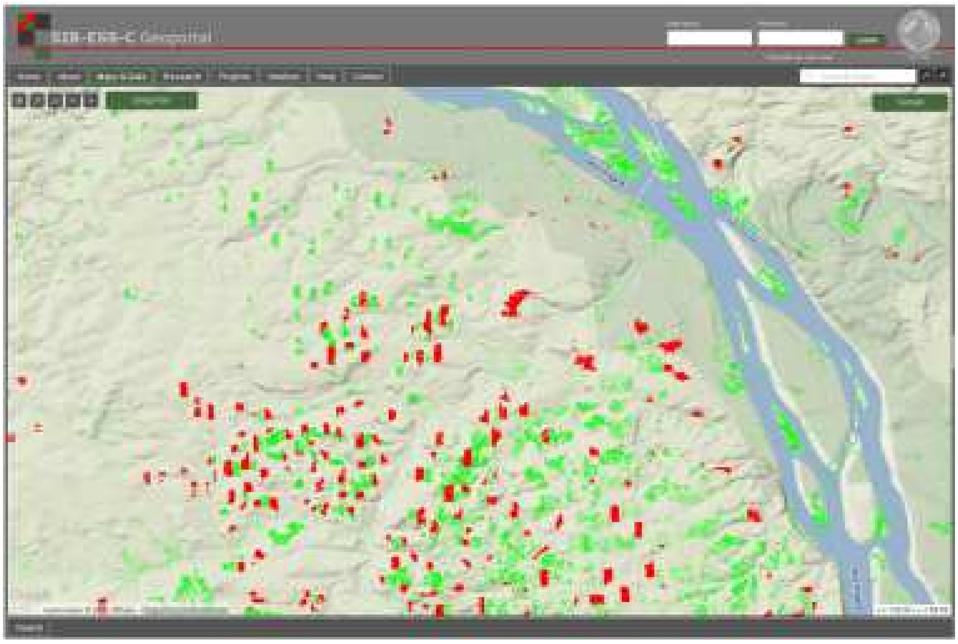

Figure 7: Visualization of logging (red) and reforestation patterns (green) based on annual biomass maps derived from ALOS PALSAR (25meter mosaics provided by JAXA's Kyoto and Carbon Science Initiative). The example of the SIB-ESS-C visualization of two forest change maps indicate the state and dynamics between 2007 and 2010 of a massive Central Siberian deforestation area near the Angara River. Image Credit: ZAPÁS.

Author bio

Christian Hüttich is a geographer focused on land-cover mapping, climatic and socio-economic induced land-cover and land-use dynamics analyses, change detection and time series analysis using satellite data, and geographic data synergies and standards. He works as a post-Doc and project manager at the Department for Earth Observation of Friedrich-Schiller-University in Jena, Germany.

References

[1] H. M. Pereira, S. Ferrier, M. Walters, G. N. Geller, R. H. G. Jongman, R. J. Scholes, M. W. Bruford, N. Brummitt, S. H. M. Butchart, A. C. Cardoso, N. C. Coops, and E. Dulloo, "Essential Biodiversity Variables," *Science* (80-.)., vol. 339, no. January, pp. 277–278, 2013.
[2] M. A. White, "A global framework for monitoring phenological responses to climate change," *Geophys. Res*. Lett., 32, L04705 DOI, p. 101029/, 2005.
[3] S. J. Goetz, A. Baccini, N. T. Laporte, T. Johns, W. Walker, J. Kellndorfer, R. Houghton, and M. Sun, "Mapping and monitoring carbon stocks with satellite observations: a comparison of methods.," *Carbon Balance Manag.*, vol. 4, p. 2, Jan. 2009.
[4] M. Santoro, C. Beer, O. Cartus, C. Schmullius, A. Shvidenko, I. McCallum, U. Wegmüller, and A. Wiesmann, "Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements," *Remote Sens. Environ.*, vol. 115, no. 2, pp. 490–507, Oct. 2010.
[5] O. Cartus, J. Kellndorfer, M. Rombach, and W. Walker, "Mapping Canopy Height and Growing Stock Volume Using Airborne Lidar, ALOS PALSAR and Landsat ETM+," *Remote Sens.,* vol. 4, no. 11, pp. 3320–3345, Oct. 2012.

[6] G. D. De Grandi, A. Bouvet, R. M. Lucas, M. Shimada, S. Monaco, and A. Rosenqvist, "The KC PALSAR Mosaic of the African Continent: Processing Issues and First Thematic Results," *IEEE Trans. Geosci. Remote Sens.,* vol. 49, no. 10, pp. 3593–3610, 2011.
[7] M. Santoro, C. Schmullius, C. Pathe, and J. Schwilk, "Pan-boreal mapping of forest growing stock volume using hyper-temporal Envisat ASAR ScanSAR backscatter data," in *Geoscience and Remote Sensing Symposium (IGARSS),* 2012, pp. 7204 – 7207.
[8] F. Seifert, "GlobBiomass – User Consultation Meeting," 2012. [Online]. Available: http://due.esrin.esa.int/meetings/meetings283.php. [Accessed: 25-Jul-2013].
[9] C. Hüttich, C. C. Schmullius, C. J. Thiel, C. Pathe, S. Bartalev, K. Emelyanov, M. Korets, A. Shvidenko, and D. Schepaschenko, "ZAPÁS. Assessment and Monitoring of Russian Forest Resources in the Framework of the EU – Russia Space Dialogue.," in *Let's Embrace Space. Space research achievements under the 7th Framework Programme.*, European Commission, 2012.
[10] B. Ryan, "Introduction to GEO," in UNFCCC COP-18, 26 November – 07 December 2012, *Doha, Qatar,* 2012, p. 10.
[11] C. Hüttich, C. . C. Schmullius, C. . J. Thiel, S. Bartalev, K. Emelyanov, M. Korets, and A. Shvidenko, "Assessment and monitoring of Siberian forest resources in the framework of the EU-Russia ZAPÁS project," in *Geoscience and Remote Sensing Symposium* (*IGARSS*), 2012 IEEE International, 2012, vol. 5, no. 1, pp. 7208–7211.
[12] J. Eberle, S. Clausnitzer, C. Hüttich, and C. Schmullius, "Multi-Source Data Processing Middleware for Land Monitoring within a Web-Based Spatial Data Infrastructure for Siberia," ISPRS Int. J. *Geo-Information*, vol. 2, no. 3, pp. 553–576, Jun. 2013.
[13] C. Hüttich, C. Schmullius, C. Thiel, C. Pathe, M. Urbazaev, M. Korets, S. Bartalev, E. K., A. Shvidenko, and D. Schepaschenko, "ZAPÁS – Assessment and Monitoring of Forest Resources in the Framework of EU-Russia Space Dialogue. Progress Report I," Jena, 2012.
[14] S. Bartalev, A. Belward, D. Erchov, and A. Isaev, "A new SPOT4-VEGETATION derived land cover map of Northern Eurasia," *Int. J. Remote Sens.*, vol. 24, no. 9, pp. 1977–1982, 2003.
[15]Baraley, S.A; Egrov, V.A.; Loupian, E. A.; Khvostikov, S.A. A new locally-adaptive classification method LAGMA for large-scale land cover mapping using remote-sensing data. Remote Sens. Lett. 2014, 5, 55-64.
[16] S. Quegan and J. J. Y. J. J. Yu, *Filtering of multichannel SAR images,* vol. 39, no. 11. IEEE, 2001, pp. 2373–2379.
[17] A. Rosenqvist, T. Ogawa, M. Shimada, and T. Igarashi, "Initiating the ALOS Kyoto & Carbon Initiative," *IGARSS 2001 Scanning Present Resolv. Futur. Proc. IEEE 2001 Int. Geosci. Remote Sens. Sym*p. Cat No01CH37217, vol. 1, no. C, pp. 546–548, 2001.
[18] A. M. Prasad, L. R. Iverson, and A. Liaw, "Newer Classification and Regression Tree Techniques: Bagging and Random Forests for Ecological Prediction," *Ecosystems*, vol. 9, no. 2, pp. 181–199, Mar. 2006.
[19] K. McGarigal, S. A. Cushman, M. C. Neel, and E. Ene, "FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst.," *Analysis*, vol. 3.3, no. 2007. University of Massachusetts, Amherst, p. The following citation is recommended by the autho, 2002.
[20] D. Mollicone, H. D. Eva, and F. Achard, "Ecology: human role in Russian wild fires.," *Nature*, vol. 440, no. 7083, pp. 436–437, 2006.
[21] A. V. Prishchepov, D. Müller, M. Dubinin, M. Baumann, and V. C. Radeloff, "Determinants of agricultural land abandonment in post-Soviet European Russia," *Land use policy,* vol. 30, no. 1, pp. 873–884, Jan. 2013.

[1] H. M. Pereira, S. Ferrier, M. Walters, G. N. Geller, R. H. G. Jongman, R. J. Scholes, M. W. Bruford, N. Brummitt, S. H. M. Butchart, A. C. Cardoso, N. C. Coops, and E. Dulloo, "Essential Biodiversity

Variables," Science (80-.)., vol. 339, no. January, pp. 277–278, 2013.
[2] M. A. White, "A global framework for monitoring phenological responses to climate change," Geophys. Res. Lett., 32, L04705 DOI, p. 101029/, 2005.
[3] S. J. Goetz, A. Baccini, N. T. Laporte, T. Johns, W. Walker, J. Kellndorfer, R. Houghton, and M. Sun, "Mapping and monitoring carbon stocks with satellite observations: a comparison of methods.," Carbon Balance Manag., vol. 4, p. 2, Jan. 2009.
[4] M. Santoro, C. Beer, O. Cartus, C. Schmullius, A. Shvidenko, I. McCallum, U. Wegmüller, and A. Wiesmann, "Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements," Remote Sens. Environ., vol. 115, no. 2, pp. 490–507, Oct. 2010.
[5] O. Cartus, J. Kellndorfer, M. Rombach, and W. Walker, "Mapping Canopy Height and Growing Stock Volume Using Airborne Lidar, ALOS PALSAR and Landsat ETM+," Remote Sens., vol. 4, no. 11, pp. 3320–3345, Oct. 2012.
[6] G. D. De Grandi, A. Bouvet, R. M. Lucas, M. Shimada, S. Monaco, and A. Rosenqvist, "The KC PALSAR Mosaic of the African Continent: Processing Issues and First Thematic Results," IEEE Trans. Geosci. Remote Sens., vol. 49, no. 10, pp. 3593–3610, 2011.
[7] M. Santoro, C. Schmullius, C. Pathe, and J. Schwilk, "Pan-boreal mapping of forest growing stock volume using hyper-temporal Envisat ASAR ScanSAR backscatter data," in Geoscience and Remote Sensing Symposium (IGARSS), 2012, pp. 7204 – 7207.
[8] F. Seifert, "GlobBiomass – User Consultation Meeting," 2012. [Online]. Available: http://due.esrin.esa.int/meetings/meetings283.php. [Accessed: 25-Jul-2013].
[9] C. Hüttich, C. C. Schmullius, C. J. Thiel, C. Pathe, S. Bartalev, K. Emelyanov, M. Korets, A. Shvidenko, and D. Schepaschenko, "ZAPÁS. Assessment and Monitoring of Russian Forest Resources in the Framework of the EU – Russia Space Dialogue.," in Let's Embrace Space. Space research achievements under the 7th Framework Programme., European Commission, 2012.
[10] B. Ryan, "Introduction to GEO," in UNFCCC COP-18, 26 November – 07 December 2012, Doha, Qatar, 2012, p. 10.
[11] C. Hüttich, C. . C. Schmullius, C. . J. Thiel, S. Bartalev, K. Emelyanov, M. Korets, and A. Shvidenko, "Assessment and monitoring of Siberian forest resources in the framework of the EU-Russia ZAPÁS project," in Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International, 2012, vol. 5, no. 1, pp. 7208–7211.
[12] J. Eberle, S. Clausnitzer, C. Hüttich, and C. Schmullius, "Multi-Source Data Processing Middleware for Land Monitoring within a Web-Based Spatial Data Infrastructure for Siberia," ISPRS Int. J. Geo-Information, vol. 2, no. 3, pp. 553–576, Jun. 2013.
[13] C. Hüttich, C. Schmullius, C. Thiel, C. Pathe, M. Urbazaev, M. Korets, S. Bartalev, E. K., A. Shvidenko, and D. Schepaschenko, "ZAPÁS – Assessment and Monitoring of Forest Resources in the Framework of EU-Russia Space Dialogue. Progress Report I," Jena, 2012.
[14] S. Bartalev, A. Belward, D. Erchov, and A. Isaev, "A new SPOT4-VEGETATION derived land cover map of Northern Eurasia," Int. J. Remote Sens., vol. 24, no. 9, pp. 1977–1982, 2003.
[15] I. A. Uvarov and S. A. Bartalev, "The Algorithm and Software Suite for Land Cover Types Recognition Based on Locally-adaptive Supervised Classification of Satellite Imagery," Contemp. Earth *Remote Sens.* from Sp., vol. 7, no. 1, pp. 353–365.
[16] S. Quegan and J. J. Y. J. J. Yu, Filtering of multichannel SAR images, vol. 39, no. 11. IEEE, 2001, pp. 2373–2379.
[17] A. Rosenqvist, T. Ogawa, M. Shimada, and T. Igarashi, "Initiating the ALOS Kyoto & Carbon Initiative," IGARSS 2001 Scanning Present Resolv. Futur. Proc. IEEE 2001 Int. Geosci. Remote Sens. Symp. Cat No01CH37217, vol. 1, no. C, pp. 546–548, 2001.
[18] A. M. Prasad, L. R. Iverson, and A. Liaw, "Newer Classification and Regression Tree Techniques: Bagging and Random Forests for Ecological Prediction," Ecosystems, vol. 9, no. 2, pp. 181–199, Mar. 2006.

[19] K. McGarigal, S. A. Cushman, M. C. Neel, and E. Ene, "FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst.," Analysis, vol. 3.3, no. 2007. University of Massachusetts, Amherst, p. The following citation is recommended by the autho, 2002.
[20] D. Mollicone, H. D. Eva, and F. Achard, "Ecology: human role in Russian wild fires.," Nature, vol. 440, no. 7083, pp. 436–437, 2006.
[21] A. V. Prishchepov, D. Müller, M. Dubinin, M. Baumann, and V. C. Radeloff, "Determinants of agricultural land abandonment in post-Soviet European Russia," Land use policy, vol. 30, no. 1, pp. 873–884, Jan. 2013.

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