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ASSESSMENT AND MONITORING OF FOREST RESOURCES IN THE FRAMEWORK OF THE EU- RUSSIAN SPACE DIALOGUE - THE ZAPÁS PROJECT

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ZAPÁS investigates and cross validates methodologies using both Russian and European Earth observation data to develop procedures and products for forest resource assessment and monitoring. Earth observation data include ENVISAT MERIS and ASAR in different acquisition modes, METEOR-M and RESURS-DK1. The methodologies include state-of-the-art optical and radar retrieval algorithms as well as investigation of innovative synergistic approaches. Products include biomass change maps for the years 2007-2008-2009 on a local scale, a biomass and improved land cover map on the regional scale, and a 1 km land cover map as input to a carbon accounting model.

Objectives

The geographical focus of research and development is the test region in Central Siberia, which contains two administrative districts of Russia, namely Krasnoyarsk Kray and Irkutsk Oblast. The overall concept of the ZAPÁS project is sketched at Fig. 1. The left column presents the required input data, including forest inventory data for Krasnoyarsk Kray and Irkutsk Oblast. With regards to the EO data, SAR and optical data featuring a wide spectrum of geometric resolutions are considered. Included are ESA data (ASAR, MERIS), ROSCOSMOS data (RESURS-DK1, METEOR-MI) and third party data by JAXA (PALSAR). All data provide the input for methodology development and product delineation. The coarse scale products (> 300 m x 300 m) as well as the results of the terrestrial ecosystem full carbon accounting are addressed to the Federal Forest Agency as federal instance.

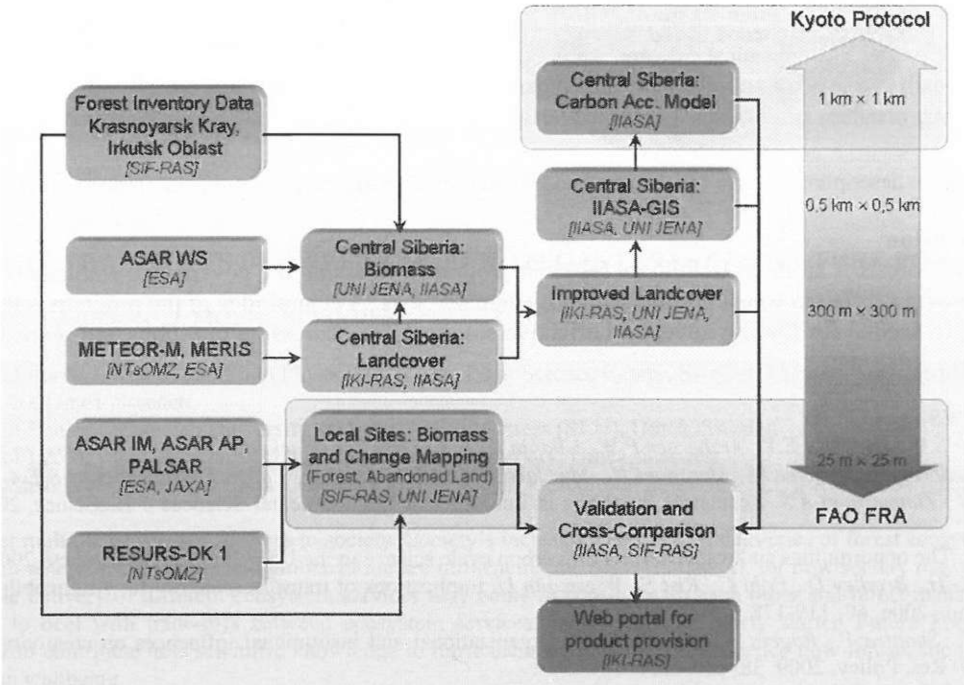

Fig. 1. Overall Project Concept.

Besides the input data (left column) also preliminary and final products are depicted in Fig. 1 (pale green and light green boxes, second and third column). In terms of scale in general two lines of products can be distinguished. The high resolution products feature one line (the lower half of the sketch) and comprise biomass and change maps for selected local sites within Krasnoyarsk Kray and Irkutsk Oblast. These products are addressed to support the UN FAO Forest Resources Assessment as well as the requirements of the local forest inventories.

The other line comprises the medium to low scale products, medium scale EO data provides the input: METEOR-MI, MERIS, and ASAR WS. The first two products are delineated in parallel (see second column in Fig. 1): The biomass map and the land cover map will be generated for Central Siberia (featuring the complete administrative entities Krasnoyarsk Kray and Irkutsk Oblast). The ASAR WS biomass map forms already one final product; the land cover map will be improved by means of a knowledge based merging process which combines the information of the biomass and land cover map. This step will result in the next final product: The improved land cover map. This information has to be implemented into the IIASA GIS (scale 1:500,000), which contains all required information for carbon accounting, including information on the land cover. Eventually, terrestrial ecosystem full carbon accounting will be accomplished. These coarse scale products are addressed to support global environmental issues such as UNFCCC and its Kyoto Protocol as well as the requirements of Russian Federal Agencies.

Methodological background

SAR based forest cover change and biomass mapping. Due to their sensitivity for the geometric properties of the targets radar data offer great potential for forest biomass assessment. In numerous studies and for diverse regions and forest types a in part high sensitivity of backscattering intensity [1, 4-8] and interferometric coherence [9-14] for forest biomass has been verified. Particular high correlations were found for the homogeneous and frugal structured forests of the boreal zone. With regard to polarimetric systems a link between forest biomass and polarimetric phase was discovered [15].

ASAR (Synthetic Aperture Radar) sensor emits microwave pulses and subsequently detects the respective backscattered energy. At forest covered areas an increase of backscattered energy with increasing forest biomass or related parameters such as stem volume was observed in numerous studies. This association has been successfully simulated by means of simple empirical [16], semi-empirical [17-19], and complex physical models [20-23]. However, it was also observed that the impact of forest biomass on the radar signal already saturates at low biomass levels, i.e. after a specific biomass level the further increase of biomass causes no further increase of the backscattering intensity. This specific biomass saturation level is determined inter alia by the radar frequency. Lower frequencies such as L- and P-band are preferable as saturation emerges at higher biomass levels [15]. Further impacts on the saturation level are the radar polarisation [24], the forest characteristics [27, 52], and further general conditions such as weather, soil moisture or surface roughness [25-26]. Furthermore it could be demonstrated, that by means of the application of SAR data time series the acquisition date can be optimised for forest biomass derivation. In fact, the integration of many SAR scenes can increase the sensitivity of radar backscatter for forest biomass and the saturation level [17, 27, 28]. By further incrementing the number of SAR scenes (i.e. >30) it was demonstrated by [28, 29] that saturation is not the limiting factor anymore. Even high accuracies are achievable following this hypertemporal data assimilation approach. Within these studies ASAR WS (Wide Swath) data have been implemented. Due to the large overlap between the tracks each pixel was covered more than hundred times, which might be the cause for these surprising results - one must consider that ASAR is operated in C-band. Recent work on that topic has been accomplished within the ESA project BIOMASAR (ESA Contract No. 21892/08/iI-BC) at the Friedrich-Schiller-University Jena. Improvement of sensitivity for biomass and saturation level can also be achieved by using multiple radar frequencies and polarisations [24, 30].

Additionally to the backscattering intensity the radar phase can be exploited. This specific SAR parameter contains ancillary information regarding forest biomass. The SAR interferometry studies the interferometric phase. Two examination approaches can be distinguished. Firstly, digital height models (DHM) can be generated. These models, depending on the wavelength, contain the height of the vegetation as increment. Secondly, a measure called interferometric coherence [9, 11, 31] can be computed. It is a measure for the complex correlation of two SAR images. Both examination approaches require an appropriate SAR image pair [10, 11]. Appropriateness refers firstly to the temporal baseline and the in each case prevailing environmental conditions (precipitation, wind speed, soil moisture etc.) [10-12, 32]. Very stable conditions as to be found during the durable very cold winters in the boreal zone can be combined with long temporal baselines (weeks or months). Otherwise short temporal baselines are preferable (days). In addition it applies, that the shorter the wavelength, the more sensitive is the coherence to change and the shorter is the required temporal baseline. Secondly, the spatial baseline is of particular relevance [9, 10]. Moreover, this spatial baseline must not exceed a critical value.

Regarding the interferometric coherence in a large number of publications a dependency of this parameter on forest biomass has been emphasised [9, 11, 13, 14], The coherence decreases with increasing biomass. The reason for this relationship is the volume decorrelation which is coupled to biomass [9, 31].

Large area land cover mapping based on medium resolution optical data. In framework of the Global Land Cover 2000 (GLC2000) project the SPOT-VEGETATION satellite instrument data with 1-km spatial resolution were used to produce the land cover map for Northern Eurasia [33], which differentiates several forest classes based on leaves types and their phenology. The map has been developed using method, which, in particular, include elimination of pixels contaminated by clouds and shadows, unsupervised classification of spectral-temporal image composites and labelling of clusters by experts. Being highly automated these methods still require significant human input at the final mapping stage, which leads to limited level of exercise repeatability and consequently to limited possibility for land cover change analysis.

The GLOBCOVER project produced the global land-cover map for tentatively the year 2005 using as its main source of data the fine resolution (300 m) mode data to be acquired by the MERIS sensor on-board the ENVISAT satellite. The MERIS composite products are generated on a bimonthly and annual basis and they are output of the GlobCover pre-processing chain applying geometric and radiometric corrections. The bimonthly MERIS provide for each spectral band the average surface reflectance calculated from all valid observations of two months period. The annual MERIS FR composite is computed by averaging the surface reflectance values of the bimonthly product generated over one year. The Land Cover Classification is derived by an automatic and regionally-tuned classification of a time series of the MERIS FR Composites.

The resent developments in automatic land cover mapping methods based on new locally-adaptive classification algorithm have been successfully applied to produce 250 m resolution land cover map of Russia using Terra-MODIS satellite data [31, 34]. The method uses the monthly cloud-free MODIS composites and provides an opportunity for dynamic land cover mapping, which makes the basis for regular (e.g. annual) land cover change analysis.

Terrestrial ecosystems full carbon accounting. Particular role that terrestrial (specifically forest) ecosystems of Northern Eurasia play in current and future functioning of the Earth System follows from the specifics of the region (the globally coldest vast land mass situated mostly on permafrost with vulnerable ecosystems which historically developed under cold climate) and expected dramatic warming in the region (up to + 12oC increase of the annual temperature in high latitude under the global increase +4oC that is expected by end of the 21st century). Very likely, it will accelerate the processes of destruction of permafrost (which contains from 500 to 900 Tg carbon (C) in frozen grounds and wetlands) with the subsequent drastic increase of carbon emission to the atmosphere. Thus, knowledge of the terrestrial ecosystems full carbon account (FCA) is crucial for understanding the current and future behaviour of the Earth climatic machine. The FCA quantifies dynamics of carbon pools and fluxes of major direct and indirect carbon contained greenhouse gases (C02, CH4, CO, BVOC) to the atmosphere, along with aerosols and other components of particulate carbonaceous matter (PCM) that are produced by the biosphere for all ecosystems and all processes continuously over time [84]. However, uncertainties of assessments of major components of the FCA are large [36, 37], hindering scientific understanding of the problem [36] and hampering political and economic decision making e.g. [37]. Major uncertainties follow from insufficient and obsolete data on land use - land cover and its dynamics due to natural and anthropogenic drivers. Northern Eurasia is a region of rapid changes of land cover that may result in a shift in direction of the net carbon flux from the terrestrial sink of previous decades to a net source [38, 39]. Reducing uncertainties is of a crucial importance, both for scientific understanding of the problem and the basis for implementation of the post-Kyoto economic mechanisms. Overall, it leads to the need for a verified FCA, i.e., an accounting method that (1) assesses explicitly, reliably and comprehensively, uncertainties of the intermediate and final results, and (2) presents an effective tool for uncertainty management, which would not exceed previously set thresholds [40, 41], Introduction of the verified FCA in international practice is an important political and economic issue and this practically has no alternatives for reaching the eventual goals of the UNFCCC. We plan to introduce a modified methodology of the FCA developed by the International Institute for Applied Systems Analysis which is crucially based on the multi-sensor remote sensing concept.

Zapás project outcome

With regards to the availability of recent and forthcoming SAR data and sensors the algorithm development of this project will rely on EN VIS AT ASAR and ALOS PALSAR data. Thus, recent data is available and the processing chains can be adapted to the forthcoming sensors Sentinel-1 and ALOS II. Multitemporal metrics will be computed based on ENVISAT ASAR IMP and APP data. These metrics will be combined with ALOS PALSAR backscatter information for forest cover change monitoring. A knowledge based decision tree will be developed for the synergistic classification of C- and L-band data. The capability of L-band coherence for biomass estimation was demonstrated by a number of studies. Additionally, also L-band intensity is sensitive for this parameter, even if saturation occurs at low to medium biomass levels. The saturation problem can be alleviated by using cross-polarisation data. Within this project ALOS PALSAR cross-polarisation intensity and coherence will be combined for the first time for high resolution biomass retrieval at local sites.

The implementation of hypertemporal ENVISAT ASAR WS data was demonstrated being able to retrieve forest biomass for large areas at low resolution. So far, the retrieval model has been trained with local forest inventory data. Within this project another training strategy has to be developed, as forest inventory data is not available area-wide. Furthermore, for meeting the product requirements, the geometric resolution of the final product has to be improved.

The output of the three mentioned above activities will provide a basis for the land cover mapping study using MERIS and METEOR-MI data within the proposed ZAPÁS project. The GLC2000 and new MODIS derived land cover maps will be used as sources of reference data on various thematic classes, including forest types along with other vegetation and non-vegetated lands. The time-series of the GlobCover bi-monthly MERIS data (300 m) composites over the test region in the Central Siberia will be classified using supervised locally-adaptive algorithm and processing chain developed by IK.I-RAS in order to derive land cover map with set of classes, elaborated based on requests of the carbon accounting in the forest ecosystems with the HAS A approach. The METEOR-MI data over test region are also considered as an additional input for the planned land cover mapping study in order to demonstrate impact of higher (50 m and 100 m) spatial resolution on mapping accuracy and details. Both the MERIS and the METEOR-MI data derived land cover maps will be compared with the MODIS derived land cover map to estimate impact of the temporal resolution of the satellite observation on mapping accuracy and thematic richness. The land cover mapping results validation will involve a comparison with forest inventory data on local test sites as well as with the land cover maps derived over selected areas using multi-temporal SPOT images.

Basing on the biomass and land cover map for Central Siberia an improved land cover map will be generated. The improvement refers to A) cross comparison of both maps and correction of the land cover map if required, and B) refinement of the land cover map with regards to a refinement of the thematic resolution, i.e. increasing the number of classes by means of introduction of different biomass levels. A clear strategy based on logics and expert knowledge needs to be developed for combining both data sets. This strategy will incorporate reliability flags provided with the biomass and the land cover map. The reliability flag will help to weight the information contained within the land cover and biomass map respectively on a pixel basis. It will demonstrate possibility of a verified terrestrial ecosystems full carbon account for large territories of temperate and boreal domains; point out the indispensable role of remote sensing in understanding the biosphere role of terrestrial ecosystems; consider relevant ways for application of remote sensing in forest monitoring and forest management; and finally contribute to development of policies directed to mitigate undesirable consequences of global climate change in the region.

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