THE SIBERIA-II PROJECT AS SEEN BY ENVISAT ASAR

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ABSTRACT

In the SIBERIA-II project Earth Observation (EO) data are used to derive a set of products, which are then fed into global and regional greenhouse gas accounting approaches. The overall aim of the project is to devise an integrated "EO-modelling" methodology for full carbon accounting at regional scale, and to quantify the accounting for an over 3 Mio km^2 area in Central Siberia. For the derivation of the EO products, SIBERIA-II makes use of most of current orbiting satellites and currently represents the major user of ASAR ENVISAT data. Within the project several issues ranging from data post-processing to derivation of EO-products and development of new techniques for land applications are treated. An experiment on geometric and radiometric validation of Wide Swath data showed the importance of the processor used for preparing the data to be further used in applications. The interferometric coherence from ASAR repeat-pass pairs acquired under stable winter conditions shows contrast between forests and bare soils. Alternating Polarisation data seems to be promising for forest/non-forest mapping. For wetlands, ASAR Wide Swath data is used for the operational monitoring of open water surfaces, reaching high classification accuracy. ASAR Wide Swath is also evaluated for pollution damage identification and fire scar detection. Finally, the long time series of ERS and ASAR Image Mode data allows detecting deforestation activities over almost one decade.

INTRODUCTION

The objective of the EC-project SIBERIA-II (Multi-Sensor Approach for Full Greenhouse Gas Accounting in Siberia) is the integration of Earth Observation (EO) in biosphere process models to provide a full greenhouse gas (GHG) accounting for an over 3 Mio km^2 area in Central Siberia. The project region stretches from 52° to 72° N and 88° to 110° E (Fig. 1). It embraces steppe, tundra and taiga forests, and represents one of the most important environmental and climatic hotspots on Earth because of the significant changes that have been occurring during the last decades.

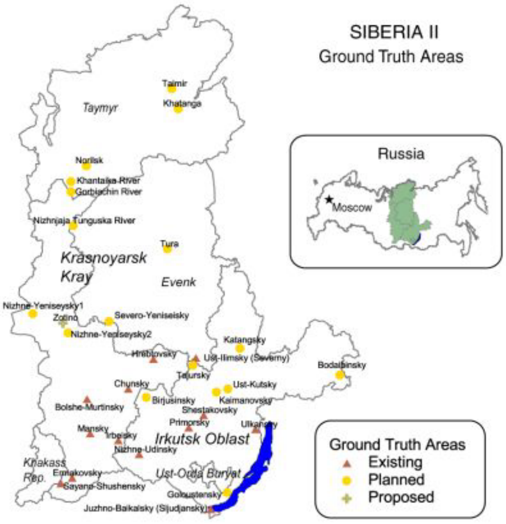


Fig. 1. The SIBERIA-II project study area

To achieve the goals of the project, data from a variety of EO spaceborne sensors are utilised to derive some of the biophysical parameters needed as input by the process models, namely the Lund-Potsdam-Jena (LPJ) Dynamic Vegetation Model (DVM), the Sheffield DVM and a landscape-based accounting approach developed at the International Institute of Applied Systems Analysis (IIASA-GIS). The IIASA-GIS also contains the necessary ground truth information for regional applications while local verification is supplied by the Russian forest enterprises.

Data from the Advanced Synthetic Aperture Radar (ASAR) on ENVISAT represent an important source for the derivation of the EO-products and they are used for both operational and research purposes. The first part of the paper reports on an ASAR Wide Swath (WS) calibration and registration experiment within the project region. The second part of the paper deals with current applications of ASAR data both at mid-resolution using WS data and high resolution using Image Mode (IM) and Alternating Polarisation (AP) data.

DATA CALIBRATION AND REGISTRATION

A very intense ENVISAT ASAR data acquisition strategy was defined for the SIBERIA-II project. Since March 2003, and planned up to July 2004, all ascending passes of ENVISAT over the project region are scheduled to operate ASAR in WS acquisition mode. Descending passes are planned with ASAR in IM and AP mode. ASAR in WS mode covers an area approximately 400 km x 400 km with a geometric resolution of about 150m. Each month more than 60 scenes are received. A big amount of data has been collected and processed by ESA and several PACs up to processing Level 1p which include a slant range to ground range correction. However, for the purpose of the SIBERIA-II project, further processing steps were set up with the aim to get geographic and topographic correction of the images as well as calibration of all the SAR images.

As input for terrain correction of ASAR WS data SRTM DEMs have been resampled at a pixel spacing of 100 m x 100 m and merged with GTOPO30-Globe data. Final calibrated and geocoded data are provided in dB and Albers Conical Equal Area projection optimised for the Siberian regions. For further analyses, incidence angle matrixes are provided as well. For the validation of the ASAR WS processing results a cross-comparison of the DLR processing chains with a range of available SAR software packages has been performed. The DLR processing chain, Gamma SAR and Interferometry software, and SARscape (by Sarmap) gave satisfying results with geolocation errors of less than one pixel, although different approaches are used to some extent. Considerable geometric errors occur with BEST since terrain information is not employed for the registration process.

A robust and automatic ASAR WS processing environment has been created, which allows the processing of large amounts of data (more than 400 scenes are available for 2003 alone) with good radiometric calibration and geometric accuracy. This forms a base for the retrieval of biogeophysical parameters for such a large region as the SIBERIA-II area and multitemporal and multi-incidence angle analysis.

APPLICATIONS OF ASAR DATA

Forest Mapping

Forest/non forest mapping and mapping of forest biomass are two objectives of SIBERIA-II using ENVISAT/ASAR Narrow Swath data. IM coverage for repeat pass interferometry was requested over the region in December, January and February 2003-2004. Longer temporal series of AP data (HH and HV polarisation) at low and high incidence angles were required in 2003-2004 at a number of test sites in the region.

ASAR Repeat-pass Interferometry

Interferometric coherence from the ERS-1/2 tandem mission has been used to map land cover and forest biomass in Central Siberia (SIBERIA-I project) [1]. Although the biomass classes were limited to low values of growing stock volume (less than $80m^3$/ha) the 1 Million km^2 biomass map was found very useful, e.g. for updating the Russian forest map [1] and for validating the Dynamic Vegetation Models [2]. After the loss of ERS-1, only repeat-pass SAR interferometry, InSAR, is possible with current satellite SARs. In this study, we evaluate if ASAR repeat-pass coherence during stable winter conditions in Siberia is less sensitive to temporal decorrelation, and thus can be used for estimation of growing stock volume.The approach which will be undertaken on the expected image pairs includes a) coherence estimation, b) analysis of coherence with respect to land cover and biomass classes using GIS information available at SIBERIA-II test sites and d) development of mapping method applicable to the large project area. In the following, an example of preliminary work performed over one of the test sites using the data acquired in March-April 2003 is reported. The coherence estimation was done with an adaptive window size taking into account phase slope, texture of the averaged backscattering coefficient and the local coherence level. The repeat-pass coherence shows relatively high values. Fig. 2 shows the composite image (the Gamma coherence product), with coherence (red), average backscattering coefficient (green) and change in backscatter (blue) in the region of Tura (64.8 N-100.5 E).

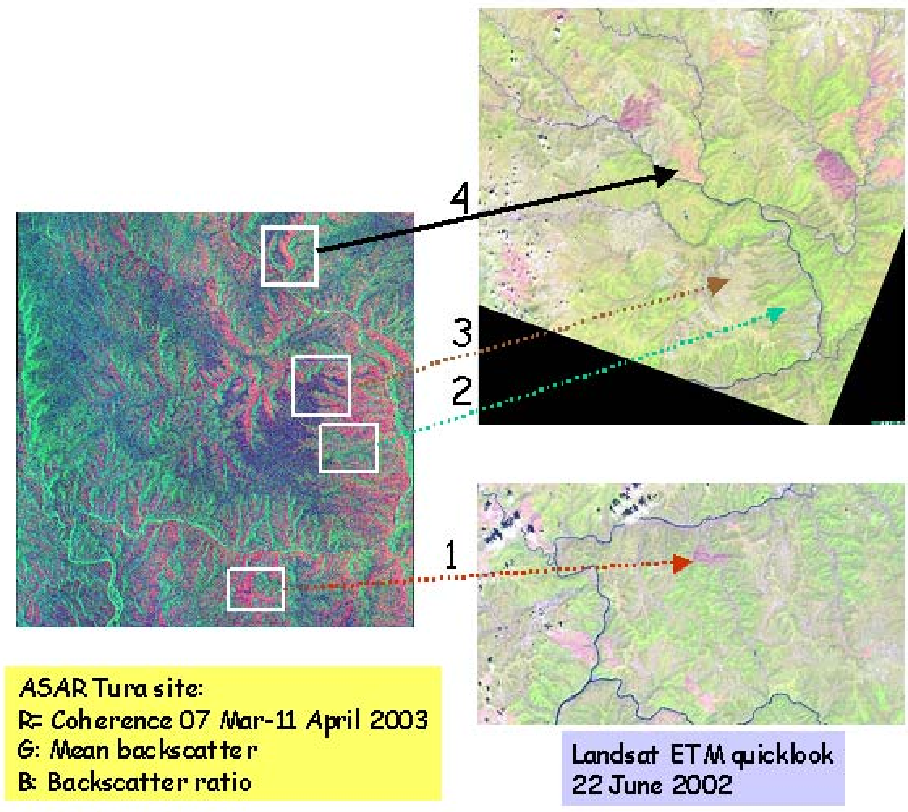


Fig. 2. ASAR repeat-pass interferometric images from 07 March-11 April 2003 on test site north of Tura (left). The regions of interest are selected based on interpretation of Landsat ETM quicklook. Region 1: recent burnt area; region 2: forests; region 3: exposed low vegetation area; region 4: old burnt area.

Ground data and land cover maps are necessary to interpret quantitatively the data. In a first analysis, three sections of the image have been selected based on interpretation of Landsat ETM quicklook images of the region, acquired in June 2002. Region 1 contains an area identified as clear-cut or recently burnt area, region 2 a forested area, region 3 an area with low vegetation (grassland on exposed site) and region 4 an old burnt area. Coherence is high for areas that appear to have low biomass vegetation including areas interpreted to have recent fires. However, for low vegetation on sites exposed to melting or refrozen effects between March and April, the coherence is also low, but in this case the backscatter will have no significant change. It could be possible to use backscatter information (HH but also HV or other incidence angles) to map forests in specific study cases. But for a robust methodology applicable to a large region, it is required to have data acquisitions dates associated to minimum changes in surface conditions, probably during the December-February period in Siberia.

ASAR Alternating Polarisation

The objective of the study at different SIBERIA-II test sites is to assess the best ASAR measurements for mapping of the broad surface types (water, bogs, grasslands, agriculture, forests) and for mapping of low/high forest biomass. The data are currently analysed following the different steps: coregistration, multitemporal filtering, geocoding and registration to GIS forest database. The temporal, polarisation and angular behaviours of the backscattering coefficient of different land cover and forest types are studied. Initial results suggest that (a) HV is more adapted to forest/non forest mapping, (b) the temporal variation is indicative of different surface types, (c) the seasonal effect is significant in this region where winter temperature is very low.

Fig. 3 shows an example of HV (Green) and HH (Red and Blue) image in March 2003 over the Bolshe-Murtinsky test site (57.1° N, 92.2° E). Low values of HV (magenta colour on the image) indicate low biomass areas (deforestation and agriculture fields), high values of HV (green) indicate forested areas. Fig. 4 shows the temporal variation of HV from March to June. Forest, water and clear-cut/burnt area and agricultural fields can be separated well except in May where the snow and ice melting affect the HV scattering.

Water Bodies Mapping with ASAR WS

The northern part of the SIBERIA-II area is characterized by tundra environment where vast polygon mire systems can be found in the lowlands. Bogs and swamps (forested wetlands) are found in the middle and southern part within the boreal zone. Wetlands are an important source for methane and some type of wetlands (peat lands) feature a considerable CO_2 sink. Methane is not only produced from bogs, small lakes contribute actively as well. A mean emission of 3.5 mg CH_4/(m² day) has been measured near Tarko-Sale, Western Siberia, [3] and 0.94 mg CH_4/(m² hr) near Barrow, Alaska [4]. Inundation is a key indicator for anaerobic conditions, which are necessary for methane production. Its spatial and temporal patterns are mostly related to snow melt within the study area. This requires multitemporal analysis focusing on spring and summer data.

ASAR WS data acquired in ascending orbit are applied for the wetland mapping. In a first step open water bodies are delineated from summer and early autumn scenes. Further on inundation patterns will be analysed utilising spring and summer data from 2003 and 2004. About 130 scenes were available for June to September 2003, covering only the western part of the SIBERIA-II region. Water bodies are extracted from the normalized images applying a simple threshold algorithm under the assumption that all wetlands occur on flat or moderate terrain. First results from the northwestern tundra region showed that the extent of water surfaces has been underestimated considerably so far. Numerous small shallow lakes, which are part of mire systems, are below the spatial resolution of other data available from project partners (University of Wales, Swansea, MODIS land cover classification with 500m resolution and IIASA's water bodies layer based on 1:1 Mio maps), but they can be identified based on the 150 m ASAR WS resolution. In some areas to the north of Putorana plateau where the amount of open water surfaces is less than 1 % in the MODIS land cover classification and zero in the IIASA map a value of 30 % is calculated using ASAR WS. This could be verified using topographic maps. Quantitative accuracy assessment has been carried out in areas where forestry inventory data exist. The classification accuracy for water bodies based on a mosaic from scenes acquired in August and September at an inventory site near to Noril'sk (69.3° N, 88.1° E) is 95% (kappa coefficient = 0.82). The test site has a size of ca. 640 km². The extent of water surfaces as classified from ASAR WS is approximately 100 km². All other data sets give lower values: 77 km² for the MODIS land cover map and 28 km² in the 1:1 Mio water bodies layer (see Fig. 5).

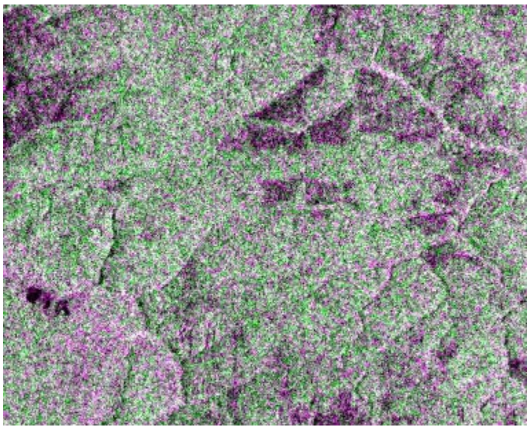


Fig. 3. ASAR HV (Green) and HH (Red and Blue) image in March 2003 over the Bolshe-Murtinsky test site (57.08-57.18 N, 92.12-92.33 E).

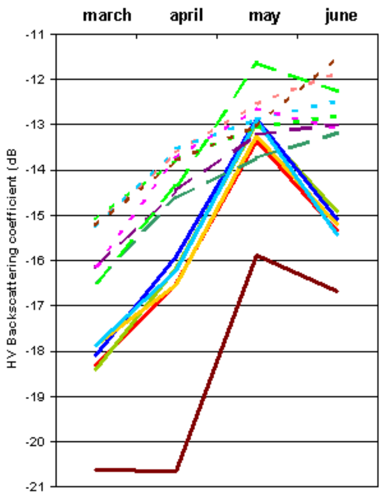


Fig. 4. Temporal variation of HV backscatter coefficient (in dB). Bottom curve: water, solid curves: clear cut and agricultural fields, dashed curves: forests of different values of biomass (the uppermost curve with long dashes corresponds to the forest inundated in May).

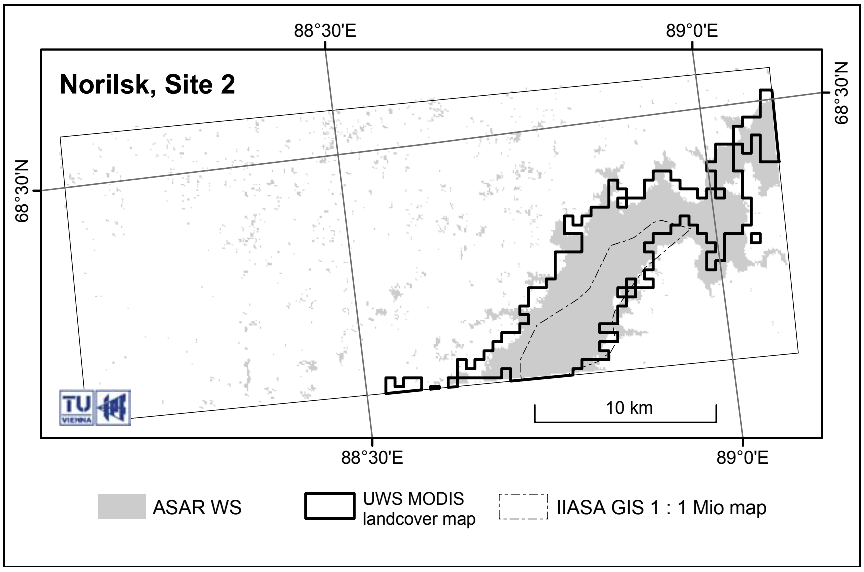


Fig. 5. Comparison of water bodies between ASAR WS, MODIS land cover (from UWS) and a polygon layer based on a 1:1 Mio map (provided by IIASA).

The water bodies' product provides valuable detailed information on this land cover type and will be used for the improvement of land cover data, which serve as input for the ecosystem models. Further on it provides a base for wetland detection over regions where sufficient overlapping ASAR WS scenes from spring and summer are available.

Detection of Pollution Effects with ASAR WS

The city of Noril'sk is situated north of the Arctic Circle in the tundra and taiga boundary region of Siberia, The canopy cover is 10-30% and the trees grow on frozen soil that is subject to seasonal thawing to a depth of 15-70 cm. The vegetation in the vicinity is mainly influenced by severe climate conditions and high emission levels from industrial copper and nickel plants due to the exploitation of the second biggest nickel sulphide deposit in the world.

17 ENVISAT ASAR images in WS mode, acquired between March and June 2003, were used to detect the extent of vegetation damage. Fig. 6 shows the temporal dynamics of backscatter for two classes of disturbance impact. Sites nor5_6 and nor6_7 are situated respectively in the far south of the Rybnaya valley and directly south of Noril'sk in the area with the highest deposition from the smelters. The 5th of May is the first date above freezing and the 6th of June is the last night with minus degrees. The 14th of July and the 27th of August have high precipitation. The other days in the snow-free period had no precipitation in the preceding few days, so based on daytime temperatures it can be assumed that the soil was dry. The 18th of June lies within the warmest period of 2003. Using Maximum likelihood classification, four levels of vegetation damage were identified. The results in Figure 7 show that ASAR images can be used for detection of pollution induced vegetation damage in the area around Noril'sk.

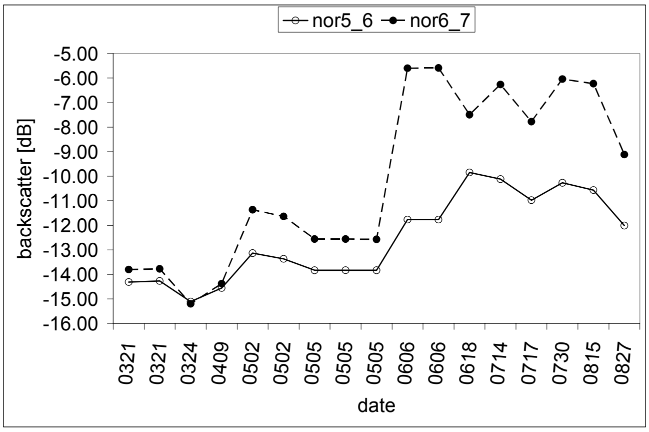


Fig. 6. Backscatter (dB) for two test sites at different areas affected by pollution.

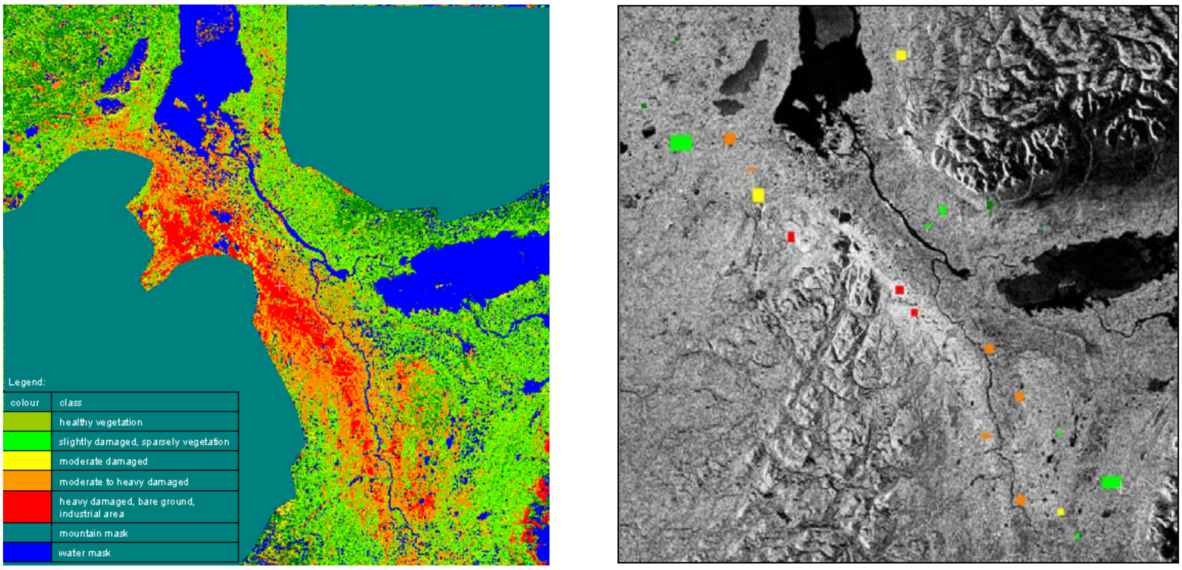


Fig. 7. Left: Maximum likelihood classification for images from the 18th of June until the 27th of August within the Rybnaya valley. Right: Location of training sites.

Fire Scar Detection with ASAR WS

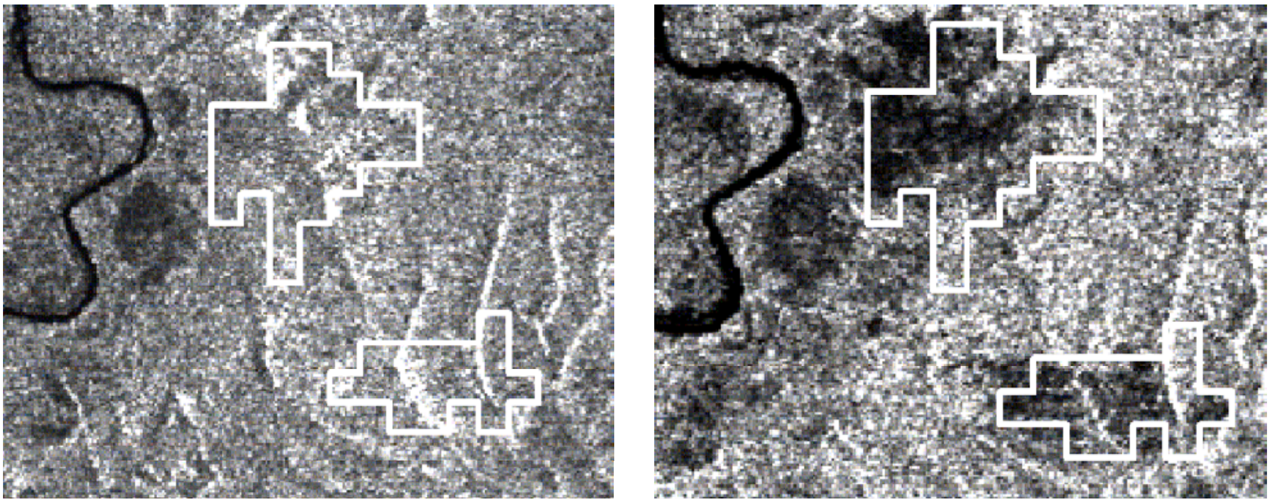
Forest fires are a major cause of forest disturbance in Siberia and as such release stored terrestrial carbon and cause change in land surface albedo. Burnt area may vary by an order of magnitude between high and low fire years, with massive differences in published estimates of burnt area. In the SIBERIA-II project forest disturbance (including burnt area) are being mapped using MODIS data at a scale of 1km x 1km. ASAR WS images will be used in a cross-comparison exercise to investigate the impact of the higher spatial resolution of ASAR (75m x 75m) and the differences created by using a SAR, rather than an optical sensor, to view the disturbances. Preliminary results show that the fire scars are clearly visible in the ASAR data with strong decreases in backscatter observed after a fire has occurred (Fig. 8).

Af-, Re-, Deforestation with ERS SAR and ASAR IM

In the Kyoto Protocol and the following agreements of Bonn and Marrakech, the definitions of Afforestation, Reforestation and Deforestation (ARD) have been introduced and refined. Afforestation is the direct conversion of land that has not been forested for at least 50 years to “forest”, reforestation refers to the conversion of temporarily “non-forested” land back to “forest” and deforestation is the conversion of “forest” to “non-forest” [5]. According to the Kyoto Protocol, monitoring ARD activities means to define quantitatively human-induced forest cover changes, having 1990 as baseline year.

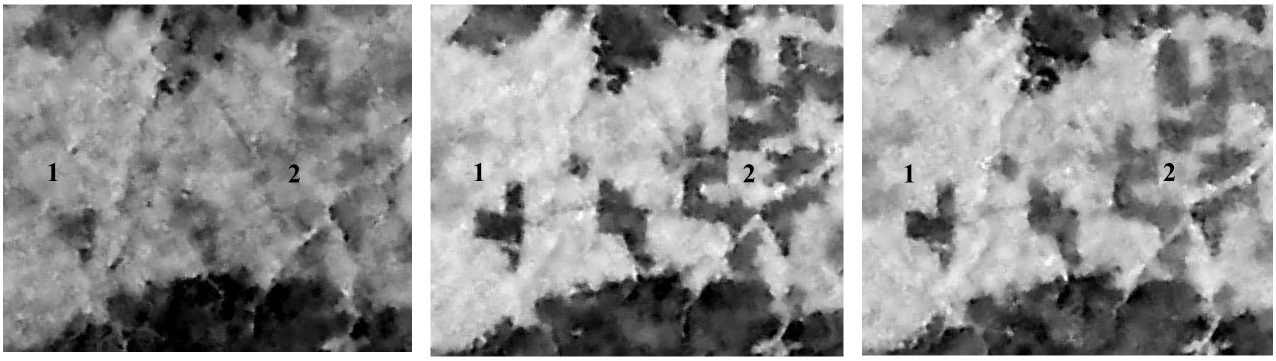
Since spaceborne remote sensing (RS) data have been available for approximately the last two decades, the assessment of afforestation requires historical ground data. Reforestation and deforestation can be quantified with RS, although only optical imagery can fulfil the temporal requirements set in the Kyoto Protocol. Radar data have been acquired as early as 1991 (by ERS-1); nonetheless, SAR images from ERS-1/2 and Envisat ASAR span nowadays over 13 years, thus allowing long term monitoring of reforestation and deforestation activities.

Within the SIBERIA-II project area ARD monitoring is carried out at test sites, using Landsat images with a 30 m pixel size [6]. High-resolution C-band SAR data, ERS and ASAR Image Mode (IM), are currently investigated to support the Landsat-based classification and to assess the possibilities of a radar-stand-alone ARD product. In this paper we present some preliminary results for the test site of Bolshe-Murtinsky where ERS SAR and ENVISAT IM ASAR images have been acquired between 1993 and 2004.



a) 14/07/2003 pre-fire ASAR image   b) 18/08/2003 post-fire ASAR image

Fig. 8. Decrease in ASAR backscatter caused by a forest fire occurring between a) 14/07/03 and b) 18/08/03. The white polygons show the burnt area identified using MODIS imagery.



a) 5 December 1996 (ERS-2) b) 29 December 2000 (ERS-2) c) 27 February 2004 (ASAR IM)

Fig. 9. SAR backscatter images of a 1200 km^2 area located in the test territory of Bolshe-Murtinsky.

A common problem when detecting forest cover changes with SAR data is misinterpretation that can occur when the images to be compared have been acquired under different weather or seasonal conditions. Since over the test site ERS and ASAR images have been most frequently acquired in winter under frozen conditions, these images were considered for further analysis. Currently three images are available, acquired respectively by ERS-2 on 5 January 1996 and 29 December 2000, and by ASAR on 27 February 2004. At acquisition time, the temperature was always around –20 °C, the snow depth was between 20 and 50 cm and snowfall occurred. Image processing included calibration, multi-looking, additional speckle filtering with a Gamma-MAP filter and geocoding to 30-m pixel size.

Over open areas and forests temporal consistency of the backscatter could in general be observed. Fig. 9 shows an area where very likely clear-cutting activities took place between 1996 and 2000. In the 1996 image the contrast between forest and non-forest is lower than in the other two images, so that the non-forested areas appear only slightly discernible from forests. Nonetheless, two new clear-cuts occurred between 1996 and 2000 are visible (areas 1 and 2). Both areas are characterised by a decrease of backscatter by 1-2 dB. Reforestation activities could not be detected as straightforward as in the case of deforestation because of the very small backscatter difference between bare ground and young vegetation.

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