ANALYSIS OF ASAR APP TIME SERIES OVER SIBERIA FOR OPTIMISING FOREST COVER MAPPING - A GSE FOREST MONITORING STUDY

Carolin Thiel, Christian Thiel, Tanja Riedel, Christiane Schmullius

Friedrich-Schiller-University Jena, Institute of Geography, Earth Observation, Grietgasse 6, 07743 Jena, Germany, Email: Carolin.Thiel@uni-jena.de, Christian.Thiel@uni-jena.de, Tanja.Riedel@uni-jena.de, c.schmullius@uni-jena.de

ABSTRACT

Russia holds the largest forestry resources in the world (ca. 22%). One of the most wooded regions of Russia is the district Irkutsk. The detection and monitoring of forest management activities and disturbances in this district is of great interest for the State Forest Service. Large changes in forest management due to legal and illegal logging and as well as disturbances such as fires, insect outbreaks or wind damage are very common.

For the Russian Service Case of GSE Forest Monitoring ENVISAT ASAR data were used. The optimisation of forest cover mapping comprises the refinement of the map delineation procedure and the ascertaining of the ideal data acquisition date. Thus, emphasis is put on the analysis of time series throughout the seasons. The investigation comprises the temporal analysis of the signatures of the relevant landcover classes, and the separability of these classes. This study is embedded into the GSE Forest Monitoring Project.

1. INTRODUCTION

Russia features the largest forestry resources in the world with about 22% of the world’s forest. One of the most wooded regions of Russia is the district (Russian: Oblast) Irkutsk compromising about 10% of Russian forested territory. About 82% of this Oblast is covered with boreal forests. Presently, all forest information is collected at a local level in periodical inventories every 10-15 years. Large changes in forest management due to legal and illegal logging as well as natural disturbances such as forest fires, insect outbreaks or wind damage are very common. Those short termed changes can not be sufficiently captured by the State Forest Service. Spaceborne Earth Observation techniques are suited to overcome these restrictions [1].

1.1. GSE-FM Project Background

GSE Forest Monitoring is one element of the Global Monitoring for Environmental and Security (GMES) initiative of the ESA Earthwatch Programmes. GSE FM was initiated in 2003 with consolidation stage 1, followed by the implementation stage 2 started in 2005 with three year duration. The international consortium is led by GAF AG and consists of 18 Service Providers and 25 End User. The main goal is to deliver customised policy-relevant and operational information mainly based on EO data in ready-to-use packages in the field of Climate Change, Sustainable Forest Management as well as in Environmental Issues and Natural Protection. The supplied products and services are validated and standardised to support decision-making and improved policies that enable cost effective sustainable forest management in various countries [2].

1.2. The Russian Service Case

The Russian Service Case relates to the Irkutsk Oblast (Fig. 1 & 3). The Service Case is based on an agreement with the Forest Agency of Irkutsk General Survey of Natural Resources (FA of GSNR) of Russian Ministry of Natural Resources (MNR). The GSE FM service case in Russia has a large influence on effective forest monitoring and inventory at regional scale. Recent information on forest extent and changes therein are currently generated using high-resolution ENVISAT ASAR APP IS7 (HV/HH) data. The provided products of this service case include a forest area map, a clear-cut/burned area map and a forest area change map. The forest area map is derived from recently acquired ASAR data. The generation of the other maps comprises archived LANDSAT TM data around year 1990. Specifications of the products require geometric accuracy of an RMS < 30 m and a minimum mapping unit of 1 ha. Both requirements can be fulfilled. The acceptability threshold of the thematic mapping accuracy is 90% for non-change maps and 85% for change maps, respectively. All products will be implemented into the forest inventory of the FA of GSNR and are produced within three years for regions of rapid change in the Irkutsk Oblast, comprising a total area of 200,000 km². In the first year an area of about 50,000 km² has already been processed, the service area will be extended by ~20% each year (see Fig. 1).

Figure 1. Mapping areas of phase 1 and phase 2 within Irkutsk Oblast, black frames mark location of ASAR time series, dots mark indicative climate stations
1.3. SAR Data Processing and Mapping Approach

The SAR data methodology chain comprises preprocessing (calibration, orthorectification, topographic normalisation [3, 4], and ratio computation), classification, post-classification refinement, manual separation of clear-cuts and burned areas with the forest area map as origin and change map production. Data analysis and classification are based on image objects (segments), where segments are identified using a multiresolution segmentation algorithm [5, 6]. One single ASAR scene (three channels: HH/HV/ratio\([\text{HH/HV}]\)) provides the input for detecting forest and non-forest areas, whereas non-forest areas enclose the classes clear-cuts and burned areas. To ensure the requested minimum mapping unit of 1 ha, no speckle filter is applied but nevertheless due to the application of image segments, the noise effect of SAR speckle can be reduced. Several samples for each class are identified before conducting the supervised classification (nearest neighbour) based on \(\sigma_0\) in dB. Manual post-classification refinement is necessary to fulfil the requested mapping accuracy. Basing on the forest area map which comprises the mixed class “clear-cuts and burned areas” clear-cut and burned area maps are produced. The separation of this mixed class is conducted by means of the analysis of the genesis driven discrepancies of the object shapes and fire event data.

For the production of forest area change maps archived LANDSAT TM scenes from years around 1990 are classified using the same procedure as described above. The classification results are then combined with the forest area maps to create the forest area change maps (Fig. 2).

Figure 2. Left: Example of forest area map (2006); grey: forest, black: non-forest. Right: Example of forest area change map (1990-2006); grey: forest, white: regrowth, black: deforestation, dark grey: non-forest (subset size ca. 10 x 11 km)

1.4. Site characteristics

The Irkutsk Oblast is located in central Siberia in Russia reaching from 52° to 64° north and 96° to 118° east and comprises about 739,000 km². The Middle Siberian Plateau in the southern part of the territory is dominated by hills up to 1700 m. The northern part is plain with heights up to 500 m. Characteristic taiga forests (birch, aspen, pine, larch etc.) dominate the Irkutsk Oblast and cover about 82% of the region.

Current forest monitoring is accomplished by the conduction of periodical forest inventories, generally every 10 to 15 years [1].

The Irkutsk Oblast exhibits continental climatic conditions. The yearly amount of precipitation is generally below 450 mm; the winters are very cold and dry, the summers are warm and feature the precipitation season. Drastic short term temperature variations are common. Key climatic parameters are depicted in Fig. 4 and Fig. 5 respectively for the stations Tulun and Vitim (year 2006). These stations are indicative for the area covered by the ASAR time series (see Fig. 1).

Figure 3. Russian Service Case Site Irkutsk Oblast

Figure 4. Climatic data Tulun station for year 2006 (weekly averages for Tmax and snow depth, weekly sum for precipitation)

Figure 5. Climatic data Vitim station for year 2006 (weekly averages for Tmax and snow depth, weekly sum for precipitation)
1.5. SAR Data Time Series

The production of the recent forest/non-forest maps relies on high-resolution ENVISAT ASAR APP IS7 HH/HV SAR data. The time series comprises two scenes with bordering tracks (376 and 104) and the same frame (2493) as depicted in Fig. 6. The time series consists of six acquisition dates for each scene as summarised in Tab. 1.

![Figure 6. ASAR time series: two bordering scenes, six acquisition dates each, March data depicted (RGB = HH-HV-HV)](image)

**Table 1. ASAR time series: acquisition dates per scene**

<table>
<thead>
<tr>
<th></th>
<th>West</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td>05.03.2006</td>
<td>21.03.2006</td>
</tr>
<tr>
<td>March</td>
<td>05.03.2006</td>
<td>21.03.2006</td>
</tr>
<tr>
<td>April</td>
<td>14.05.2006</td>
<td>25.04.2006</td>
</tr>
<tr>
<td>May</td>
<td>18.06.2006</td>
<td>25.04.2006</td>
</tr>
<tr>
<td>June</td>
<td>23.07.2006</td>
<td>04.07.2006</td>
</tr>
<tr>
<td>September</td>
<td>27.08.2006</td>
<td>07.09.2006</td>
</tr>
<tr>
<td>October</td>
<td>05.11.2006</td>
<td>21.11.2006</td>
</tr>
</tbody>
</table>

2. ANALYSIS OF ASAR APP TIME SERIES

2.1. Presumptions

At this point it should be stated that this study is strongly application oriented. It aims at answering the pragmatic question for service provision at the boreal region of Irkutsk Oblast: What is the ideal acquisition period/season for intensity based forest/non-forest discrimination? By a number of L-band studies (e.g. [7, 8, 9]) it could be proved that summer data are superior to winter data. At C-band clear-cut vegetation and remaining trees at fire scars could cause (too) high backscatter whereby the discrimination from forest would be hindered. There is a number of in places opposing factors and processes which need to be considered to answer the above stated question. Some examples are given in the following [7]:

- What are the clear cut and fire scar conditions (remaining vegetation, surface roughness etc.)?
- What are the forest conditions (stand characteristics as age, density, tree type etc.)?
- What is the soil moisture and surface roughness (of forested and unforested patches)?
- Is there a significant snow layer and if yes what are the snow conditions? Do thawing processes play a role? Is there snow on tree canopies? Does the snow act as attenuator or as (surface) scatterer?
- Is the trees canopy frozen?
- Is there an effect of rainfall or topography?

2.2. Signature Analysis

A preliminary visual appraisal initiated the analysis of the time series. This assessment already emphasised the importance of the choice of the acquisition date for forest/non-forest discrimination, as neither summer nor winter data appeared to be best suited. The highest contrast was evident at the April-scene. A signature analysis was conducted for substantiating this observation. For taking the variability of forested and non-forested areas into account, the forest classes “(prevailing) needle leaved”, “(prevailing) broad leaved”, and “young forest” (age about 10 years) have been considered. Non-forest was separated into “clear-cut” and “burnt”. Additionally the classes “water”, “settlement”, and “agriculture” have been introduced. For each of these classes about 15 sample areas have been generated per scene. Each sample area was considered being an image object, thus the average backscattering coefficient per sample area was used as input for further statistical investigations.

![Figure 7. ASAR time series: mean backscattering coefficient for each acquisition date separated by landcover class and polarisation for the eastern scene. Enclosed are three forest classes, two non-forest classes and the classes “settlement” and “water”. Agriculture does not appear in the eastern scene. Strong temporal backscatter variation is apparent for all classes. The high backscatter of “water” during the winter months is due to freezing. The forest classes exhibit their backscatter maximum during the growing season, although this trend is more distinct for the “broad leaved”, and “young forest”. Due to canopy freezing the backscatter decreases during winter. The temporal difference between minimum and maximum backscatter of “broad leaved” and “young forest” reaches 4 dB at HH and 5 dB at HV polarisation. For “needle leaved” it is only 2 dB/4 dB (HH/HV). The non-forest classes “clear-cut” and “burnt” exhibit similar temporal backscatter variation. High backscatter is apparent during the growing season; low backscatter appears in winter and spring. The absolute minimum emerges in late April. The temporal dynamic range between minimum and maximum backscatter is](image)
Regarding the temporal dynamic range of the backscattering intensity the forest and non-forest classes feature a comparable behaviour. Additionally, the backscattering intensities do not differ very much at each acquisition date (0-2 dB). The only exception is the April acquisition (4 dB/5 dB for HH/HV). This verifies the result of the visual appraisal.

Fig. 7. Temporal variation of backscatter separated by landcover class and polarisation, eastern scene

Fig. 8 shows the same issue as Fig. 7 for the western scene. As agriculture takes place within this scene this class is embedded. Its very high temporal dynamic range reflects the cultivation cycle. The other classes behave similar to the eastern scene. Unfortunately no scene was acquired in the April cycle. Thus, the spread of forest and non-forest in terms of backscattering intensity during spring could not be documented for the western scene.

Fig. 8. Temporal variation of backscatter separated by landcover class and polarisation, western scene

Fig. 9 outlines the temporal variations of backscatter for the two key classes. The “forest” class was generated by merging the signatures of the three above stated forest classes; the “non-forest” class contains the merged signatures of the above “burnt” and “clear-cut” classes. The signatures of both scenes are embedded in the graph. The error bars denote minimum and maximum backscatter respectively (e.g. minimum refers to respective sample area with the least mean backscatter). Seasonal effects can be easily recognised. The mean backscatter decreases in winter and increases in summer. The temporal difference in backscatter is larger for the cross-polarisation. The differences of the mean backscatter of forest and non-forest are larger in winter and at cross-polarisation. For some summer acquisitions forest and non-forest areas feature equal backscattering intensities. The acquisition with the most distinct backscatter difference between forest and non-forest was conducted in April. At this date not even the max-min bars are overlapping.

Fig. 9. Temporal variation of backscatter for forest and non-forest separated by polarisation, both scenes. Error bars flag min and max respectively

2.3. Separability calculation

To ensure an impartial and accurate analysis of the acquisition date driven separability of forest and non-forest a separability measure was calculated. The normalised Jefferies-Matusita distance was selected for this task (1.0 = signatures separable; 0.0 = signatures inseparable). The separability analysis was performed on pixel level. The signature for each class was derived basing on the above described sample areas. Performing on pixel level was necessary to derive a useful gradation of the separability for the various acquisition dates. Tab. 2 shows the separability of the non-forest classes “burnt” and “clear-cut” against the forest classes “forest” (needle and broad leafed merged) and “young forest”.

Table 2. Separability of key classes, eastern scene

<table>
<thead>
<tr>
<th>clear-cut vs. young forest</th>
<th>burnt vs. young forest</th>
<th>clear-cut vs. forest</th>
<th>burnt vs. forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.02</td>
<td>0.26</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>21.03</td>
<td>0.24</td>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>25.04</td>
<td>0.76</td>
<td>0.78</td>
<td>0.77</td>
</tr>
<tr>
<td>04.07</td>
<td>0.34</td>
<td>0.43</td>
<td>0.32</td>
</tr>
<tr>
<td>12.09</td>
<td>0.36</td>
<td>0.57</td>
<td>0.36</td>
</tr>
<tr>
<td>21.11</td>
<td>0.12</td>
<td>0.29</td>
<td>0.23</td>
</tr>
</tbody>
</table>
High separability at each column is aspired, as for example “young forest” needs to be separated from non-forest. Tab. 3 holds the same information for the western scene. Tab. 4 summarises the separability of forest and non-forest for both scenes. Generally the separability analysis reflects the results of the signature analysis. Intra-seasonal separability variations (especially in the growing season) exceed a general separability difference between summer and winter. This outcome certainly refers to short term variations such as precipitation effects [11]. Those variations are smaller in winter. Also the separability seems to be slightly higher during winter (compare [7, 11]). Hence, for ASAR APP based forest/non-forest discrimination winter data could be preferred against summer data. However, there is still the outperforming separability of 25th April. Additionally, high separability of forest/non-forest at late April / early May is also evident for many other scenes (were no complete time series was on hand). Those scenes are listed in Tab. 5.

3. DISCUSSION

During the thawing period wet snow conditions can be assumed. This is especially true if it is raining on the snow layer, as occurred in April 2006. The trees canopy at this time is generally free of snow, not frozen and partly developed. The ground vegetation at the non-forest areas is barely developed. The snow layer at non-forest areas is wet and more or less even. Incoming radar waves are reflected specular or will be absorbed. Thus, the amount of backscatter from those surfaces is

<table>
<thead>
<tr>
<th>Track</th>
<th>Frame</th>
<th>Date</th>
<th>Centre Coord.</th>
</tr>
</thead>
<tbody>
<tr>
<td>104</td>
<td>2421</td>
<td>25.04.2006</td>
<td>59.24 / 104.23</td>
</tr>
<tr>
<td>104</td>
<td>2439</td>
<td>25.04.2006</td>
<td>58.35 / 103.96</td>
</tr>
<tr>
<td>104</td>
<td>2493</td>
<td>25.04.2006</td>
<td>55.70 / 103.20</td>
</tr>
<tr>
<td>104</td>
<td>2511</td>
<td>25.04.2006</td>
<td>54.82 / 102.96</td>
</tr>
<tr>
<td>104</td>
<td>2529</td>
<td>25.04.2006</td>
<td>53.93 / 102.73</td>
</tr>
<tr>
<td>61</td>
<td>2493</td>
<td>22.04.2006</td>
<td>55.70 / 104.63</td>
</tr>
<tr>
<td>61</td>
<td>2511</td>
<td>22.04.2006</td>
<td>54.82 / 104.39</td>
</tr>
<tr>
<td>61</td>
<td>2527</td>
<td>22.04.2006</td>
<td>54.68 / 104.35</td>
</tr>
</tbody>
</table>

333 2421 11.05.2006 59.24 / 104.94
333 2439 11.05.2006 58.35 / 104.67
147 2457 28.04.2006 58.27 / 102.50
147 2421 28.04.2006 59.24 / 102.79
147 2439 28.04.2006 58.35 / 102.52
190 2477 01.05.2006 56.46 / 100.53
190 2439 01.05.2006 58.35 / 101.08
190 2485 01.05.2006 54.85 / 100.09
190 2457 01.05.2006 58.27 / 101.06
rather small. This forms a good contrast to the medium/high backscatter generated from the tree canopies (compare Fig. 12). These special conditions allow the C-band based forest/non-forest division [7, 8].

![Figure 12. Scattering processes during thawing period](image)

During the growing season the ground vegetation and the high surface roughness at the non-forest areas hinders their separation from forest. During winter the trees canopy is frozen and produces much less backscatter. Thus the forest/non-forest contrast is reduced. Additionally at the non-forest areas some backscatter is generated via SAR wave-ground interaction (interpenetration of very dry snow) or scattering within the (inhomogeneous) snow layer [7, 10].

4. CONCLUSION AND OUTLOOK

The Siberian boreal region is characterised by continental climatic condition comprising a long and cold winter with considerable accumulation of snow. The thawing process typically initiates suddenly and takes 1-4 weeks. If C-band based forest/non-forest discrimination in boreal regions is aspired the thawing season might be the best choice for acquisition. Shorter temporal sensor baselines would ensure to meet the assigned acquisition time frame. The initiation date of thawing is subject to regional and temporal variations, thus weather and snow conditions must be checked before acquisition.

For phase 3 of GSE FM PALSAR data will be introduced for service production. The mapping area of the third year will be about 90,000 km². L-band (ALOS) winter coherence images (2006/2007) will complement the data input. This new data input is assumed to minimize the costly manual classification refinement afforded. Eventually it is aspired to combine ASAR C-band and PALSAR L-band data for product extension.

5. ACKNOWLEDGEMENT

This work formed part of the ESA financed project “GSE-Forest Monitoring” (ESTEC Contract 19277/05/I-LG).

6. REFERENCES