

AN OBJECT-BASED CLASSIFICATION PROCEDURE FOR THE DERIVATION OF BROAD LAND COVER CLASSES USING OPTICAL AND SAR DATA

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ABSTRACT:

The availability of up-to-date and reliable land cover maps is of great importance for many earth science applications. For the generation of operational and transferable land cover products the development of semi- and fully-automated classification procedures is essential. The Enviland project deals with the development of novel approaches for the generation of land cover products using both optical and SAR data. In a first step an automatic classification scheme for the delineation of broad land cover categories such as water, forest, urban areas and agricultural fields / grassland will be designed. This paper presents the first results of the sub-project “scale integration”. The study area is located in northern Thuringia, Germany, including mainly forested regions like the eastern part of the low mountain range Harz as well as intensively used agricultural areas. From April to December 2005 optical and SAR data were acquired continuously over the test site building up a comprehensive time series (e.g. 4 Landsat-5 TM, 17 Envisat ASAR APP and 10 ERS-2 scenes).

In this paper an object-based hierarchical classification scheme for the derivation of broad land cover classes using both optical and SAR data is presented. The segmentation of the EO-data was done using the eCognition software. The thresholds of the decision tree are based on reflectance values, the backscattering coefficient and texture information. By the integration of textural features in the classification process the classification accuracy could be improved significantly, especially in the context of urban areas. In this study the power of the grey level dependency matrix – rarely used in the field of remote sensing – is demonstrated.

1. INTRODUCTION

Earth observation represents a unique cost-efficient method for large-area land cover mapping providing spatially consistent and multitemporal information. The availability of reliable and up-to-date land cover information is required for a multitude of applications ranging from regional to global scales such as land cover change studies, ecological monitoring, map updating, management and planning activities or the implementation and control of national and international treaties (Franklin & Wulder, 2002 and Jensen, 2000).

For operationalization the development of transferable, semi-automated and automated approaches are worthwhile in order to save time and manpower. Aim of the joint research project Enviland, which is funded by the German Ministry of Education and Research (BMBF) and the German Aerospace Center (DLR) (FKZ 50EE0405), is the development of a software prototype for the generation of land cover maps exploiting the complementary information provided by SAR and optical sensors. The software will include pre-processing, segmentation and classification procedures. This paper presents first results regarding the design of an automatic classification scheme for the delineation of broad land cover categories such as water, forest, urban areas and agricultural fields / grassland (phase 1). The methodology should be robust and transferable to other regions in Europe providing high classification accuracies for a limited number of input data and various sensor types. As multispectral data are often not available (e.g. due to frequent cloud cover), emphasis of this study was to develop a working flow including a limited number of optical data only, but exploiting the information content of multitemporal SAR data. The focus of the second project phase will be on a more

detailed classification, especially for urban and agriculturally used areas.

2. STUDY AREA AND EXPERIMENTAL DATA

The study site is located in the northern part of Thuringia, Germany (Figure 1) including mainly forested areas characterized by high topography like the low mountain range Harz (north) and the Kyffhäuser (south) as well as intensively used agricultural areas like the “Goldene Aue” east of Nordhausen.

From April to December 2005 optical and SAR data were acquired continuously over the test site building up a comprehensive time series (Figure 2). HH/HV-polarized ASAR APP data (swath 2) and ERS-2 data were recorded nearly simultaneously providing C-band data at all polarizations. Due to good weather conditions on July 10 Landsat TM5 and SAR data acquired within one hour are available. This data set provides an excellent basis for studying synergy effects.

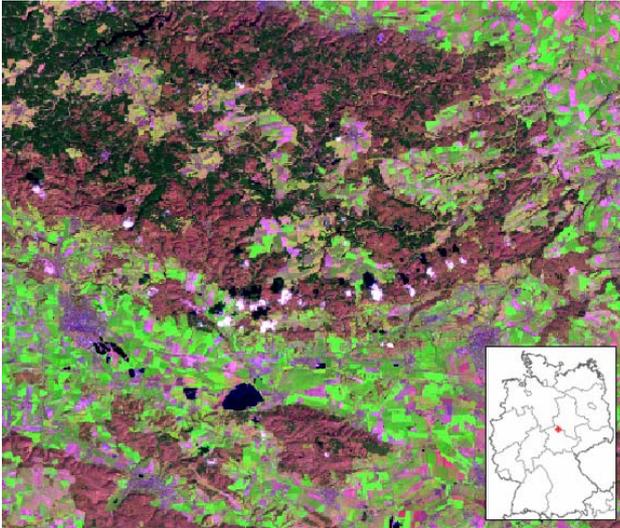


Figure 1. Landsat TM 5 image of the test site from April 21, 2005 (channel 5-4-3)

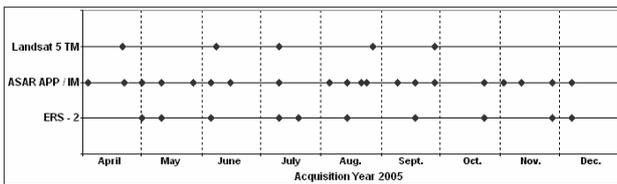


Figure 2. EO-data base 2005

3. METHODOLOGY

Land cover maps were generated applying an object-based, hierarchical decision tree classification scheme. First of all, the EO-data were pre-processed on base of commonly used techniques. For the calibration and geocoding of the SAR data the Gamma software was used. As parts of the test site are characterized by significant topography, the normalization procedure proposed by Stussi et al. (1995) was applied. The optical data were atmospherically corrected with ATCOR and orthorectified using the C-band SRTM DEM.

After pre-processing of all EO-data, image objects were delineated on base of the optical data using the multiresolution segmentation approach (Baatz & Schäpe, 2000) implemented in the eCognition software. The scale factor was decreased stepwise. The fusion of optical and SAR data was performed following a feature-based approach, i.e. on segment basis. To each image object a land cover class was assigned applying characteristic, object-related thresholds based on reflectance values, backscattering coefficient, ratios and texture information. For the selection of optimal / characteristic parameters the time series were analysed in a systematic manner. Additionally, information reported in literature and libraries (e.g. European RADar-Optical Research Assemblage library - ERA-ORA) were considered. Especially for the detection of urban areas texture parameters are a valuable tool. In the framework of this study the potential of various texture measures such as standard derivation, data range and parameters derived on base of the grey-level co-occurrence matrix (GLCM) were investigated. Additionally, the neighbourhood grey level dependency matrix (NGLD) was

calculated. This measure is invariant with respect to texture direction. The NGLD matrix was calculated for a moving window of 5x5 pixels. For every pixel of the window the relation to all neighbouring pixels at a specified distance d is investigated and the number of pixel pairs satisfying the relation is counted. The NGLD matrix is a squared matrix describing the pixel value a in one direction and the number of pixel pairs fulfilling the given relation n_r in the other direction. Each element of the matrix describes the number of occurrences of every possible combination of a and n_r . Analogous to the widely used co-occurrence matrix several texture measures could be extracted from the NGLD matrix such as entropy, energy, minimal and maximal emphasis. The potential of the various texture parameters investigated was evaluated by separability analyses as well as by classification accuracy assessment. Therefore, the Jeffries-Matusita distance (JM), which is a widely used measure in remote sensing to determine the statistical distance between two multivariate, Gaussian distributed signatures, was calculated. The JM distance varies between 0 and 1414, whereas 0 signifies no and 1414 a very high separability

Thematic map accuracy was assessed by calculating the confusion matrix and the kappa coefficient using the eCognition software. Reference segments were selected on base of high resolution optical data (Quickbird and Hymap) and air photographs with a reduced resolution of 2m. Segments with uncertain class membership were not considered in the evaluation process. In order to test the robustness and stability of the proposed methodology, the classification scheme was applied to EO-data acquired in 2003, too.

4. RESULTS AND DISCUSSION

The image features used for the classification of the EO-data are listed in table 1 and will be described in detail in the following section.

class	optical	C-band SAR	optical & C-band SAR
water	ch6, NDVI	HV	ch6, NDVI
urban areas	ch5, GLCM entropy	NGLD-HH, HV	NGLD - HH, HV, ch5
forest	ch2, ch4	HV	HV, ch4
agriculture/grassland		HV	HV

Table 1. Image parameters used for classification

The first step in the hierarchical classification procedure was the mapping of water bodies. For optical data the NIR and SWIR channels as well as the NDVI or LSWI are often used to create a water mask. Best classification results were achieved using the relationship between NDVI and LSWI as proposed by Xiao et al. (2005) for MODIS data or the NDVI and Landsat 5 TM channel 6, respectively. For the mapping of water bodies using C-band SAR data only, cross-polarized images acquired at the very end of the growing season or directly after harvest (before tillage) are required. If multitemporal scenes are available, the multitemporal mean of radar backscatter observed should be below the threshold of -22 dB.

Urban areas in optical EO-data were mapped on base of the reflectance in channel 5 and textural features. Best performance

was achieved – in former West and East Germany - when using the co-occurrence entropy calculated for each polygon with the eCognition software. For the detection of urban areas using multitemporal SAR data only, Cilhar et al. (1992) proposed the usage of the radar backscatter and the dynamic range. The authors analysed nine airborne C-band SAR scenes (8x HH + 1xVV) acquired over Ottawa, Ontario, Canada. Urban areas are characterized by both a low dynamic range of less than 3 dB during the year and a high radar backscatter. All other land categories – forest, water, grassland and agriculture – showed a low radar signal, a high dynamic range or both. However, it was not possible to differentiate forest and urban areas using this approach. Besides this, many studies demonstrated the power of texture measures for the mapping of urban extent using medium resolution EO-data (Dekker, 2003; Dell’ Acqua & Gamba, 2003 and Nyongui et al., 2002). In the framework of this study several texture measures were tested. Contrary to Nyongui et al. (2002) the application of a speckle filter prior the derivation of texture did not improve the achieved classification results significantly. Figure 2 illustrates eclectic texture parameters derived from HH-polarized ASAR APP data acquired on April 22, 2005. A visual interpretation of the texture images indicated the potential of the NGLD matrix to map urban areas. The

relation used for the computation of the NGLD-matrix is a difference of 0.1 between neighbouring pixels (a distance of one and two pixels was considered). This relation was selected on base of a statistical analysis of various test areas indicating a proportion of > 40% of neighbouring pixels with a difference of at least 0.1 in urban areas. Besides this, urban areas are characterized by a high radar backscatter at co-polarized C-band data. To account for this behaviour, the following parameter, hereinafter called UADP, was calculated on base of the NGLD matrix:

$$UADP = \sum_{a=0}^{gz-1} \sum_{n_r=0}^N Q_d(a, n_r) * n_r * a \quad (1)$$

where a = radar backscatter at HH-polarization
 n_r = number of pixels satisfying relation
 Q_d = number of occurrences of combination a and n_r

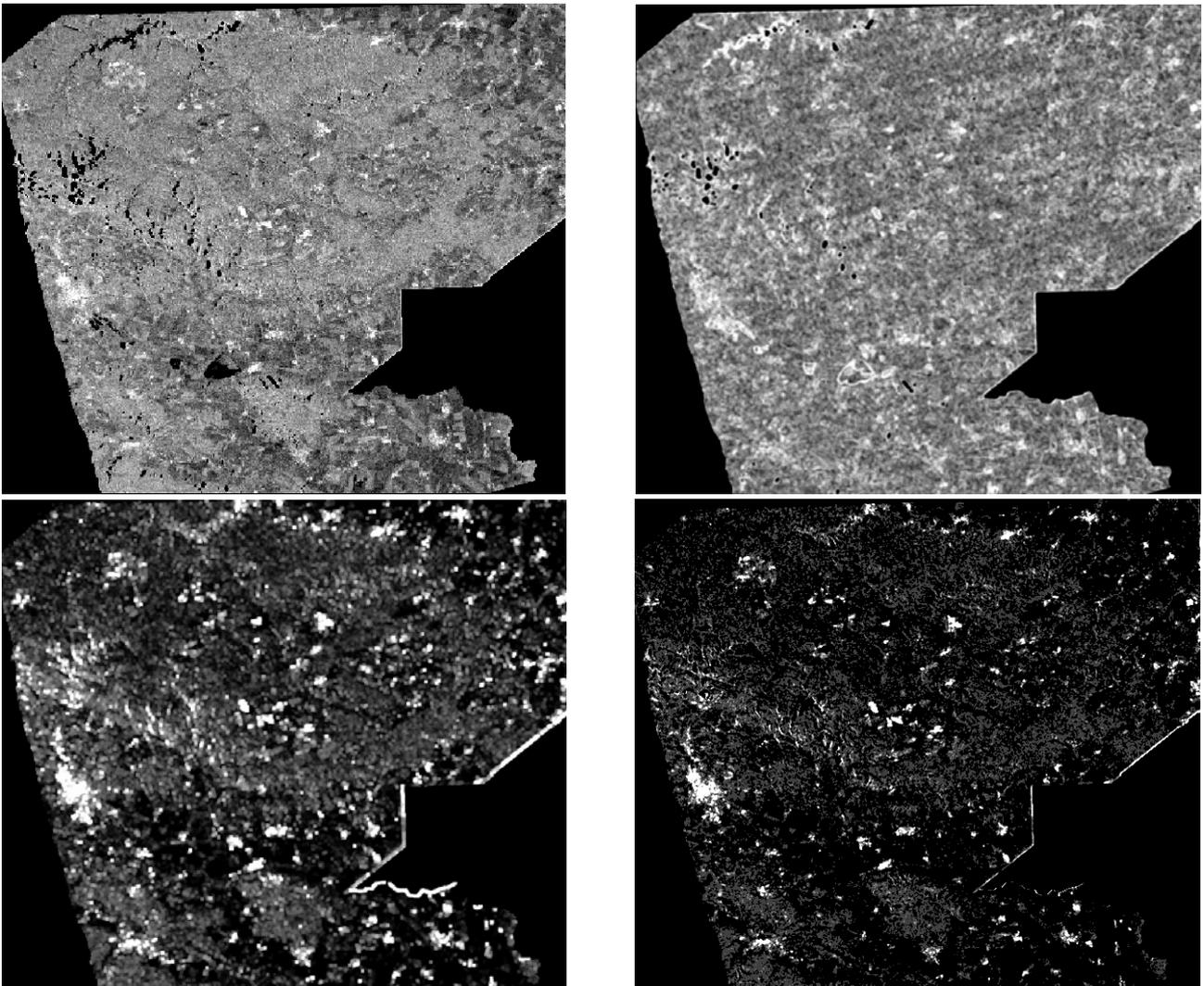


Figure 2 Eclectic texture features derived from HH-polarized ASAR APP data acquired on April 22, 2005 – top left: original image, top right: standard deviation, bottom left: entropy (both window size 11x11), bottom right: UADP

Two different approaches for the extraction of textural features were investigated. First, texture parameters were calculated on the base of a moving window (ENVI, PCI) and used as additional input channel in the eCognition software. The mean texture value of each image segment was used for classification. The second approach utilises the object-oriented texture measures provided in the eCognition software. The performance of the textural features for the mapping of urban extent was evaluated by calculating the JM distance for different reference areas. Especially small villages and low density residential areas such as districts with one-family houses and allotment gardens were considered, as the classification of these structures is most problematic (Figure 3). Using the pixel-based approach, the choice of the window size is a critical issue. The impact of the window size used for texture extraction on class separability is illustrated exemplary for the co-occurrence measure entropy in Figure 4 indicating a significant rise in separability with increasing window size. The same trend was observed for the other texture features investigated. Besides the separability analysis, the classification accuracy for the different texture measures was studied. The analysis indicated a high potential for following parameters: standard derivation, UADP, dissimilarity and entropy. Generally, misclassifications between urban and forested areas often appear in regions characterized by high topography, i.e. in direct neighbourhood to radar shadow and overlay. In comparison to the object-based approach, the observed classification accuracy was slightly higher for the pixel-based approach. This is due to a stronger underestimation of the urban extent in the object-based approach resulting in reduced producer accuracy (89.3 vs. 79.7%). Contrary, misclassification with the forest class was higher for the pixel-based approach. Figure 5 shows the derived urban maps based on the three HH-polarized ASAR APP scenes acquired on April 22, August 14 and 24 using following features: standard derivation, dissimilarity and UADP. Best performance was found for the NGLD matrix approach (Table 2).

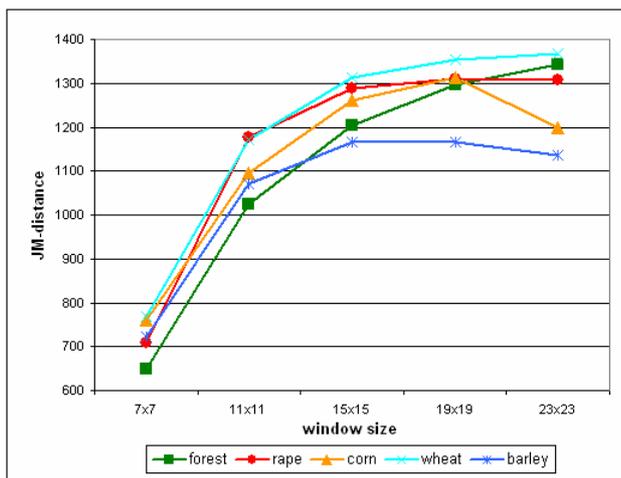


Figure 4. Separability of low density urban areas as a function of window size - texture feature co-occurrence entropy

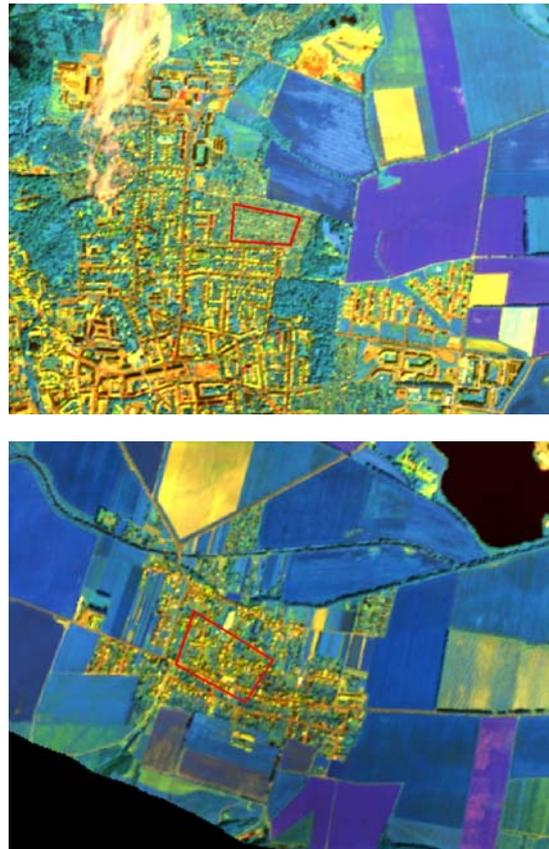


Figure 3. Low density urban areas used for separability analysis (reference: Hymap data)

Textural feature	User accuracy	Producer accuracy
Dissimilarity (object-based)	73,1	82,4
Standard derivation (pixel-based, 25x25)	79,3	89,3
UADP	87,17	87,7

Table 2 Classification accuracies of urban area maps based on multitemporal HH-polarized ASAR APP images

As outlined above, the main problem in generating urban area maps based on SAR data is the distinction between residential and forested areas. This problem could be solved by the fusion with optical data. Both classes could be separated using the green channel under leaf-off and leaf-on conditions. Classification results based on optical data only including texture measure were less accurate than the fused one. The threshold for the UADP was reduced from 3.0 to 2.5 in the fused version. In order to test the stability of the proposed methodology, the classification scheme was applied to data acquired in different months of the year. Achieved classification accuracies for residential areas are listed in Table 3. By the usage of multitemporal images the results will become more stable.

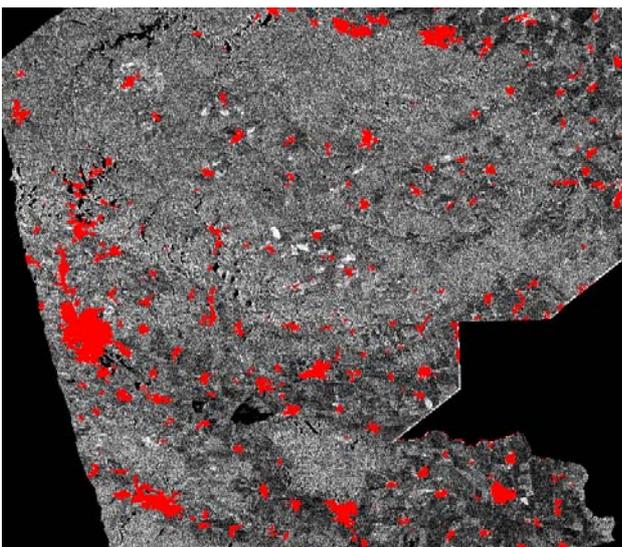
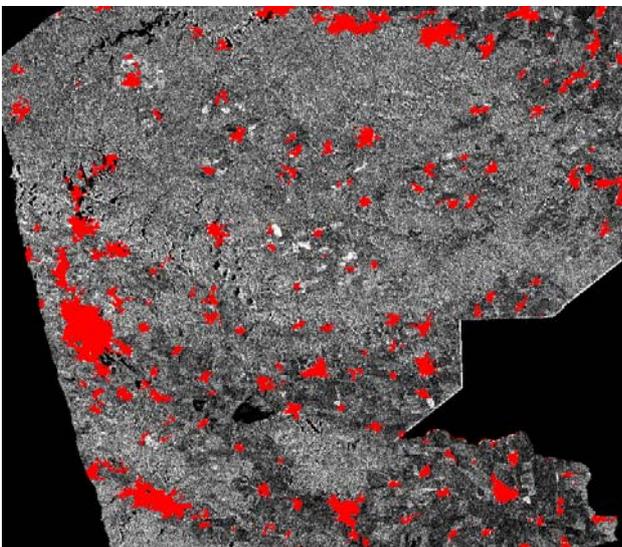
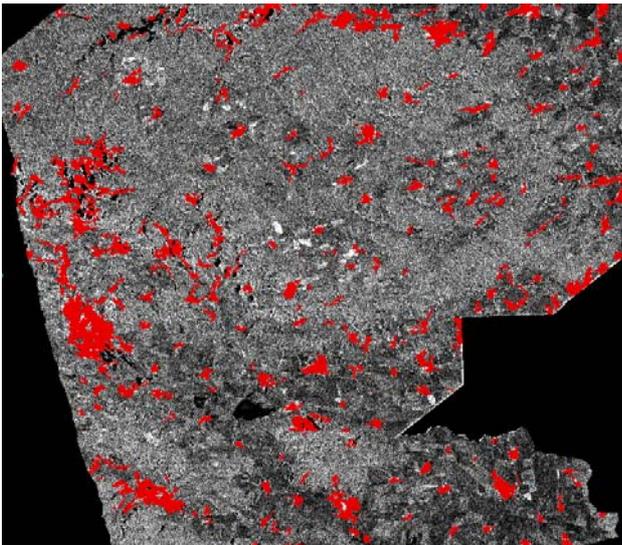


Figure 5. Urban area maps based on GLCM dissimilarity (top), standard deviation (middle) and UADP (bottom) – input data: ASAR APP HH acquired on April 22, August 14 and 24, 2005

SAR	optical	SAR only		Fusion optical & SAR	
		UA	PA	UA	PA
22.04.	21.04.	72.9	85.4	94.1	85.7
10.07.	21.04.	92.5	76.5	96,1	79.5
14.08.	21.04.	72.8	86.2	90.3	86.2
24.08.	21.04.	72.7	80.1	92.1	76.6
22.04.	10.07.	72.9	85.4	93.0	86.1
10.07.	10.07.	92.5	76.5	95.5	79.8
14.08.	10.07.	72.8	86.2	91.9	86.5
24.08.	10.07.	72.7	80.1	92.4	77.2

Table3. Classification accuracies of urban area maps based on one SAR image and the fusion of one optical and one SAR scene respectively

class	SAR only		SAR & optical	
	UA	PA	UA	PA
water	82,2	100,0	93,6	99,9
forest	89,9	90,0	90,3	91,5
urban	85,0	92,5	85,4	95,8
agr./grassl.	90,2	89,9	91,1	89,2
overall acc.	89,5		90,3	

Table 4. Classification results of the derived land cover maps – Input data: Landsat 5 TM from April 21 and ASAR APP HH from April 22, August 14 and 24, 2005

The next step in the hierarchical classification procedure is the mapping of forested areas. For optical data the classification is based on the reflectance values in the green and NIR channel under leaf-off conditions. In the summer months the usage of the green channel was sufficient. For SAR data the backscatter at HV-polarization is most appropriate.

All segments, which did not fulfil the conditions for water, urban and forested areas were assigned as agriculturally used area / grassland. This land use class can be mapped with a high accuracy using multitemporal HV-polarized C-band SAR data. Bare fields and fields covered by crops in an early growing stage are characterized by a low backscatter value. In April/early May for corn and summer cereal fields as well as for most winter wheat fields a radar backscatter below -18.5 dB was observed. Rape, winter barley and winter rye fields could be separated from the other classes at the base of SAR scenes acquired after harvest and tillage. All segments characterized by a radar backscatter above -18.5 dB for all SAR scenes included in the analysis were assigned as unclassified.

Figure 6 illustrates the derived land cover maps based on SAR data only and on the fusion of optical and SAR data, respectively. The corresponding classification accuracies are listed in Table 4. Especially for water bodies and urban areas the classification accuracy was improved by the synergetic usage of optical and SAR data. In this context it must be considered, that only image segments were used for the computation of the confusion matrix, which could be definitely assigned to one land cover class.

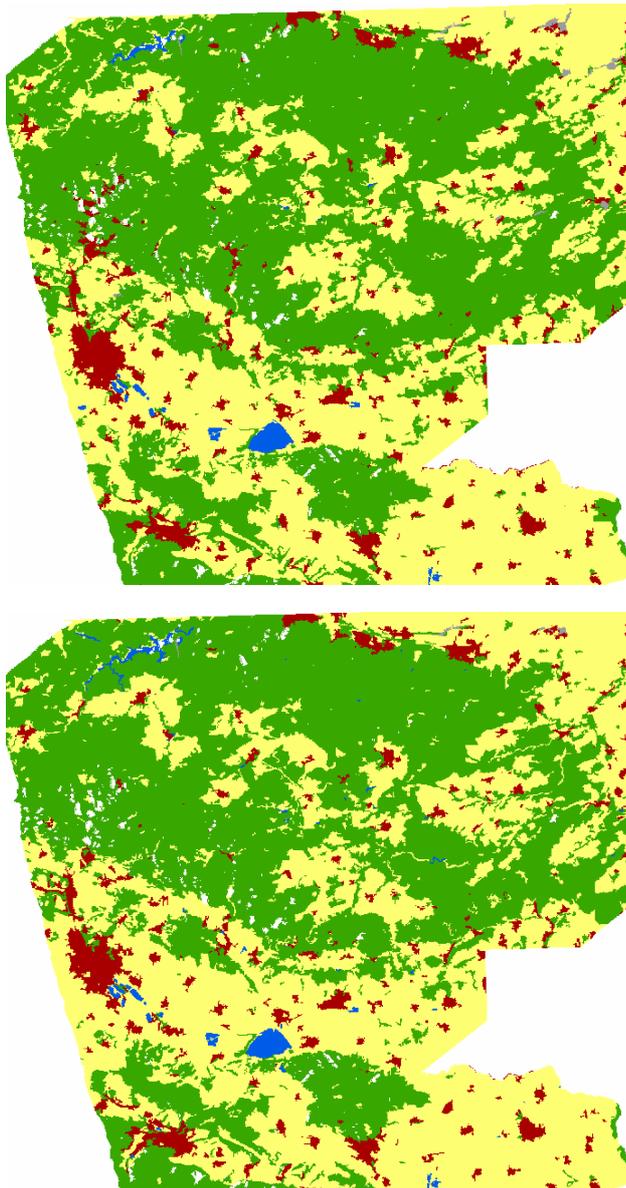


Figure 6. Classification result for SAR data (top) and fused image (bottom) (blue – water, green – forest, red – urban areas, yellow – agriculture/grassland, white – radar shadow/overlay, grey – unclassified)

5. SUMMARY

A robust, hierarchical classification scheme for the generation of land cover maps has been presented. As multispectral data are often not available due to cloudy weather conditions, emphasis of this study was to develop a working flow including a limited number of optical data only, but exploiting the information content of multitemporal SAR data. For the derivation of broad land use classes on base of SAR data at least three Envisat ASAR APP scenes (preferable alternating polarization mode - HH / HV polarized) acquired at the beginning of the growing season in April, at the end of the growing season and after harvest and tillage are required. By the fusion with optical data the classification accuracy could be improved significantly, especially for the land use categories water and residential areas.

For the mapping of urban areas using radar data the potential of the NGLD-matrix was demonstrated. The parameter UADP shows relatively stable classification results during the entire year. First results using ASAR WSM data indicate the applicability of this texture measure even at coarser scales using the same threshold.

The transferability of the proposed methodology to other regions in Europe will be investigated in near future. Furthermore, the generation of more detailed land cover maps is planned, especially for urban and agricultural used areas.

6. ACKNOWLEDGEMENT

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