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ANALYSIS OF MULTI-TEMPORAL LAND OBSERVATION AT C-BAND

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ABSTRACT

The availability of reliable land cover information is crucial for a wide range of applications, like for example monitoring of land use change and land degradation as well as administrative matters in global, regional and local scales. In this paper the potential of SENTINEL-1 C-band SAR data for land cover applications, e.g. generating level-2 land cover classification products has been investigated. Therefore, the planned short revisit and dual polarization concept of SENTINEL-1 has been simulated using multi-temporal ERS-2 and ENVISAT ASAR AP C-band backscatter intensity data. For classification, several multi-temporal metrics and the minimum amount of SAR data acquired during one growing season have been analyzed to derive five basic land cover classes with accuracies greater than 85%.

Index Terms— SENTINEL-1, land cover mapping, multi-temporal metrics, ERS-2, ENVISAT ASAR AP

1. STUDY AREA

The intention for a multi-temporal land monitoring investigation at C-band was given by the upcoming ESA's SENTINEL mission, where a series of five operational satellites will be put in space to fulfill the requirements of the Global Monitoring for Environment and Security (GMES) of the European Union. The first satellite is SENTINEL-1, a pair of polar orbiting synthetic aperture radar (SAR) imaging satellites for the continuation of operational SAR applications and maintaining ESA's series of C-band radar missions ERS-1, ERS-2 and ENVISAT ASAR. In case of continental to global scale, land cover products derived from radar satellites seem to be marginal in comparison to land cover products derived from optical satellites, e.g. Globcover. Regional land cover mapping using radar satellite data has been successfully investigated within the tropics [1, 2] as well as in the temperate zone [3, 4] and boreal zone [5]. In the first phase of the AMOC project financed by European Space Agency, an algorithm for the classification of five basic land cover classes, namely water, grassland, agriculture, forest and settlement was developed based on multi-temporal datasets of C-band backscatter intensities and derived multi-temporal metrics.

2. STUDY AREA

The area of investigation is located in central Germany, in the northern part of Thuringia (Figure 1). It includes the eastern part of the lower mountain range Harz which is characterized by rough topography. The main part is a former subrosion depression with very fruitful clay soil due to natural floods dominated by vast forests and small villages often surrounded by grasslands and intensively used agricultural areas. It comprises approximately 10 x 15 km. The site is located in the transitional zone from atlantic to continental semihumid-moderate warm climatic conditions. The yearly amount of precipitation is generally around 550 mm. The annual temperature amounts of about 8°C.

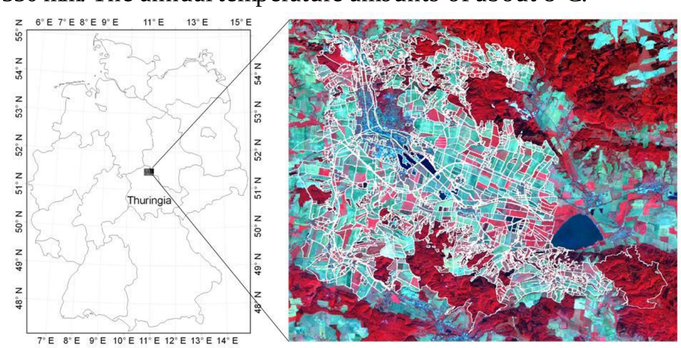

Fig. 1. *Left:* Study Area in Thuringia, Germany. *Right:* Landsat ETM 04.09.1999 (R-4, G-3, B-1).

3. SAR DATA

For this study region, multi-temporal C-band SAR dataset from ENVISAT ASAR AP and ERS-2 from 2005 were available (see table 1). It comprises 10 ERS-2, 3 ENVISAT ASAR Image Mode 'IM' VV Polarisation and 14 ASAR Alternating Polarization 'AP' HH/HV acquisitions. All

ENVISAT images were acquired in swath 2, i.e. 23° incidence angle. For 8 acquisition dates, both ASAR AP and ERS-2 data were available. The data was delivered as Precision Images 'PRI', i.e. already corrected for antenna gain pattern/ range spreading loss and in ground-range geometry. The images were acquired from four different tracks of which two were ascending and two were descending orbits. The repeat interval of both sensors onboard ENVISAT and ERS are 35 days. As the test site was covered from several tracks in ascending and descending orbits, repeat intervals were in some cases as short as 10 days.

Tab. 1. Track, Frame and Acquisition data for the study area.

Track	Frame	ERS-2	ASAR IM I2 VV	ASAR AP I2 HH/HV
2358	1035			22.04.2005
0480	2565	01.05.2005	01.05.2005	
0129	1035	11.05.2005		11.05.2005
0358	1035			27.05.2005
0480	2565	05.06.2005		05.06.2005
0129	1035			15.06.2005
0480	2565	10.07.2005		10.07.2005
0480	2565	20.07.2005		
0358	1035			05.08.2005
0480	2565	14.08.2005		14.08.2005
0129	1035			24.08.2005
0358	1035		09.09.2005	
0480	2565	18.09.2005		18.09.2005
0129	1035			28.09.2005
0480	2565	23.10.2005		23.10.2005
0251	2565		11.11.2005	
0480	2565	27.11.2005		27.11.2005
0129	1035	07.12.2005		07.12.2005

Ground GIS data was provided by the Thuringian Agency for Environment and Geology (TLUG) and contain information about the main land use /land cover types, e.g. crop types. The data was used as training classes for classification as well as for accuracy assessment.

4. SAR DATA PREPROCESSING

The SAR data are delivered in ground range geometry. The afterward processing comprised radiometric calibration, DEM based orthorectification [6], topographic normalisation [7], and layerstacking. As the analysis of the Equivalent Number of Looks (ENL), which is a common measurement of the magnitude of speckle, proved to be quite low (< 5) a multilooking by the factor 2 has been applied. Therefore, the geometric resolution is condensed to 25 m by 25 m in ground range geometry. To reduce even more speckle a multi-temporal speckle filter developed by [8] has been applied. Beneficial consequence is a quite large reduction of speckle mostly retaining the geometric resolution. The filtered image J_k is calculated as a weighted linear combination of M input channels:

$$J_k = \frac{\sigma_k^0}{M} \sum_{i=1}^{M} \frac{I_i}{\sigma_i^0} \tag{1}$$

where σ^0 denotes the radar cross section to be estimated in each image of the multi-channel image stack for i=M channels, appropriate for output image J_k. I_i corresponds to the intensity images. With increasing number of images up to 10 used for filtering, the ENL increased to ~50.

5. LAND COVER CLASSIFICATION

5.1. Multi-temporal metrics of C-band backscatter for classification of land cover

For the classification of the basic land cover classes 'Water', 'Forest', 'Settlement', 'Grassland' and 'Agriculture', four metrics were analysed characterising the temporal variation of SAR backscatter:

- minimum / maximum / mean backscatter for each pixel in all images
- mean annual variation (MVA) (see figure 2 (a))

The MVA is calculated as following [9]:

$$mva = 10 \cdot \log\left[\frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j>i} R_{ji}\right]$$
$$R_{ij} = \max\left(I_i / I_j , I_j / I_i \right) \tag{2}$$

where N represents the number of images and R the normalized ratio of intensities. When calculating the MVA for the speckle filtered VV, HH and HV polarised data, a clear difference between agricultural areas and the land cover classes forest, settlement and grassland could be found. The difference was most obvious for the HV data (figure 2).

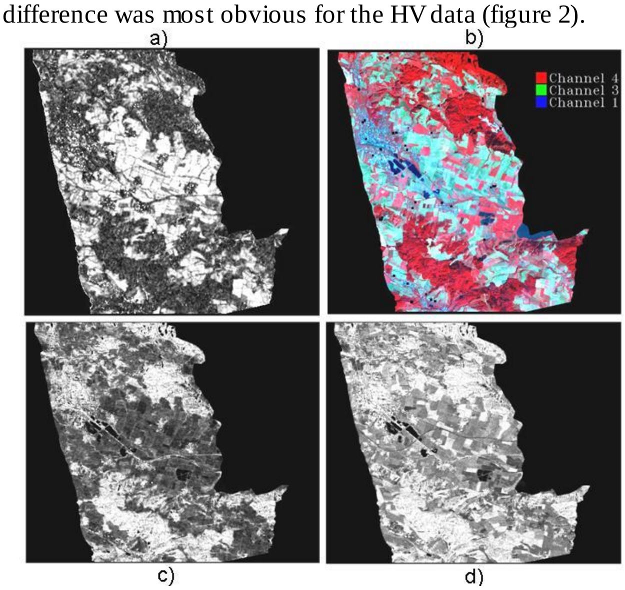

Fig. 2. Multi-temporal metrics of 14 ASAR AP HV polarisation intensity images with a) MVA, c) annual minimum σ^0, d) annual mean σ^0, b) Landsat ETM+ image 04.09.1999 R-4, G-3, B-1.

Figure 3 presents the histograms of four multi-temporal metrics for five land cover types. The MVA generally reflected the high temporal stability of backscatter over forest, settlements and grassland. The best contrast between these classes and the agricultural areas was found for HV polarization. Forest had a MVA below 1 dB in the co-polarised images and below 2 dB in the cross-polarised images. Settlements showed very stable backscatter as well but for some dense urban areas high MVA was observed as well, which might have been related to the different viewing directions of the ascending and descending orbits [10].

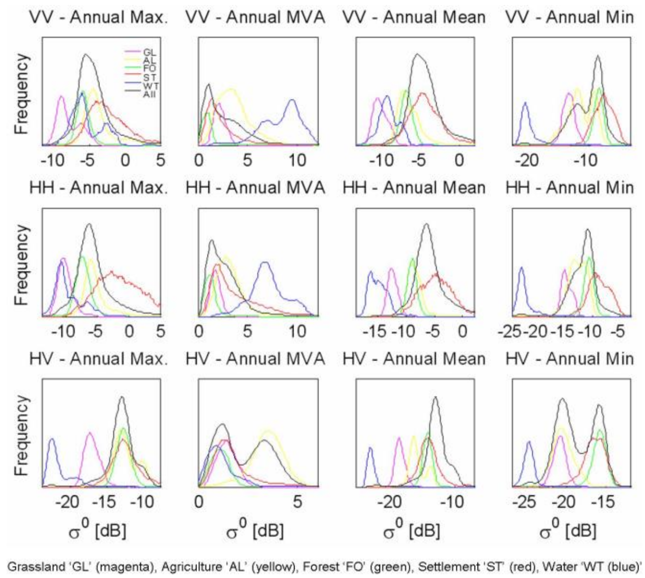

Fig. 3. Histograms of multi-temporal metrics for the land cover classes Grassland, Agriculture, Forest, Settlement and Water for VV, HH, and HV polarisations.

Water surfaces showed very variable backscatter in the co-polarised images which was clearly related to the wind-induced roughness of the water surfaces. However, the very low HV backscatter over water surfaces allows a simple discrimination of this class from the other classes. A differentiation of forest and grassland was not possible using the MVA but for the annual mean, maximum and minimum backscatter in all three polarisations this is possible. The differentiation of forest and settlement, however, seems not sufficient for classification only based on the multi-temporal metrics. This is why textural measures had to be used as well.

5.2. SAR data classification

For classification, Decision Tree (DT) and Maximum Likelihood Classification (MLC) were tested and both methods achieved good results. Anyhow, only the results of the MLC will be shortly presented here. The classifier was trained with the in-situ data for the full annual coverage of ERS-2 and ENVISAT ASAR data. In order to consider the dual polarization capabilities of SENTINEL-1, classification was also carried out for HH & HV (given for 14 acquisition dates) as well as VV & HV (given for 8 acquisition dates in form of combined ERS-2 and ASAR AP HV images). The multi-temporal metrics of both polarizations were used as input for the classifier. The question came up, if all multi-temporal metrics are required for classification, as some of the parameters introduce a variability that reduces the stability of the classification with respect to the variation of the input data. Especially the minimum and maximum backscatter metrics were considered as they could be very sensitive to one-time events like rain or snow melt. Annual mean backscatter and MVA are always calculated from all images in the input dataset, which makes them less sensitive to such events. It could be ascertained, without the inclusion of the annual maximum and minimum backscatter the accuracy was always greater than 85% (including ~70%). Therefore, both metrics were not considered for classification.

An analysis of the variation of the number of input images and the impact on classification resulted in a minimum of four seasonal acquisitions. The class statistics for the MLC respectively the trees for DTC were trained for the metrics of all images in each polarization which were multi-channel filtered using all available images (12 x VV pol. from ERS-2 and ASAR IM, 14 x HH resp. HV from ASAR AP). Classification was repeatedly carried out using these fixed classifiers but with varying number and combination of images. The analysis proved to use at least four acquisitions; the overall accuracy was always above 85% and also the minimum class user accuracy was greater than 70%.

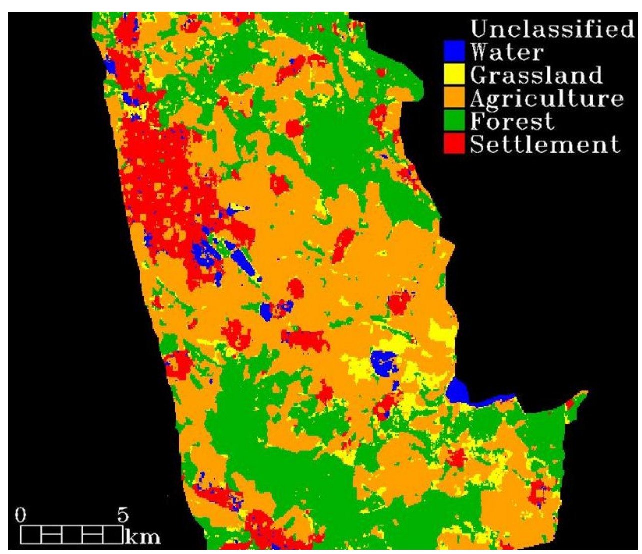

Fig. 4. Result of MLC and accuracy using four VV and HV polarized intensity image pairs.

For both classifications, the class ‘Grassland’ was found to be the most critical. The user accuracy was lower than 80%. The main confusion occurred with the class ‘Agriculture’, i.e. agricultural areas were misclassified to grassland and settlement. Obviously, there were cropland areas, whose annual backscatter characteristics were close to those of grassland, e.g. low variability. When looking into the crop type reference map, mainly orchard and trefoil were classified as grassland, as both types exhibit low annual variability in backscatter. Figure 4 presents the classification result of the MLC by using the minimum required images of four annual acquisitions.
Table 2 illustrates the accuracy and confusion matrix of Maximum Likelihood Classification using four VV and HV polarized intensity images.

Tab. 2. Classification accuracy and confusion matrix of MLC using the annual mean backscatter, MVA and texture derived from four VV and HV polarized intensity images

MLC VV & HV (4 acq. Dates)	Water	Grassland	Agriculture	Forest	Settlement	User Accuracy
Water	**96.82**	4.08	0.37	0.01	1.09	88.66
Grassland	1.50	**90.98**	1.46	0.28	0	78.12
Agriculture	1.06	4.87	**95.03**	1.75	16.91	95.85
Forest	0	0.072	2.39	**97.76**	0.085	98.34
Settlement	0.62	0	0.74	0.19	**81.91**	83.53
Prod. Accuracy	96.82	90.98	95.03	97.76	81.91	**96.13**

6. SUMMARY AND CONCLUSION

In this first investigation of the project, the potential and robustness of SENTINEL-1 was tested considering the prospective level-2 land cover products derivation. An algorithm was developed using multi-temporal metrics like annual mean, MVA and texture to produce good results for land cover classification with five classes. A reliable distinction (accuracy > 85%) into water, grassland, agriculture, forest and settlement is possible when having two polarizations (HH/HV or VV/VH) from at least 4 acquisition dates during one growing season. The expected advantage compared to ENVISAT ASAR is obvious by looking into the data archives of ENVISAT ASAR AP data. It is very difficult to find consistent multi-temporal datasets over Europe to classify large regions. With its 250 km wide swath and a resolution like that of ASAR AP (in Interferometric Wide-Swath Mode), SENTINEL-1 will provide consistent multi-temporal coverage for large areas.

7. OUTLOOK

Since March 2009 the research project is in the second phase and will last until February 2010. Subject of the current study is the transferability of the developed algorithm to different and larger areas in Europe. Two test sites are considered. One covers parts of the Netherlands, Belgium and southwest Germany and the other one is placed around Demmin in north-eastern Germany. Furthermore, the impact of varying incidence angles will be analysed using different ENVISAT ASAR swaths as this might play an important role using the 250 km interferometric Wide-Swath Mode.

8. ACKNOWLEDGEMENTS

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