Environmental Mapping using ENVISAT ASAR Data

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ABSTRACT:

Increasing demands for lasting and environmentally conscious use of our natural resources together with a cost effective and restrictive use of fertilizers and pesticides require the employment of new technologies in agriculture. In this research and development project, ENVISAT polarimetric SAR data (provided free of charge by ESA within a pilot project “AO335”) are examined for their usefulness to environmental monitoring within a drinking water protection area. An attempt to characterize the current agricultural land use in this area named "Fuhrberger Feld", north east of the city of Hannover, is being made using the SAR images together with GIS information like topographic maps, orthophotos, some ASTER satellite images and also ground surveys, which have been carried out very close to the time where the images have been taken. Based on the structural composition of that area resulting among others from phenological development, soils and other site related factors, it is planned to develop a prognosis method to use the present area balance and its development to characterize future trends. This research work is being carried out together with the Institute for Landscape Planning and Nature Conservation, University of Hannover, working in the field of GIS based impact modelling of different agricultural treatments with respect to drinking water quality. Using this information, farmers could improve their efforts in establishing good agricultural practice, as being claimed by recent legal and environmental jurisdiction.
Presently, data is collected and first investigations will be presented in this paper. This includes an analysis of the present ASAR imagery and ground truth data sampled at different locations representing the typical land use of the area of concern. Also first results in examination of phenological features inherent to the polarized SAR data in comparison to crop calendar and ground truth sampling are presented and first attempts using “multispectral” and multitemporal approaches for image segmentation and classification will be shown.

1. INTRODUCTION

The water quality reports of the past years of the lower saxony state office for water and refuse state in numerous surface near fair groundwater places nitrate values above the drinking water-threshold of about more than 50 mg nitrates per liter. These values reflect a strong hazard to the sustainability of the drinking water extraction. Herewith the raw water quality depends next to the chemically-microbiological conversion in the water body itself (STREBEL et al. 1985) especially on the distribution of land use in that area and the related land use specific quality and groundwater regeneration rate (quantity). While the habitat specific causes (climate, ground and other.) must be accepted as given, utilization contingent effects on the quality and the quantity of the groundwater are controllable. With respect to the edaphic conditions, the danger of eluviation of nitrate raises with the existence of clay to loamy and sandy soils. Drinking water catchments with sand soils like that of the »Fuhrberger Feld«, in the north Hannover, are influenced accordingly especially through nitrate emissions. Under same climatic and edaphic conditions a decline within the threat potential exists (WALTHER & SCHEFFER ,1988) following the present land use (see figure 1).
Forest stands do have a relatively small threat potential. In addition the extent and spatial distribution of forest stands does not change very much, while in agricultural habitats of drinking water catchments a great variability of usages exist, which also changes very much over time. This makes it difficult or even impossible to map with established procedures.

Estimating the threat potential of catchments by area wide land use mapping requires an enormous effort using traditional survey methods, but they are indispensable in order to assess the complex interrelationships in time and space of the effective emissions into the soil and hence into the drinking water.

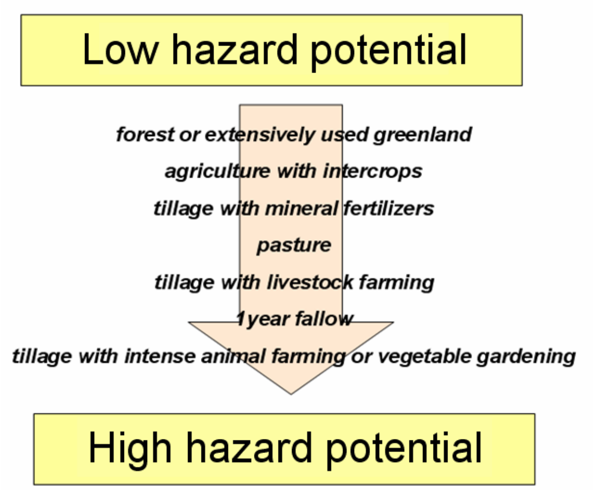

Figure 1: Influence of land use to the threat potential of drinking water catchments

A possible solution to this bottleneck could be the use of remote sensing techniques, but due to frequent cloud cover only microwave techniques of SAR systems on satellites like ENVISAT can be used for an effective regular monitoring.

Airborne remote sensing techniques offer a good alternative but cannot be used because of the associated high data acquisition costs (REDSLOB, 2000) in comparison to satellite data. This project therefore makes use of ENVISAT dual polarized ASAR data, which is provided free of charge by ESA within a pilot project.
Imaging radar systems show apart from effects being due to the imaging procedure (wavelength dependency, polarization and depression angle), a high correlation to effects caused by the topography, the water content of the imaged object and the roughness of the surface. Topographic effects can be neglected within the area under investigation, therefore only the water content and structure of the vegetation and the treatment of the investigated agricultural soils are the major influencing forces, having impacts on the images. Because of their specific habit, different plants show differing treatment structures and different surface characteristics depending on the growing stage and the amount of used fertilizers. Potentially these phenological features may be derived out of imaged time series of the structural variability of the different species. These (phenological) structure types to be investigated (i.e. growing stage, vegetation density, degree of ripeness, etc) showing different degrees of water content and structural behaviour then might be used within a strategy for a hierarchical multitemporal image classification and correlated to the quality of the drinking water of that area. This modelling will be carried out by the Institute for Landscape Planning and Nature Conservation of Hannover University. Investigations of REDSLOB, 1999 have shown, that the classification result of SAR images may be improved, if additional parameters influencing the backscatter signal are acquired. This holds for soil moisture (as a function of precipitation), treatment patterns (surface roughness, orientation), wind fields and density of leaves.
Therefore it is the aim of this project not to find simply a good solution for the segmentation of SAR images, but rather to find and extract those features, which might be used to classify the agricultural land use by analyzing the SAR information alone or, if not possible, to identify necessary additional information, like for example optical images, in order to ensure a correct feature extraction (see also NRSC, 1997 and KATTENBORN et al., 1996).

2. TEST AREA, GROUND TRUTH MEASUREMENTS AND SATELLITE DATA

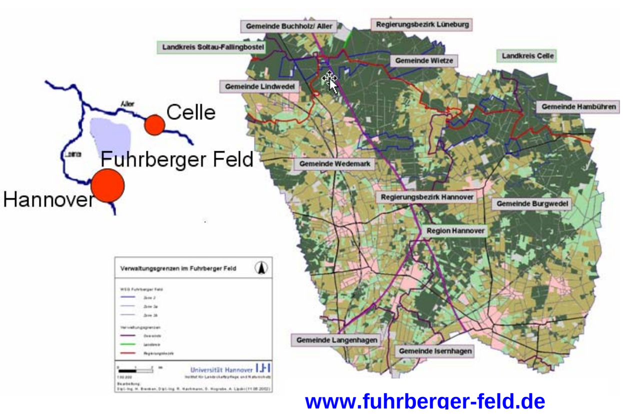

Figure 2: Testsite >>Fuhrberger Feld<<

The Fuhrberger Feld (figure 2) is situated north the capital from Lower Saxony of Hannover. The water protection area of the same name in which about 90% of the drinking water is produced for the region of Hannover extends over a size of approx. 300 sq. kms. About three quarters of the water protection area belong to the municipalities Wedemark and Burgwedel. In the Fuhrberger field about 100 000 people live.
The official land use statics is shown in the following table.

Authority	No. of Farms	Area	Agri-culture	Perm. Crops	Perm. Green-land
		ha	ha	ha	ha
Burgwedel	112	5 775	4 227	2	1 544
Isernhagen	80	3 457	2 369	89	998
Langenhagen, City	71	2 953	1 884	4	1 062
Wedemark	191	9 011	6 965	25	2 016

Table1: Statistics of test site Fuhrberger Feld

Within this area a total of 50 fields around the village Brelingen and the city of Fuhrberg have been selected as ground truth samples. The location of these fields is marked in figure 3.

Figure 3: 50 sample field plots for ground truth data collection

For these field plots, topographic maps, basemaps and digital orthophotos in color are available. In general the in-situ ground truth was collected at the time of satellite overpass. Although a monthly coverage of satellite acquisitions was planned to get a whole growing season of the different vegetation types, many data takes could not be performed as planned due to priority programming of the satellite for other projects.
Table 2 lists the data takes, which have been acquired so far.

Image Date	Inspecting Date	Orientation
17.11.2003	26.11.2003	Descending
17.03.2004	19.03.2004	Descending
05.04.2004	05.04.2004	Descending
21.04.2004	21.04.2004	Descending
10.05.2004	10.05.2004	Descending
26.05.2004	10.05.2004	Descending
30.06.2004	14.06.2004	Descending
11.09.2004	08.09.2004	Descending
13.10.2004	13.10.2004	Descending
06.12.2004	06.12.2004	Descending

Table 2: Data takes of ENVISAT ASAR APG images, polarisation VV/VH, IS 5-7

The images have been processed by the different PAF's into geocoded products using a pixel spacing of 12.5 m in range and azimuth direction. This corresponds to a resolution of 30 m using 2 looks in azimuth and 3 looks in range. Only looking angles between 35.8 – 45.2 deg. (corresponding to Image Swath IS5 to IS7) and VV / VH polarisation have been used. An example of a multitemporal composite (VV and VH) is shown in figure 5 (30. June 2004, 10. May 2004, 05. April 2004 as R/G/B)

Ground truth consisted if sampling general information like usage, direction of treatment, distance of treatment or plant rows in the field, if existing. Additionally information on the kind of mechanical treatment of the soil and the plants, vegetation coverage and color, observable fertilizers, irrigation etc. have been sampled and introduced into a GIS, based on the ArcView® software.

In addition, digital ground photographs have been taken, like those shown for the case of rape in figure 4.

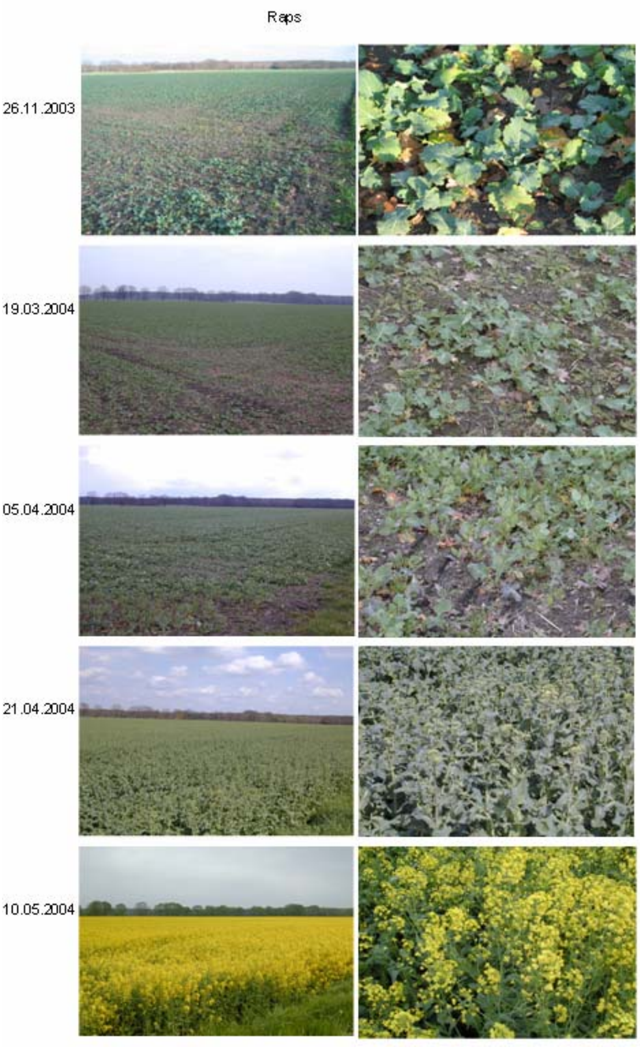

Figure 4: Ground photographs taken from a rape field at different acquisition dates

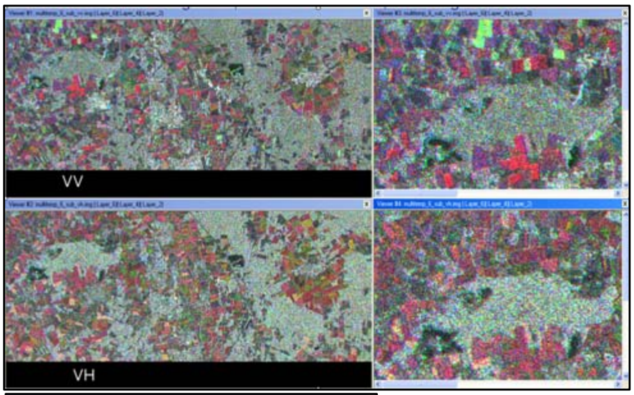

Figure 5: (©ESA, 2004) Multitemporal ASAR composite 30.06. /10.05./05.04.2004 as RGB, 12.5 m Pixel Desc. Orbit ; # of Az. looks: 2; # of Range looks: 3

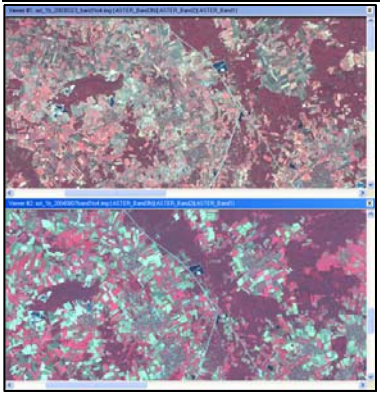

Figure 6: CIR combination of ASTER 3/2/1 (23.03.03 top, 17.08.2004 bottom)

In addition to the SAR images 2 acquisitions of ASTER data have been acquired, which are shown in the following figure. The images have been taken in March 2003 and October 2004 respectively and a vast amount of change can be observed by comparing both optical color infrared images of the investigated test site. These images, however, are not used at the present moment.

An analysis has been performed to check the temporal correlation of the different acquisition dates. As can be seen by the following graphics, the correlation between both polarisation directions per data take is obvious, but temporal correlation between different acquisitions is not observable.

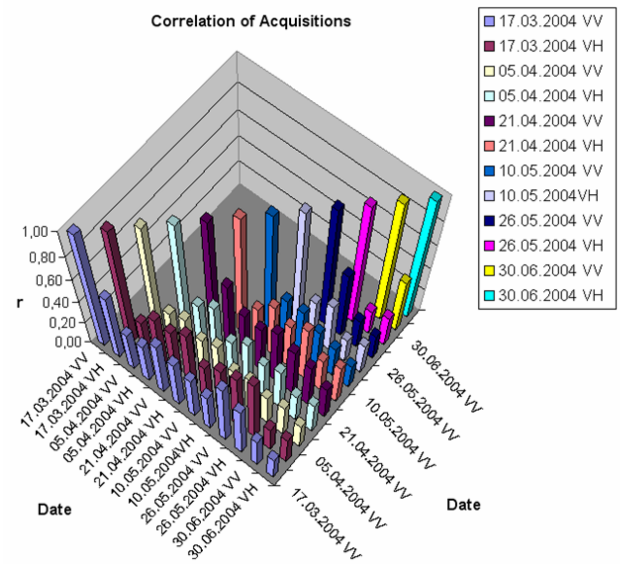

Figure 7: Correlation of SAR data at the different acquisition dates

The correlation has been computed globally for the whole test site.

For single fields the phenological signatures can be computed as shown in the next chapter.

3. PHENOLOGICAL ASPECTS AND THEIR IMAGE REPRESENTATION

Using the existing shapes of the fields under investigation a computation of the backscatter signatures of the different species as observed in the SAR data has been computed. The results are shown in the next 2 graphics. First it can be shown, that the variance of signal within a type of vegetation (each bar represents the mean value of one species being averaged for all the fields in the test site, together with the standard variation of the mean) is relatively high. This is due to the speckle (despite multi-look processing), that has not been removed sufficient by preprocessing the data. In our opinion, using these 6 acquisition dates alone does not allow to extract unique signatures which can be used as features for multitemporal classification of the agricultural land use alone. In addition it can be seen, that even within one class of crop or cultivation, the land use may change (see arrows) due to decisions of the farmer, who in many cases uses temporarily grown crops as organic fertilizer. This makes automatic procedures for monitoring land use even more difficult.

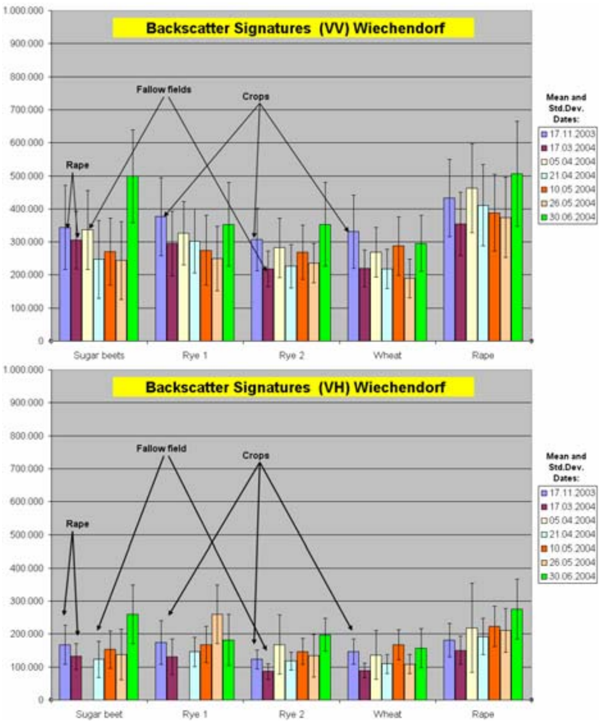

Figure 8: Temporal backscatter signatures for different cultivations in a subset of the test site as computed from the SAR signal.

4. DATA PREPROCESSING AND FIRST CLASSIFICATION RESULTS

Before the multitemporal SAR data is being used in image classification, the speckle has to be removed, because it diversifies the signature of a single field significantly.

Quite a number of methods to despeckle radar images exists so far. These methods can be grouped into three classes:

-Conventional Filters (LEE, 1981, FROST et al., 1982)

-Multilook Methods (http://envisat.esa.int/dataproducts/asar/)

-Multitemporal (wavelet based) Methods (DE GRANDI et al., 1997 and 1999)

(http://www.landmap.ac.uk/software/sarscape/sarscape.htmlT)

Conventional filters use a single image for speckle removal. They compute statistics in a spatial window to reduce the variance of the pixel values trying to keep most of the visible details in the image.

If simultaneous recorded radar images of a region are available from different looks, a multilook averaging method is the best choice for speckle removal.

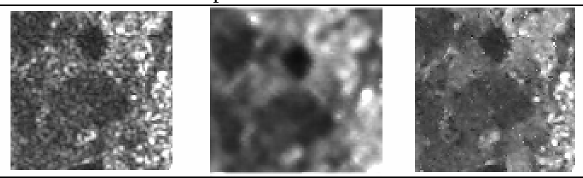

Figure 9: Effect of speckle filtering (left original, middle Lee 7x7, right multitemporal filter).

The multitemporal method, as implemented within the SARscape® software of ENVI® uses different images of the same region recorded at different times and look directions. The method tries to find and filter any pixel which is incoherent to same pixels in the other images. This method results in an output band for each input image. The filter computes some type of wavelet decomposition of the input images. A statistical test on the coefficient of variation is performed then on a selected wavelet level for a window around a certain pixel on the several input images (all the independent tests performed on the several images shall be satisfied). If the test is successful, the selected wavelet level is selected for obtaining the output pixel of each input image. If not, a finer wavelet level is selected and the test is repeated, until the maximum resolution has been reached (i.e. no filtering is performed). After selecting a certain level, a refined-Lee approach is used to identify if a sub window along preferential directions shall be selected. The "window size" concept is substituted by the wavelet decomposition level resolution one (DE GRANDI et al., 1997 and 1999). The window size of the filter is variable depending on the signal stationary, and the maximum window size used by the filter can be up to 17x17 pixels (down to 1x1 for point targets).

Concerning the existing data, conventional filters and the multitemporal method have been tested (figure 9).

Because of the spatial resolution of the images and the size of the test fields a square kernel size of 7 pixels (7*12.5m=87.5m) is used. The examined different conventional filters (lee, lee-sigma, local region, frost, gamma-map) showed very similar results, with the exception that the lee filter kept the boundaries and small features slightly better than the others.

A demo version of Sarscape (improved by ESA for ENVI® and ArcView®) applying the multitemporal method was tested in addition. The effect of filtering applied to the VV-Band of the image recorded on 26.05.2004 is presented in figure 10. This diagram shows the mean, minimum and maximum value of raw and filtered data and reflects how much the filters decrease this variation. In addition by looking to the mean values it can be seen how similar many of the fields appear in time series of radar images which makes the classification even more difficult.

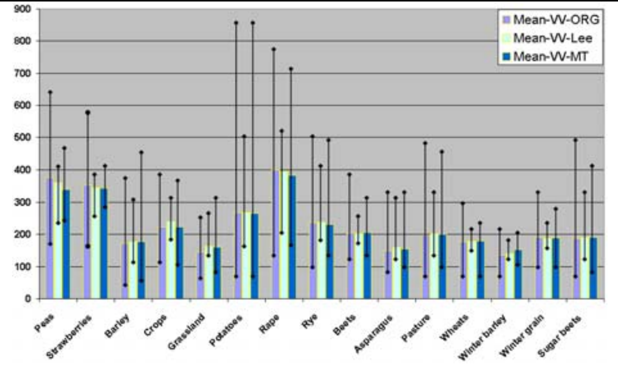

Figure 10: Effects of Lee (7x7) and multitemporal filter on statistics of the image of 26.05.2004 (Mean, Min, Max value)

Classical statistical classification has been tested with the images using both bands (VV and VH). The results show that on an average only 20-30% of the sample fields of an unfiltered image are correctly classified.

This value increases to 25-35% for an image despeckled using the multitemporal method and to 35-45% for an image filtered by the Lee-Filter (7x7).

The classification results of 2 acquisition dates are presented in figure 11, showing the importance of speckle removal.

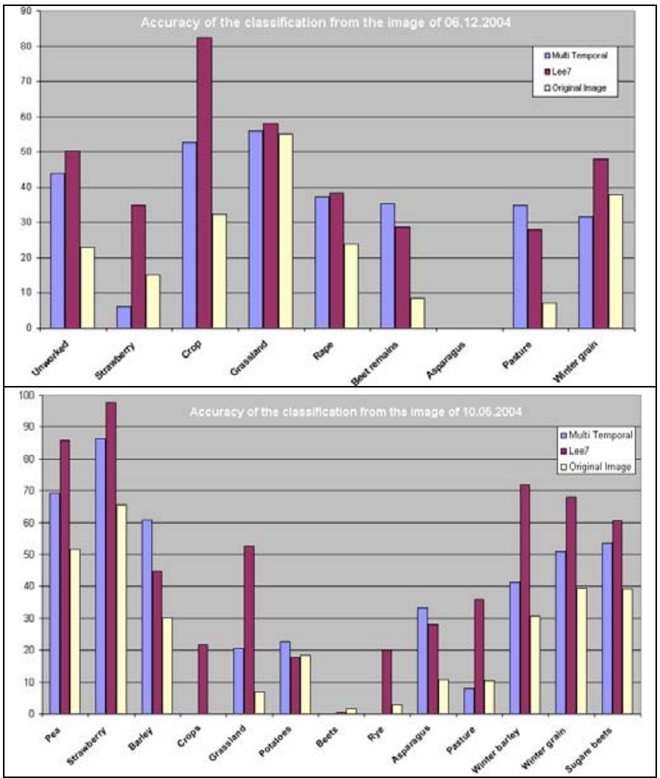

Figure 11: Accuracy of classification using filtered and unfiltered images from 10.05 and 06.12.2004

The classification accuracy in general showed a high dependency on the acquisition date. Some few classes can be classified very well at specific dates, like rape in April, peas and strawberries in May, weeds in September and pasture and sugar beets in October, and winter crops, which can be classified best in December.

This indicates that the success of a classification for each class highly depends on the season when the image has been taken. This is due to the known fact of plant phenology (SCHNEIDER, 1994), which is highly seasonal dependent.

Therefore grouped images from a specified period have been taken to classify specific types of land use separately. This has been done for all images and land use classes using both polarization bands as input.

The method has been tested for pasture and weeds using all of the images, for potatoes using only images between April and September, and for winter crops using only images between December and May. Figure 12 shows the images used to classify the specific types.

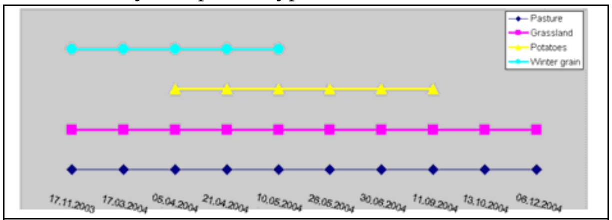

Figure 12: Images used to classify phenological groups of vegetation

The very preliminary results of the multitemporal classification as applied to some of our test fields are presented in table 3.

	Without filter		Lee (7x7)		Multitemporal	
	Right*	Error**	Right*	Error**	Right*	Error**
Pasture	90%	1%	100	0	11%	0
Potatoes	66%	2%	100	0	78%	4%
Weeds	89%	0.8%	100	0	97%	0.3%
Winter grains	59%	12%	97%	0.2%	48%	0.5%

Table3: Success of the multitemporal classification for some land use types

*area of fields covered by the desired class that are correctly classified

**percentage of areas not covered by desired class but assigned to that class

5. SUMMARY AND OUTLOOK

This paper gives an overview of the beginning work, which has been carried out in an ESA ENVISAT Pilot project AO335. The ENVISAT ASAR data has been provided in this project free of charge by ESA.

At the present time data is continuously acquired in different phenological epochs over an area, which is being used for drinking water regeneration. In order to estimate the amount of fertilizers and pesticides penetrating the soils a classification of the agricultural usage and treatment within that area is desirable. Because of heavy cloud coverage and costs this cannot be done by optical remote sensing techniques. Therefore ENVISAT ASAR data is considered to be of great importance for that task. Parallel to the acquisitions of SAR images, field data has been sampled and will be used in future together with the image data to enable a rule based multitemporal classification which will give an input to a GIS based analysis of factors modelling the quality and rate of drinking water regeneration of that area.

As these investigations only reflect the very first preliminary results, they already show the feasibility of the data and procedure once speckle has been removed. Future work will use segmentation approaches based on these data, together with other features like look direction dependant textures and signatures.

REFERENCES

De Grandi, G.F., Leysen, M., Lee, J.S., and Schuler, D., 1997: Radar reflective estimation using multiple SAR scenes of the same target: techniques and applications, Proc.of IGARRS conference, Singapore, 1997, pp 1047-1050.

De Grandi, F., Lee, J.S., Schuler, D., Kattenborn, G., Holecz, F., Pasquali, P., Simard, M.,1999: Singularity analysis with wavelets in polarimetric SAR imagery for vegetation mapping applications, Proc. IGARSS'99, paper EE05_06, Hamburg, Germany, 1999.

Frost, V.S., Stiles,J.A., Shanmugan, K.S.and Holtzman, J.C., 1982: A model for radar images and its application to adaptive digital filtering of multiplicative noise, IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 4, no. 2, pp. 157-166, March 1982.

Kattenborn, G., Klaedtke, H.-G., Güth, S., Reich, M., 1996: Potential of ERS-1 SAR for Agricultural Statistics Contract No. 10161-94-04 F1ED ISP D, Inst. of Navigation, University of Stuttgart

Lee, J.S., 1981: Speckle analysis and smoothing of Synthetic Aperture Radar Images, Comp. Graph. Image Process. Vol. 17, pp. 24-32, 1981

NRSC, 1997: A Pilot Project on the Use of Active Microwave Satellite Remote Sensing for Rapid Area Estimation of Agricultural Crops during Winter and Spring, Final Report for the European Directorate General VI Agriculture, National Remote Sensing Centre Limited Report No. DG-RT-NRL-AG-002, Oct. 1997

Redslob, M., 1999: Radarfernerkundung in niedersächsischen Hochmooren. Dissertation am Institut für Landschaftspflege und Naturschutz, Universität Hannover.

Redslob, M., 2000: Effektive Informationserhebung durch GIS-gestützte Radarfernerkundung - dargestellt am Beispiel des Niedersächsischen Moorschutzprogramms.

Strebel, O., Böttcher, J., Kölle, W., 1985: Stoffbilanzen im Grundwasser eines Einzugsgebietes als Hilfsmittel bei Klärung und Prognose von Grundwasserqualitätsproblemen (Beispiel Fuhrberger Feld).Zeitschrift der Deutschen Geologischen Gesellschaft, Band 136. p. 533-541,

Walter, W., Scheffer, B., 1998: Ergebnisse langjähriger Lysimeter-, Drän- und Saugkerzen-Versuche zur Stickstoffauswaschung bei landbaulich genutzten Böden und Bedeutung für die Belastung des Grundwassers, Schriftenreihe des Inst. f. Verkehr und Stadtbauwesen, TU Braunschweig

Schneider, D.T.,1994: Möglichkeiten und Grenzen der spektralen Trennung ackerbaulicher Oberflächentypen – eine Abschätzung anhand spektroskopischer Untersuchungen über die Vegetationsperiode, Mangstl., München, 4.Auflage