Multifrequency and Polarimetric Radar Remote Sensing of Grassland -
Geobiophysical and Landcover Parameter Retrieval with E-SAR Data

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ABSTRACT: Spatial information about vegetation and soil parameters in grassland covered areas are essential for a variety of geoscience applications. This paper focuses on the derivation of land surface parameters from multifrequency and polarimetric DLR E-SAR data for hydrological modelling. Results from two test sites and different analysis methods are presented. At Broel, Germany, a Principal Component Analysis (PCA) was applied using polarimetric L-band data. Good correlations (r=0.98) were found between the second principal component (PC2) to plant water content (kg/sqm) and a map was generated. At the test site Elbe, Germany, the Oh and Dubois soil moisture models were applied to derive soil moisture. The results, however, illustrate the influence of the grassland canopy. Again, PC1 revealed good correlations to soil moisture (r=0.79) and the generated map illustrated regional variations corresponding to interpolated TDR-measurements. As a consequence of the results from these two test sites, PCA is considered to provide a successful contribution to thematic analysis of multi-parameter SAR data.

1 INTRODUCTION

More than 17 % of the Earth’s surface is covered by grassland-vegetation. Their geo- and biophysical conditions, influenced by natural as well as cultural processes, have a fundamental importance in atmosphere-Earth surface interactions and soil erosion processes. Spatial information about vegetation and soil parameters in grassland covered areas are essential for a variety of applications, e.g. for agricultural planning and hydrological modeling.

Due to their sensitivity to dielectric and structural land surface features, microwave remote sensing techniques have shown their potential to derive spatial information from grassland areas. Especially radar backscatter from multifrequency and polarimetric SAR-systems allow a detailed description of different vegetation and soil properties (Dobson et al. 1995, Schmullius & Furrer 1992). During the last years, various investigations were presented to model the radar backscatter mechanisms from grass in different wavelengths (Chauhan et al. 1992, Saatchi et al. 1994, Stiles & Sarabandi 2000, Stiles et al. 2000). Other related studies elaborated the derivation of land use information (Schieche et al. 1999), vegetation parameters (Hill et al. 1999) and soil moisture (Lin et al. 1994, Du et al. 1999) from grass-covered areas. However, in respect to the forthcoming multi-polarization and multi-frequency spaceborne SAR systems, there is a need for further investigations and evaluations of methods to derive relevant information of grassland landscapes from radar remote sensing.

This paper summarizes the experiences and results from interpretation and analysis of multifrequency and polarimetric airborne E-SAR-data acquired during different campaigns at two test sites in Germany. These investigations were primarily focused on the derivation of land surface parameters to support hydrological applications.

2 SAR-DATA AND TEST SITES

The radar data were acquired by the airborne Experimental SAR-system (E-SAR) of the German Aerospace Center (DLR). E-SAR operates in a multi-parameter SAR-mode. The spatial resolution varies between 2-8 m in ground range. The general system configuration is shown in Table 1

<table>
<thead>
<tr>
<th>Frequency</th>
<th>X-BAND</th>
<th>C-BAND</th>
<th>L-BAND</th>
<th>P-BAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6 GHz</td>
<td>5.3 GHz</td>
<td>1.3 GHz</td>
<td>450 MHz</td>
<td></td>
</tr>
<tr>
<td>Wavelength</td>
<td>3 cm</td>
<td>5.6 cm</td>
<td>23 cm</td>
<td>67 cm</td>
</tr>
<tr>
<td>Polarization</td>
<td>HH,VV</td>
<td>HH,VV</td>
<td>HH,VV, HV,VH</td>
<td>HH,VV, HV,VH</td>
</tr>
<tr>
<td>Interferometry</td>
<td>Single pass</td>
<td>repeat pass</td>
<td>repeat pass</td>
<td>repeat pass</td>
</tr>
</tbody>
</table>

Table 1: Technical Specification of the E-SAR System

The E-SAR system was used in different hydrologically oriented studies in two experiment sites in Germany. The first test site is situated along the former bor-
der to Eastern Germany between Lenzen (Elbe-km 465) and Cunlensen (Elbe-km 485). The SAR-data were recorded during two campaigns in April and August 1997 and included X- and C-Band dual polarization, L-Band polarimetric and X-Band interferometric backscatter acquisitions. The analysis of the SAR-data was an integral part of a compound project focusing on the ecological and morphological dynamics of the river Elbe.

A second testsite was located in the catchment of the river Broel, 30 km northeast of Bonn, Germany. In this area intensive field investigations for hydrological and hydrochemical process-modeling were carried out during the last years (Bende 1997, Fluegel 1995, Fluegel & Smith 1999). In June 1996, the E-SAR sensor acquired X-, C- and L-Band polarimetric data. The SAR-information was used to support microscale hydrologic studies for hillslope hydrology.

The E-SAR data acquisition was accompanied by intensive ground truth mapping and field measurements of different radar-relevant parameters such as land use, vegetation characteristics (type, plant water content etc.), soil moisture and surface roughness.

The Broel catchment, more than 50% of the land surface is covered by grasslands. Approximately 30% are used as pasture with 1 or 2 annual cuts followed by grazing in the second half of the year. 15% are hay meadows with 3 to 4 cuts per year, 5% are purely for grazing. Some few areas are fallow grassland. Figure 1 presents the surface conditions of different utilization stages during the E-SAR campaigns in June 1996.

Figure 1: Pictures of different grassland types taken during the field campaign Broel.

![a) fresh mowed meadow (2.cut)](image)
![b) meadow (1.cut)](image)
![c) pasture)](image)
![d) fallow grassland)](image)

3 BACKSCATTER INTERPRETATION

In the Broel catchment, more than 50% of the land surface is covered by grasslands. Approximately 30% are used as pasture with 1 or 2 annual cuts followed by grazing in the second half of the year. 15% are hay meadows with 3 to 4 cuts per year, 5% are purely for grazing. Some few areas are fallow grassland. Figure 1 presents the surface conditions of different utilization stages during the E-SAR campaigns in June 1996.

Figure 2 illustrates the radar intensity signatures for these four grassland conditions. They were derived from averaged data from 3-4 test-sites each. In LHH-band, the radar backscatter strongly depends on the surface conditions. The lowest values are found for freshly mowed meadows, the highest for fallow grasslands. Radar backscatter thus increases with rising plant water content resp. biomass and vegetation height. The highest scatter in the values is indicated for the pasture as a result of selective grazing. In the LHV-channel similar backscatter dependencies are found. Indeed the values cover a wider range of sigma-naught than in the LHH-band, what indicates a higher sensitivity to varieties in dielectric grassland vegetation features.

In contrast the LVV-backscatter is less influenced by the grassland vegetation. All diverse test-areas show similar sigma-naught values indicating a widely vegetation penetration of LVV-radiation. This presumption is confirmed by the high soil moisture information content in this SAR-channel (see also section 6). Accordingly, the differences in the mean backscatter values can be associated with changes in soil moisture of the investigated fields.

![Figure 2: Mean and first standard deviation backscatter values for four grassland types](image)
The XHH backscatter information shows a discrimination between mowed and non-mowed grasslands. The cutted areas have lower sigma-naught values resulting from the homogeneous plant surface structure. In the CHH-band a slight rise of backscatter with increasing plant water content can be found.

In general, the polarimetric L-Band backscatter provides more information for the derivation of hydrologically relevant parameters than the X- and C-band backscatter. This fact has to be viewed in connection with the large incidence angles the E-SAR Sensor is recording. In the case of the investigation shown in Figure 2 the mean incidence angle is around 50 degrees what leads to higher vegetation influence on the L-Band backscatter. Because of the thin cylindrical plant structure the L-band radiation is more sensitive to changes of dielectric than structural features of grasslands. Therefore, the mainly canopy-induced backscatter differences can be attributed to the changes in plant water content.

Figure 3: Land use map derived from the E-SAR data

4 LANDUSE CLASSIFICATION

For application of pixel-wise classifiers for land use mapping from SAR-data different preprocessing steps were necessary. A Gamma-map (7x7) filter was applied for speckle reduction. For E-SAR-data acquired in the Elbe-area, a Principal Component Analysis (PCA) was performed to exclude redundant information and for further speckle reduction. The first three PC channels were selected for classification. Different approaches were tested to classify the data (unsupervised, texture-based, etc.) whereas the Maximum-Likelihood-Classifier showed the best results. Before the classification, a filter (median 7x7) was applied for further image smoothing.

Based on the spectral information shown in Figure 2 a spatial land use map was derived. Indeed the different grassland utilizations (hay meadows, pasture, mown grass, fallow), characterized by seasonal cultivation dynamics, could not be separated with monontemporal data. The class definition refers to the utilization stages during the data acquisition.

Figure 3 presents the land use distribution in a part of the test-site Broel. It clarifies the sharp delimited field boundaries. Inhomogeneities are mainly found around settlements, where a smaller garden plots are predominant.

The overall classification accuracy for the grassland classes was determined with 90,3 % in consideration of the area percentage. The most precise classification results were found for the fresh cutted meadows (2.cut) with 94,0 %. Pastures could be classified with 84,3 % accuracy. Their lower classification precision results from the inhomogeneous vegetation distribution. The meadow-class (1. cut) show a intermediate accuracy of 89,7 %.

The derivation of vegetation parameters were performed by correlation of radar backscatter and field measurements of plant water content (PWC), biomass and vegetation height. The L-band channels were processed by a principal component analysis (PCA) to extract synthetic information for the vegetation parameter estimation. The PCA is a standard image processing algorithm. Only few applications for SAR-data analysis were carried out, but the results indicate their efficiency for thematic analysis (Henebry 1997, Klenke & Hochschild 1999, Verhoest et al. 1998).

<table>
<thead>
<tr>
<th></th>
<th>Described Variance</th>
<th>Correlation with LHH</th>
<th>Correlation with LHV</th>
<th>Correlation with LVV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC 1</td>
<td>87,92</td>
<td>0,147</td>
<td>0,072</td>
<td>0,986</td>
</tr>
<tr>
<td>PC 2</td>
<td>12,00</td>
<td>0,545</td>
<td>0,834</td>
<td>-0,085</td>
</tr>
<tr>
<td>PC 3</td>
<td>0,07</td>
<td>-0,837</td>
<td>0,547</td>
<td>0,000</td>
</tr>
</tbody>
</table>

Table 2: Features of the principal components

The principal components were calculated from the backscatter information from LHH, LHV LVV for all grassland areas. Table 2 summarizes the principal component (PC) features. The PC 1 describes 88 % of the variance and mainly contains the information of the LVV-channel, found to be most sensitive to soil moisture (see section 6). For the derivation of vegetation parameters the second PC seems to be most helpful, because of the high correlation with LHH and LHV.
Figure 4: Correlation of the field measurements with radar backscatter and values of the PC 2

Figure 4 presents the comparison between the field measurements of plant water content and the radar backscatter of LHH, LHV and LVV as well as the values of the PC 2. Except for LVV-band all diagrams indicate good correlations. The best dependence from the plant water content is found for the PC 2. This result is caused by compression of the LHH- and LHV-bands in one synthetic channel with a reduction of small-spatial backscatter inhomogeneities from speckle, system noise and artifacts that only occur in one L-Band channel (e.g. horizontal-oriented metal fences in the LHH-band).

The statistical relationship in Figure 4 was used to derive the spatial PWC-distribution. A subset of the PWC-map is shown in figure 5. As indicated the spatial distribution points up the inhomogeneities within and between the single fields representing the different cultivation conditions. In light colors occur areas of fresh mowed grasslands and the pastures. Higher PWC-values are found for non-mowed meadows.

Figure 5: Map of the plant water content distribution derived from the E-SAR data

The plant water content is the primary backscatter relevant vegetation parameter. Indeed other important vegetation parameters like the biomass or the vegetation height have a high correlation with the PWC, e.g. a fresh mowed grassland has low plant water content, biomass and vegetation height. For that reason the PWC-related backscatter information from the SAR-data can be used to the spatial estimation of other vegetation properties.

Figure 6 shows good correlations between the field measurements and the values of the PC 2. The comparison of the vegetation parameters with the backscatter information from a single radar-band indicated only worse correlation. The logarithmic curve for the dry biomass results from increased proportion of dead plant material, e.g. from thatch layer, in comparison to the PWC found for the fallow grasslands.
5 SOIL MOISTURE ESTIMATION

As proposed in section 3 and in other studies (e.g. Chauhan et al. 1992) the longer wavelengths like L-Band partly penetrating through the grass-vegetation and contain information about soil properties. To model the backscatter-relevant parameters soil moisture and roughness, the semi-empirical approaches proposed by Oh et al. (1992) and Dubois et al. (1995) were applied in areas with grassland vegetation.

Both models require different polarizations for the calculation, the Oh-model HH and VV, the Dubois-model HH, VV, and one cross-polarization. To exclude areas with mainly volume-scatter only pixels of HH-VV<1 and HV-VV<-11 were used for model application (Dubois et al. 1995).

The modeling of the backscatter showed an underestimation of the E-SAR measured sigma-naught-values caused by the higher vegetation induced radar signal amplitude. This effect was most noticeable for the modeled cross-polarized backscatter, that is most sensitive for depolarization effects by vegetation-volume-scattering. The inverted models were applied to estimate spatial soil moisture information.

Figure 7 shows the comparison of measured and inverted soil moisture values in two depths for the Oh- and the Dubois-model. A good trend can be found for the moisture in depths of 4-8 cm, better than for 0-4 cm depth. The high scatter of the values around 1:1-line with mainly overestimated inverted values indicating the effects of vegetation. The most uncertain values are found for the vegetation comprised fields. Further inaccuracies result from the empirical character from the models. In fact only an uncertain inversion of the backscatter values to soil moisture could be performed, because the Oh- and Dubois-model were developed for bare soil areas.

Another tested approach was based on the assumption that single L-band-polarizations show different backscatter influences from the grass-vegetation. As a result of the first PCA (Table 2), derived from grass-covered areas in L-Band-polarizations HH, VV, HV, indicates the best correlation between the radar backscatter and the tensiometer soil moisture measurements (Figure 8). This PCA mainly contains the LVV-
information, found to be less influenced by the grass-vegetation (Figure 2).

These results contradict to the suggestions of other studies that prefer the LHH-band for soil moisture retrieval under vegetation (e.g. Engman & Chauhan 1995). Indeed for short vegetation with intense vertical cylinders like corn the LVV-backscatter is stronger influenced by the vegetation than in the horizontal polarization. Grass-covered areas with thin vegetation cylinders represent a diffuse oriented dielectric layer for L-band. For large incidence angles like in this study (50°-60°), the vegetation transmissivity of the VV-polarization increases near the Brewster angle, HH-penetration decreases (Boisvert et al. 1995, Leckie & Ranson 1998). This assumption probably explains the effect found in this study, but should be further investigated.

A spatial soil moisture distribution was derived based on the empirical approach (Figure 8). The comparison with other spatial soil moisture maps, one derived from a DEM as multiple flow topographical index (Quinn et al. 1993) and one interpolated with geostatistical methods from 51 point-TDR-measurements are shown in Figure 9.

The topography-induced spatial soil moisture variations shown by the topographical index can also be comprehended in the SAR-data based soil moisture map, e.g. the moist valley floors as well as the drier hillslopes are found. The SAR-soil moisture distribution represents a linear very moist structure in the middle of the map. The higher moisture is caused by a dip in underlying geology that leads to an accumulation of interflow. The wetter conditions within this structures are confirmed by the TDR-measurements.

6 CONCLUSION

This presentation summarizes the experiences and results in interpretation and analysis of multifrequent and multipolarimetric airborne E-SAR-data acquired during different campaigns at grass-covered test-areas in Germany.

The results show that in particular the multipolarimetric L-Band-backscatter is sufficient for derivation of geo- and biophysical as well as utilization parameters of grasslands. Different examples indicate the high potential for land use classification and estimation of vegetation parameters. Best correlation of radar backscatter and ground reference data were found for the plant water content. Furthermore spatial biomass and vegetation height information could also be estimated.

Problems occurred for soil moisture modeling using different L-Band Polarizations caused by the vegetation effects on the backscatter. Only the LVV-band were found to be less influenced by vegetation, so soil moisture differences caused by topography- and geology can be retrieved in the SAR-data even in grass-covered areas.

The Principal Component Analysis can provide a successful contribution for thematic analysis of multifrequent and multipolarimetric SAR-data. The major advantages of their information content in comparison to single SAR-channels result from distinguishing of superior backscatter pattern with reduction of small-feature effects like speckle or system noise as well as single-channel influences. Furthermore it was shown that backscatter proportions of the vegetation and the soil could be separated in different principal components.

7 REFERENCES

Boisvert, J. B., Gwyn, Q. H., Brisco, B., Major, D. J. & Brown, R. J. 1995. Evaluation of soil moisture techniques and micro-


