# EFFECT OF INTERCEPTION ON THE BACKSCATTERING BEHAVIOUR FROM CROPS

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## ABSTRACT

Objective of this study is to systematically analyse and interpret the influence of interception on the backscattering behaviour from crops. The investigations were carried out using airborne E-SAR data at L-band recorded in June 2000. Two different decomposition theorems – the eigenvector- and model based decomposition – were applied to the SAR data. The polarimetric parameters derived by the eigenvector decomposition theorems showed no remarkable changes due to wetting of the plant surfaces. Only for the β-information significant variations were obtained. These changes are highly correlated to the variations of the radar backscatter at HV polarization, indicating an increase in volume scattering processes under wet conditions. This is in agreement with the results obtained by the model based decomposition theorem. Furthermore, the second approach signifies a decline in surface scattering and double bounce interactions when water on the plant surfaces is present. The greatest changes in backscattering due to moisture were found for high grassland, barley and rye.

## 1 INTRODUCTION

One important application field of radar remote sensing is the interpretation of SAR data from agricultural areas. The backscattering coefficient from land surfaces is primarily determined by structural and dielectric attributes of the target. Intercepted precipitation rises the water content within the vegetation layer. Regarding the effect of plant surface wetness (dew and interception) on the radar backscatter only few studies have been published until now. Most investigations referred to forest [1, 2, 3] or the crop type wheat [4, 5, 6, 7]. A detailed discussion of experiments focusing on the effect of free vegetation water on the radar signal in agricultural areas is given by [8]. Most examinations documented an increase in backscatter coefficient under wet conditions by 1 – 4 dB. The influence varies with frequency, polarization and vegetation structure. The impact of dew and interception on radar backscatter is assumed to be similar [9]. Nevertheless, due to missing systematic investigations it is impossible until now to draw a general conclusion of the effect of plant surface wetness on the radar signal. The underlying mechanisms causing the increase in backscatter are still poorly understood, too [10]. Aim of this study is to investigate the effect of intercepted precipitation on effective scattering mechanisms. This possibility is provided by the methods of radar polarimetry. One approach to derive information about the relevant scattering processes is the application of target decomposition theorems. In recent years several different techniques have been proposed. A review of different approaches is given by [11].

## 2 EXPERIMENTAL DATA

The project was performed in a test site located about 25 km southwest of Munich, Germany. It covers an area of about 2x3 kilometres. The region is characterized by flat terrain. Only in the north of the study site there is an older moraine formation with significant topography (slope exceeds 10° at some points). The southern part of the test site, a sedimentary plain, is used for agriculture. It represents a typical rural landscape with small-scale land use pattern. The size of the fields included in this study varies between 0.6 and 15.3 ha. The main crop types cultivated in the area were cereals (winter and summer barley, winter wheat, rye and oat), corn, potatoes, rape, sugar peas and clover. Grassland, used as pasture and meadow, is widespread in a wetland south of the older moraine formation.

The investigations were carried out using polarimetric L-band data from the airborne E-SAR system of the German Aerospace Center (DLR) [12]. The SAR data were acquired on June 14, 2000 at 6, 9 and 12 a.m. The local incidence angles of the observed fields range between 33 and 52°. During all flight campaigns extensive field data were obtained. Soil moisture measurements were taken along profiles using TDR probes. For verification issues at some points gravimetric samples were collected, additionally. Furthermore, land use information and different vegetation parameter such us vegetation height, fractal cover and leaf area index were acquired. To describe and model the temporal variations of the amount of intercepted water on the plant surfaces microclimatologic conditions were recorded using three climate stations and 28 temperature/humidity sensors.

At the time of the first overflight the vegetation surface was very wet due to a heavy rainfall event of 24 mm in the night before the campaign. Most probably the free vegetation water had nearly reached the interception holding capacity of the plants, whereby some losses due to wind had to be considered. The day of the campaign was characterised by sunshine and high temperatures reaching up to 29°C at midday. In consequence, the evaporation rate was very high and nearly the whole intercepted rainfall was evaporated before the third overflight at 12 a.m.

## 3 METHODS

In the framework of this study two different target decomposition theorems were applied to the polarimetric E-SAR data at L-band: the eigenvector and model based approach.

The eigenvector decomposition approach [13, 14] is based on the decomposition of the 3x3 coherency matrix [T] into three independent coherency matrices [$T_i$], whereby each matrix represents a single scattering process. Its contribution to the received radar signal is given by the appropriate eigenvalue ($\lambda_i$). Based upon the eigenvector target decomposition theorem important roll-invariant parameters could be derived. The entropy H is defined by the logarithmic sum of the eigenvalues:

$$H = \sum_{i=1}^{3} -P_i \log_3(P_i);\ \text{where}\quad P_i = \lambda_i \Big/ \sum_{j=1}^{3} \lambda_j \tag{1}$$

This parameter is an indicator for the number of effective scattering mechanisms, whereby H = 0 belongs to deterministic scattering and H = 1 to totally random scattering. The second physical feature, the anisotropy A, describes the proportions between the secondary scattering mechanisms:

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3} \tag{2}$$

A only yields additional information for medium values of H. High A signifies, that besides the first scattering mechanism only one secondary process contributes to the radar signal. For low A both secondary scattering processes play an important role. Another polarimetric parameter is alpha $\alpha$, which represents the type of scattering mechanism and ranges between 0 and 90°. It is evaluated as:

$$\alpha = P_1\alpha_1 + P_2\alpha_2 + P_3\alpha_3 \tag{3}$$

Thereby $\alpha = 0$ indicates surface scattering. As $\alpha$ increases, the surface becomes anisotrop. An $\alpha$-value of 45° represents a dipole. If $\alpha$ reaches 90° the scattering process is characterised by double bounce interactions. The fourth parameter, which could be derived by the eigenvector decomposition approach, is the orientation angle beta $\beta$. It represents the orientation of the scatterer with regard to the radar line of sight and is defined as follows:

$$\beta = P_1\beta_1 + P_2\beta_2 + P_3\beta_3 \tag{4}$$

The second decomposition approach [15], the three-component scattering model was previously developed by Freeman and Durden. Surface scattering is modelled by the first-order Bragg model. Double bounce interactions are represented by scattering from a dihedral corner reflector. Finally, the volume scattering component is modelled by scattering from randomly oriented dipoles. This results in the following model for the total backscatter:

$$\begin{aligned}
&\left\langle |Shh|^2 \right\rangle = fs|\beta|^2 + fd|\alpha|^2 + fv \\
&\left\langle |Svv|^2 \right\rangle = fs + fd + fv \\
&\left\langle ShhSvv^* \right\rangle = fs\beta + fd\alpha + fv/3 \\
&\left\langle |Shv|^2 \right\rangle = fv/3 \\
&\left\langle ShhShv^* \right\rangle = \left\langle ShvSvv^* \right\rangle = 0
\end{aligned} \tag{5}$$

For dominant surface scattering α = -1 and for double bounce scattering β = 1. Thus, the model equations could be solved. The contribution of each scattering mechanism to the radar signal is:

$$\begin{aligned}
&P = P_s + P_d + P_v = \\
&= f_s\left(1+|\beta|^2\right) + f_d\left(1+|\alpha|^2\right) + 8 f_v/3
\end{aligned} \tag{6}$$

For all derived polarimetric parameters the field mean values were calculated for each SAR data acquisition time. To investigate the effect of rainfall interception on the backscattering behaviour from crops the variations of the polarimetric parameters during the morning of June 14 were analysed and interpreted.

## 4 RESULTS

Short-time changes in radar backscatter could be attributed to variations of following factors: soil moisture, plant water content and plant surface wetness [8]. The analysis of the groundtruth data indicate no changes in soil moisture conditions between the different SAR data acquisition times. Former studies documented only little impact of plant water content variations on the radar backscatter (< 1dB) [8]. Thus, this factor is expected to have only little effect on the radar backscatter. In consequence, the observed changes in polarimetric parameters obtained in this study could be most probably related changes in plant surface wetness. The mean changes in polarimetric parameters per crop type between 6 and 12 a.m. after the rainfall event are illustrated in Figure 1. Negative values indicate an increase in polarimetric parameters under wet conditions. Significant variations in backscattering behaviour were found for grassland, barley and rye only. The other crops just showed little changes during the morning of the campaign. Most of them, i.e. potatoes, corn and clover, were still very small in the middle of June and the fractal cover of the fields was relative low. As obtained in the field, the amount of rainfall intercepted by those plants was very low. Possibly SAR data acquired later in the season will be affected by water on those plant surfaces.

Regarding the parameters derived by the eigenvector decomposition it could be stated, that only the β-information showed significant changes between 6 and 12 a.m. (Fig. 1). The observed variations in β are strongly correlated to the changes in the radar backscatter at HV polarization (Fig. 2). Volume scattering processes are known to cause large cross polarized backscatter [16]. Thus, the variations in the β-information indicate an increase in volume scattering processes under wet conditions. This is in agreement with the results obtained by the model-based decomposition, which also signifies a rise in volume scattering due to moisture (Fig. 1). For single fields changes up to 3.4 dB were found. Moreover, the model-based approach indicates, that the contribution of surface scattering and double bounce interactions to the radar signal decreases when interception water is present.

The strongest changes in scattering mechanisms due to intercepted precipitation were found for high grassland. For single fields a decrease in β up to 33° were obtained during the day. The model-based approach indicate a rise in volume scattering processes of about 2.1dB (single fields up to 3.3 dB). Significant changes during the morning were obtained regarding the contribution of double bounce interactions to the radar signal. Few fields covered by high grassland showed very high variations (up to 14.7 dB; 5.3 dB in mean). Maybe these variations could be mostly attributed to geometrical changes of the target. During the collection of the groundtruth data it was noticed, that on some grassland fields the vegetation was blown down by the thunder storm at night. At the time of the third SAR data acquisition at 12 a.m. the grass was back in its vertical position.

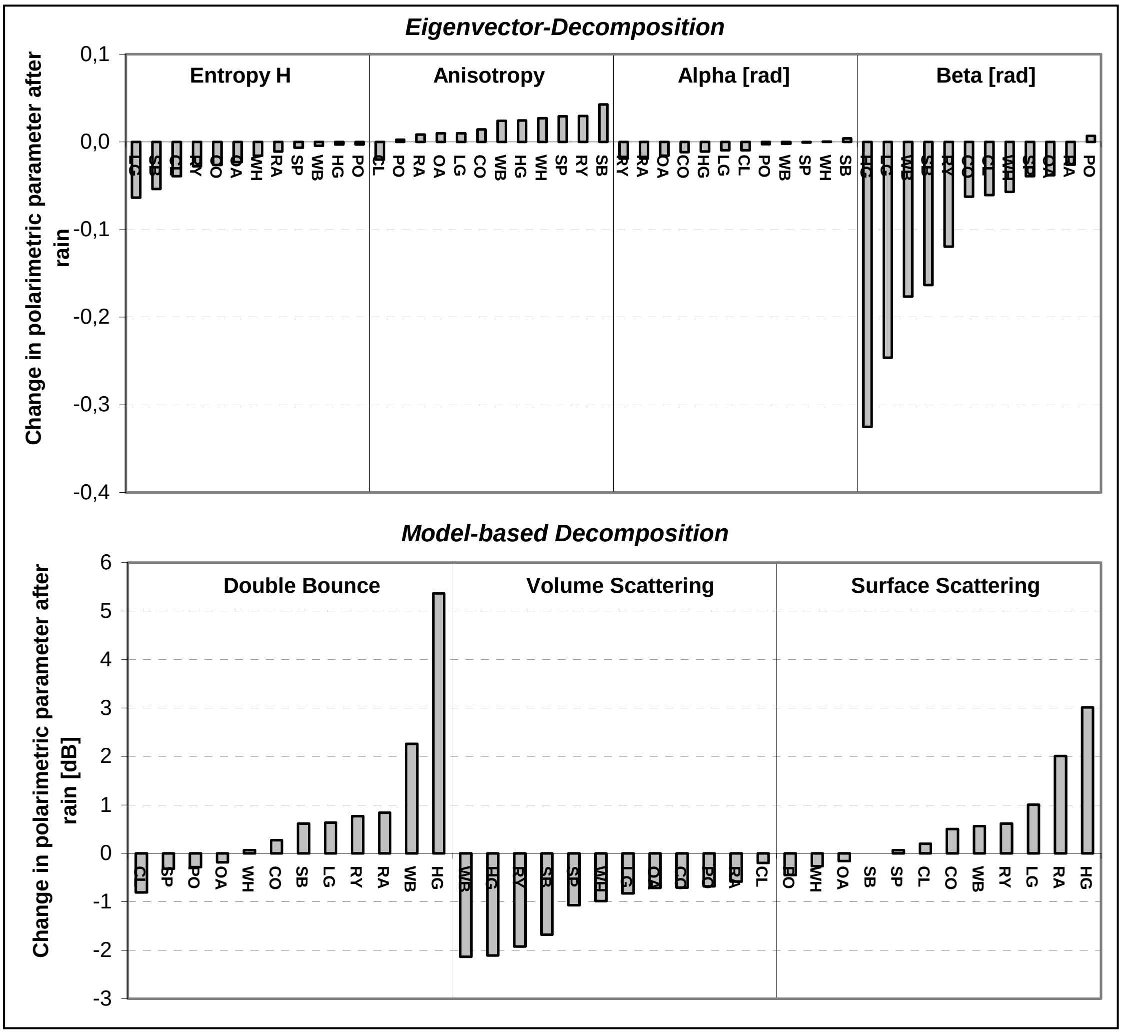

Fig. 1: Changes in polarimetric parameters per crop type between 6 and 12 am (HG → high grassland, LG → low grassland, WH → wheat, SB → summer barley, WB → winter barley, RY → rye, OA → oat, SP → sugar peas, PO → potatoes, CO → corn, RA → rape, CL → clover)

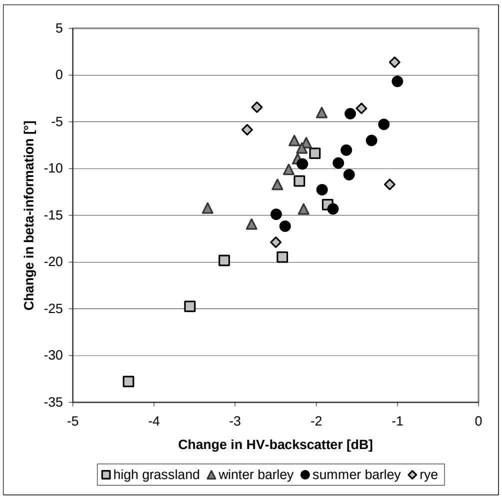

Fig. 2: Relationship between changes in radar backscatter at HV polarization and in β due to moisture

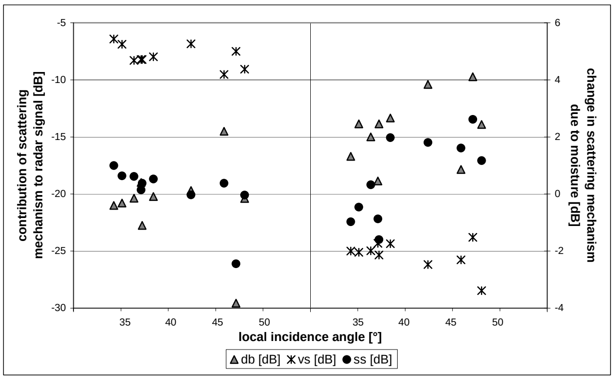

Fig. 3: Scattering behaviour of winter barley fields derived by the model based decomposition approach and its changes due to moisture

Moreover, significant changes in scattering mechanisms due to moisture were found for winter barley and two rye fields, which were in comparison to the other rye fields relative high (1,4 – 1,5 m) and in another growth stage. The groundtruth data showed, that for both crop types the yellowing of the plants had already began, whereby winter barley is in a later growing stage than rye (soft dough resp. early dough). Backscattering from ripe cereal fields is dominated by volume scattering as indicated by all decomposition theorems. The model based approach indicates, that under wet conditions the contribution of volume scattering processes to the radar signal increase by about 2 dB for most fields (Fig. 3). Contrary, surface scattering and double bounce interactions (up to 4.0 dB) decrease, especially in far range. The β-angle raises up to 15° due to interception.

For summer barley, which were just after flowering, the effective scattering mechanism strongly depends on the local incidence angle (Fig. 4). The α-values derived by the eigenvector-decomposition theorem show a significant decrease in range (r = 0,97). In near range α indicates for most fields dominant volume scattering, whereas in far range surface scattering processes prevail. This is in agreement with the results obtained for the model-based decomposition approach. Volume scattering processes play an important role at all incidence angles. The contribution of double bounce interactions is high in near range and decreases with rising local incidence angle. Surface scattering processes show an opposite trend. Due to the appearance of plant surface wetness the β-information increases up to 16°, whereby the changes are especially great for fields in far range (r = 0,89). According to the model-based decomposition approach the contribution of volume scattering processes increase under wet conditions between 1 and 2.3 dB. The changes of the other two scattering processes depends from the local incidence angle. In far range both processes become less important due to moisture. In mid and near range a slight increase in surface scattering could be found (up to 1.9 dB). Only one field in near range with a local incidence angle of 33° is characterised by declining surface scattering processes under wet conditions. But this field was covered by very low and sparse vegetation.

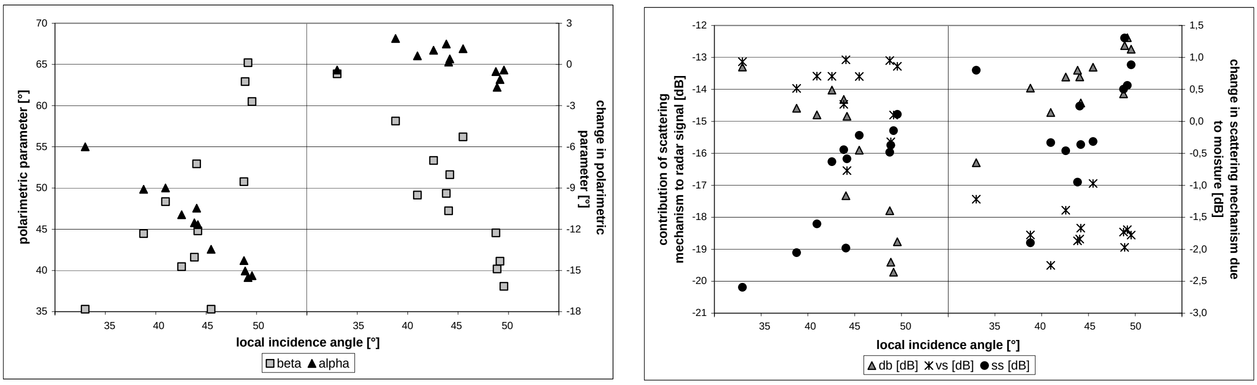

Fig. 4: Scattering behaviour of summer barley fields derived by the eigenvector (left) and model based decomposition approach (right) and its changes due to moisture

## 5 CONCLUSIONS

Aim of this study was to investigate the effect of intercepted precipitation on the scattering behaviour from crops. Significant changes in polarimetric parameters after the rainfall event were found for grassland, barley and rye only. Most of the other crops cultivated in the study site were still very small and sparse in the middle of June. Maybe later in the season the effective scattering processes will be affected by plant surface wetness. Regarding the eigenvector approach only the β-information show significant changes due to varying moisture conditions. This parameter shows a strong correlation to the changes of the radar backscatter due to plant surface wetness at HV polarization, indicating a rise in volume scattering processes. The model based decomposition approach also signifies an increase in volume scattering with moisture. Further on it indicates, that the contribution of surface scattering and double bounce interactions decrease when interception water is present.

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