An Investigation of 1989 Polarimetric SAR Data for the Flevoland Testsite

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ABSTRACT

An experiment with the NASA/JPL polarimetric P-, L- and C-band SAR was conducted in the Netherlands on August 16, 1989 and some scenes of an agricultural area in Flevoland were obtained. Several polarimetric features such as the co-polarized phase difference, the degree of polarization and the co-polarized signature were used for discrimination between agricultural fields. This study indicates that one can discriminate well between bare soil and vegetated fields using polarimetric data. It appeared that we could not discriminate significantly between the crop-types. This is probably due to the limitations of the data-set rather than to the poor potential for crop-type classification of polarimetric data.

INTRODUCTION

In remote sensing active radar imagery has an advantage over optical systems that it can be used during all weather circumstances and also at night since radar systems carry their own illuminating source. A third advantage of radar is its capability to perform *polarimetric* measurements.

Polarimetric measurements with non-imaging radars have been made since the fifties. The first airborne imaging polarimetric radar system became only available in 1985 (Zebker et al, 1987). Due to an accident which destroyed the first system, a new three- frequency system was built in 1988. The (center-) frequencies are in the P-, L- and C-band with corresponding wavelengths at 68.4, 24.0 and 5.66 cm, respectively. During the summer of 1989 this SAR system performed several measurement flights over Europe, within a measurement campaign called MAESTRO-1 (Churchill and Attima, 1989). The aim of this campaign was to give several European agencies and institutes a first opportunity to evaluate the use of multi-frequency polarimetric data for forestry and, to a lesser extent, agricultural applications. Flights were performed in France, Germany, the United Kingdom and the Netherlands (Flevopolder/Veluwe) (Freeman et al., 1990).

In the past agricultural crop discrimination research utilized the fact that different agricultural crops have different backscattering coefficients (Hoogeboom, 1985). In this paper we investigate the additional benefit of polarimetry for crop-type discrimination. Flevoland data are quite suitable for this purpose, since the site contains numerous crop-types grown in large and rectangular fields.

The paper is organized as follows. In Sect.1 we describe the data set. In Sect. 2 we define which polarimetric features we will use fro crop-type discrimination (Sect.2.1) and discuss the results (Sect. 2.2).

1. THE DATA

The multi-frequency SAR data of a 12 by 8 km area in the southern part of Flevoland was obtained on August 16, 1989. This area consists predominantly of agricultural fields. The data recording took place at about 10 AM during good weather conditions. It was partially cloudy and the temperature was about 21 degrees celsius. Humidity was about 63%. No rain was recorded in the day before the flight. Warm and dry weather preceded the flight date for more than two months.
The data was calibrated using corner reflectors deployed in some of the fields. The calibration utilized van Zyl's algorithm (van Zyl, 1990). Typical absolute uncertainties in the backscattering coefficients are on the order of 3 dB, while relative uncertainties are substantially smaller.

For the analysis we used calibrated data of both the Stokes matrix and scattering matrix format. The Stokes matrix data format is explained in (Dubois, 1987) and calibrated data was available for all three wavelength bands. Calibrated scattering matrix data was only available for the L-band.

Using the Stokes and scattering matrix data we extracted data from rectangular polygons located in 48 agricultural fields, for which ground truth data was available. The rectangles cover between 800 and 180,000 m, imply 30 to 650 independent looks. The incidence angle varied from 35 to 50 degrees for the fields. The data set comprises 9 different crop types. Since the number of fields per class is generally less than 10, only conclusions of limited statistical significance can be drawn.

2. ANALYSIS

In order to investigate the benefit of polarimetric data for crop-type discrimination we have to determine which polarimetric features we want to use for this purpose. We have chosen to use both standard features like the back-scattering coefficients and more heuristically determined features like e.g. the minimum power distribution (see next section). Finally we also inspected the co-polarized signatures for the different crop-types.

2.1 Feature extraction

We list here the features we have used in our analysis and discuss them more extensively in the following:

1. The average backscattering coefficients
2. The average co-polarized phase difference.
3. The degree of polarization
4. The co-polarized signature
5. The orientation of the minimum linear polarization

The backscattering coefficients, the co-polarized signatures and the polarization degrees are computed from the calibrated Stokes matrix data, while the other 2 features are derived from the complex scattering matrix data.

[ad 1.] We used the field averaged backscattering coefficient $\overline{\gamma}_{hh}$ and differences $\overline{\gamma}_{vv} - \overline{\gamma}_{hh}$ and $\overline{\gamma}_{hv} - \overline{\gamma}_{hh}$.

[ad 2.] The average co-polarized phase difference (Boerner et al., 1987) $\overline{\phi_{hh} - \phi_{vv}}$ and its standard derivation $\Delta\,(\phi_{hh} - \phi_{vv})$ were obtained from the distribution of one look complex scattering matrices within the polygons.

[ad 3.] The degree of polarization (Born and Wolf, 1964) was calculated from the Stokes matrix data with vertically polarized incident radiation.

[ad 4.] We observed that constant orientation cross-cuts of the signatures (van Zyl et al., 1987) are always bell-shaped and mirror symmetric (see also Borgeaud et al., 1987). Therefore, we only show cross-cuts along the $\chi = 0°$ axis for some interesting cases.

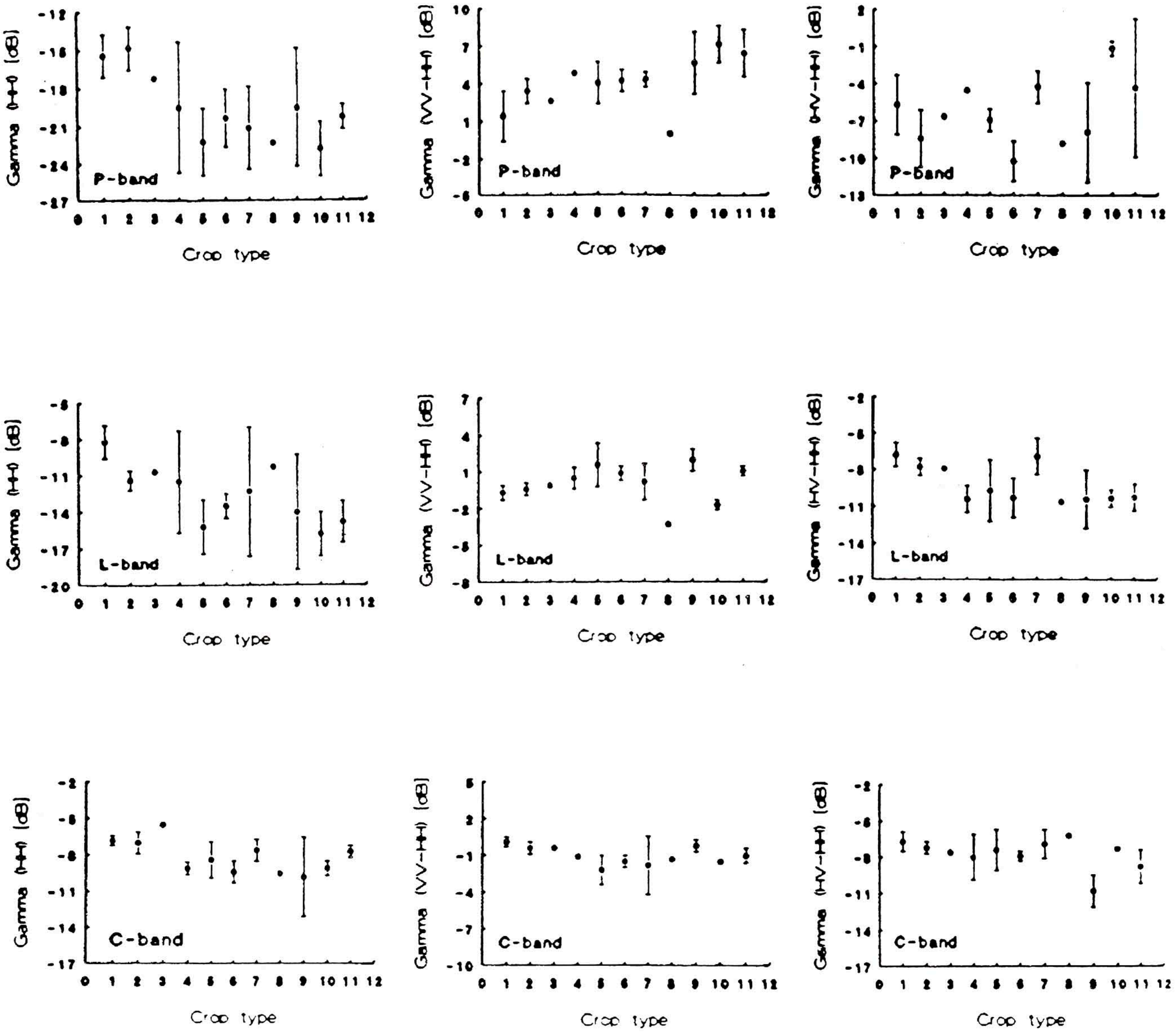
[ad 5.] Finally, we study the distribution of orientation angles of linearly polarized incident waves for which the backscattered power is a minimum (Groot and van den Broek, 1992). We denote the mode of distribution by ψ_{min}. This ψ_{min} may be a useful feature since it is expected to discriminate between isotropic crop types (e.g. sugar beets) and anisotropic crop types (maize).

2.2. Discussion

In Fig. 1 we plots of $\overline{\gamma}_{hh}$, $\overline{\gamma}_{vv} - \overline{\gamma}_{hh}$ and $\overline{\gamma}_{hv} - \overline{\gamma}_{hh}$ for the different crop types. A general trend in the Figure is that $\overline{\gamma}_{hh}$ is larger for higher frequencies. The standard deviation for $\overline{\gamma}_{hh}$ is in general larger for P - and L -band than for C-band. In some cases the standard deviation is exceptionally large, which may be due to differences within a crop type class, like vegetation density, plant geometry, soil roughness etc.
Apart from potato and sugar beet, which show a relatively large $\overline{\gamma}_{hh}$, the backscattering of the other crop types does not significantly differ. An exception is lucerne, which shows a rather small $\overline{\gamma}_{vv} - \overline{\gamma}_{hh}$ L-band value, and a relatively large (form) P-band value. Another exception is bare soil, for which the C- band $\overline{\gamma}_{hv} - \overline{\gamma}_{hh}$ value is quite small.

It appears that most co-polarized phase difference distributions resemble Gaussian distributions with means, which do not differ significantly from 0°. However, the standard deviation of the distribution shows more variation (see Table 1). The standard deviation for bare soil, wheat and repeseed stubble fields is small compared to those for the vegetated fields. This is in agreement with the result found by (Ulaby, 1987) that the width of the co-polarized distribution is smaller for surface- than for volume-scattering cases.

The degree of polarization in Table 1 tends to be larger for lower frequencies. This is true for all crop-types. In the C-band only the bare soil fields have a high degree, which value does not change much for the L- and P-band. The vegetated fields have at P-band values comparable to those for the bare soil fields. This can be explained by the fact that radiation with longer wavelengths penetrates the canopy more and surface scattering dominates. At higher frequencies volume scattering is more prominent giving lower degrees of polarization. A strong volume scatterer like lucerne shows this effect quite clearly, which is in agreement with its high value for the standard deviation of the co-pol phase difference (Eom and Boerner, 1991).



1 = potato	7 = onion
2 = sugar beet	8 = stem bean
3 = red beet	9 = bare soil
4 = maize	10 = lucerne
5 = wheat (mature)	11 = rapeseed stubble
6 = wheat (stubble)	

Fig. 1 - Backscattering coefficients versus crop type.

Table 1: Results for the different crop type classes (N = number of fields in class), sorted in order of decreasing L-band polarization degree. The pol. degrees were computed for vertically polarized incident radiation.

crop type	N	L-band ϕ_{co}		pol. degree		
		mean	s.d.	P	L	C
bare soil	6	-9	53	0.92	0.88	0.83
wheat mat.	6	-5	77	0.87	0.86	0.54
rapesd. st.	3	-5	62	0.89	0.86	0.71
wheat st.	3	-6	56	0.93	0.85	0.63
maize	2	-15	72	0.87	0.85	0.66
lucerne	2	-4	96	0.87	0.77	0.58
red beet	1	-4	68	0.79	0.72	0.68
sugar beet	9	-3	72	0.88	0.69	0.66
stem bean	1	25	99	0.77	0.68	0.51
onion	4	0	78	0.81	0.66	0.53
potato	11	6	78	0.71	0.60	0.65

In Fig. 2 we show a few typical cross-cuts of polarimetric signatures. P-, L- and C-band cross-cuts are shown for wheat, sugar beet and bare soil. Note that the P-band cross-cuts are similar and look like the one expected for bare soil indicating that scattering by the underlying soil dominates at P-band. This kind of signatures have a characterisitic maximum for $\psi = 90°$. At L- and C- band we also find other signatures. These are for example signatures with a minimum for $\psi = 90°$. Such signatures are observed for anisotropic crop types like wheat and maize. In this cases the backscattering is lower for VV polarization probably due to higher absorption by the stalks. There are also signatures with a minimum or maximum, which does not coincide with $\psi = 0°$, or $\psi = 90°$ e.g.for wheat field n. 28 shown in Fig. 2. The stalks in this field were tilted, so that the minimum is found for non-vertical polarizations. Finally we find flat signatures with no preference for a certain ψ-angle. Such signatures are especially found for potato and sugar beet which have more isotropic backscattering properties.

For many fields it was not possible to determine the ψ_{min} angle. The distributions are either too 'noisy' or, particularly, in the case of sugar beet uniform, which is probably due to the isotropic geometry of sugar beet. However, for a significant fraction of the bare soil and stubble fields we observe ψ_{min} angles near 0° or 180°. This can be simply explained by the fact that for such a rough surface it is always found that $\sigma^0_{hh} < \sigma^0_{vv}$. On the other hand, for lucerne we find ψ_{min} is around 90 degrees. Apparently vertically polarized waves are better absorbed, or scattered in other directions, than horizontally polarized waves in this case. This may be due to strong volume scattering by lucerne. Finally we wheat fields showed various ψ_{min} angles probably corresponding to the tilted wheat stalks.

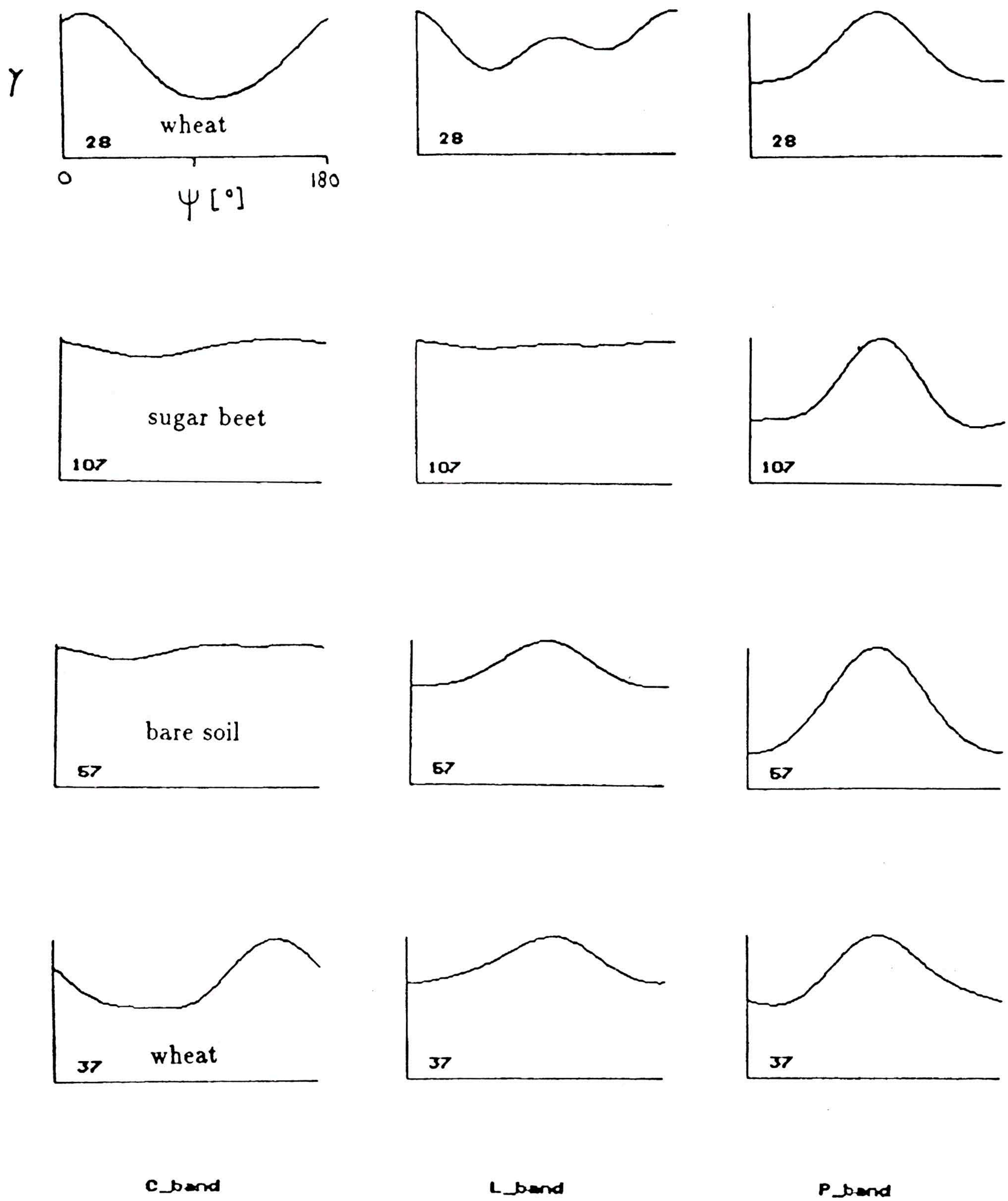


Fig. 2 - Typical cross-cuts $\chi = 0°$ of the co-polarization signatures for wheat, sugar beet and bare soil.

SUMMARY

The goal of our investigations was to estimate the potential of polarimetric data for crop type classification. For this purpose we used data obtained in the Maestro campaign for an area in Flevoland with numerous and diverse agricultural fields. It appeared quite possible using our polarimetric data to discriminate reliably bare soil fields from vegetated fields. However, due to the fact that the data were obtained rather late in the growing season and due to the restricted ground truth available, the data set was rather small. This implied that we are not able to deduce statistically reliable and general results for the discrimination between the different croptypes. An exception is lucerne which shows clear differences from the other crop types.

This paper can be considered as a preliminary study of the identification of features from polarimetric SAR data for crop- type classification. A more detailed study will be carried out with multi-temporal data of the same site in Flevoland, obtained with the JPL-SAR in the MAC-Europe campaign 1991.

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