VARIATION OF THE RADAR BACKSCATTER OF VEGETATION THROUGH THE GROWING SEASON

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ABSTRACT

In the period between 1975 and 1981 the ROVE team (Radar Observation of VEgetation) in the Netherlands collected data on the radar backscatter of crops through the growing season. Using these data general trends in the behaviour of the radar backscatter through the growing season (temporal signatures) can be determined for a number of crops. The results are reported. Comparisons are made with data from the literature and with the vegetation model developed by Attema and Ulaby. This last model can be used also to obtain information on the soil under the vegetation.

1. THE TEMPORAL SIGNATURES OF CROPS AT MICROWAVE FREQUENCIES

Figure 1 gives an example of the seasonal dependence of the radar return for a number of crops as measured by the ROVE team (Ref. 1) in 1980 for 10 GHz and a grazing angle θ of 30^0. Up till June 2 the coverage of the soil by vegetation is still small, so the soil plays the most important role in the reflection. After that date differences begin to occur due to the increasing influence of the vegetation. In this figure the peak on May 7 is due to a variation in soil moisture due to 10 mm rainfall shortly before the measurement. Further sudden peaks in the bare soil measurements later in time are indications for such sudden variations in soil moisture. They then also occur in the vegetation measurements but to a lesser extent: the canopy has a damping effect. The slow decrease in the radar return γ of the bare soils through time is caused by the effect that due to rainfall and slaking the roughness of the soil decreases through time. As can be seen the total range in γ is small: in the order of a 10 to 15 dB. It is within this range that discrimination between crops, or within crops, must be done.

Having available a number of such data sets as a function of time it becomes possible to show that

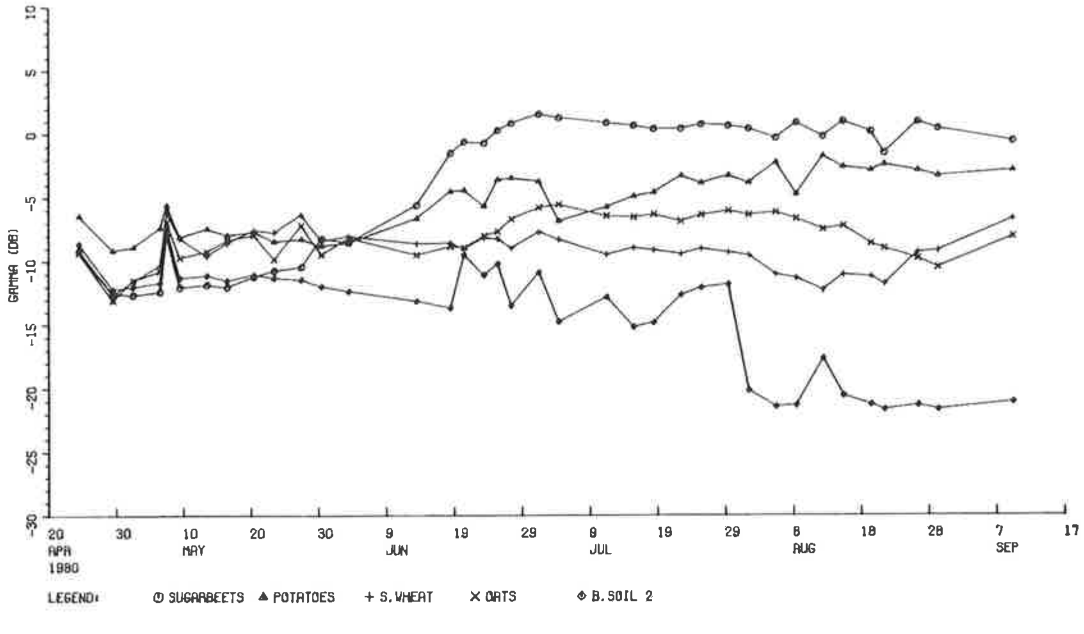

Figure 1. The radar return parameter γ as a function of time; ROVE data 1980; 10 GHz, HH polarization; grazing angle $\theta = 30^0$.

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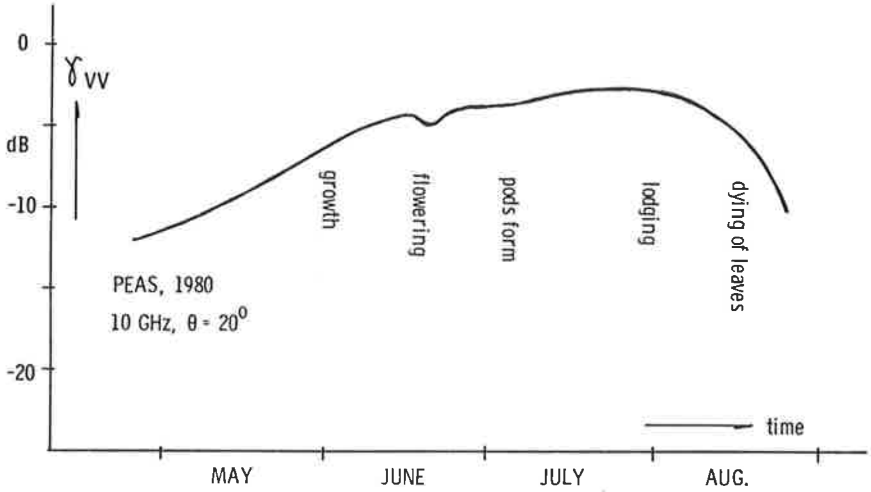

Figure 2. The temporal signature for peas. ROVE data, 1980; 10 GHz, VV polarization, $\theta = 20^0$.

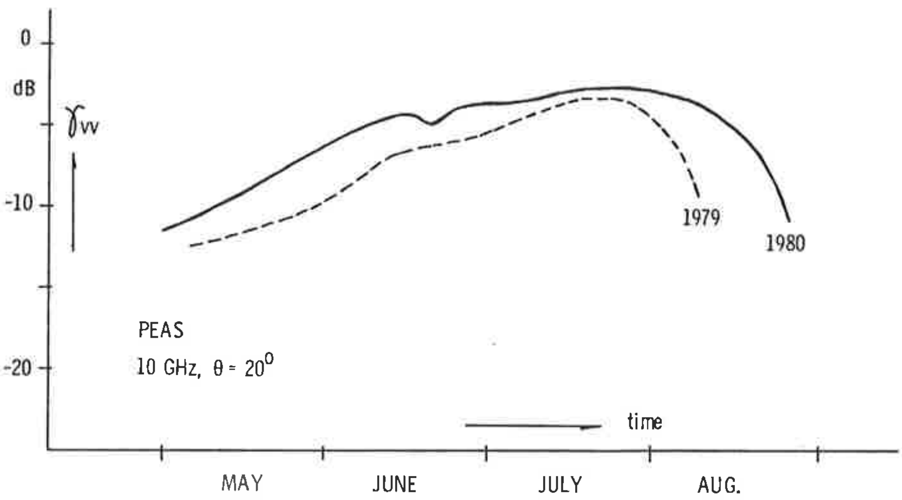

Figure 3. The variation in the temporal signature for peas due to varying meteorological conditions. ROVE data; 10GHz, VV polarization, $\theta = 20^0$.

the shape of such curves is typical for specific canopies. The measurement procedure used by the ROVE team (measurement of 10 to 15 fields in one day at 2 frequencies and 3 polarization conditions; Ref. 1) is particularly suited to adapt the number of observations per week to the growing stage. Since also measurement series are available for several growing seasons it so becomes possible to determine "temporal signatures" for specific crops. Figure 2 gives an example for peas in 1980. Even small variations, as e.g. the period of flowering, can be indicated because of the high density of the temporal measurements. This general behaviour can vary somewhat from year to year due to variations in the meteorological conditions but the general trend remains the same as figure 3 demonstrates. Similar variations (lengthening, resp. shortening of the growing cycle) occur for the other crops and in the same way in the same year.

This enables us to determine these general trends and figure 4 finally gives them for a number of crops. Figure 5 gives a similar example for data sets taken at Kansas University by Ulaby (Ref. 2). When we compare these last two figures two things can be remarked. Growth and growing stage is dependent on the place on earth and the meteorological conditions. For instance both figures show curves for wheat. They are similar in behaviour and values for γ but in figure 5 growth started earlier and the growing cycle is shorter also. Such variations have to do with latitude (climate) and are - in general - smaller than the variations in time due to local meteorological conditions as mentioned above.

Using the similarity in shape of the temporal pattern of the radar return γ for a specific crop Smit developed a method to use these temporal changes for croptype inventory purposes (Ref. 3). His proposal was later verified by the ROVE team (Ref. 4) with good results. Table 1 gives an example. In this example the data were taken at X-band and HH polarization and grazing angles under 20^0. Correct classification increased from 35% for one look to 88% for three looks in time. As we see in table 1 very good classification results are obtained for sugarbeets and potatoes after two flights already. At this moment it is investigated if this property can be used for the control on

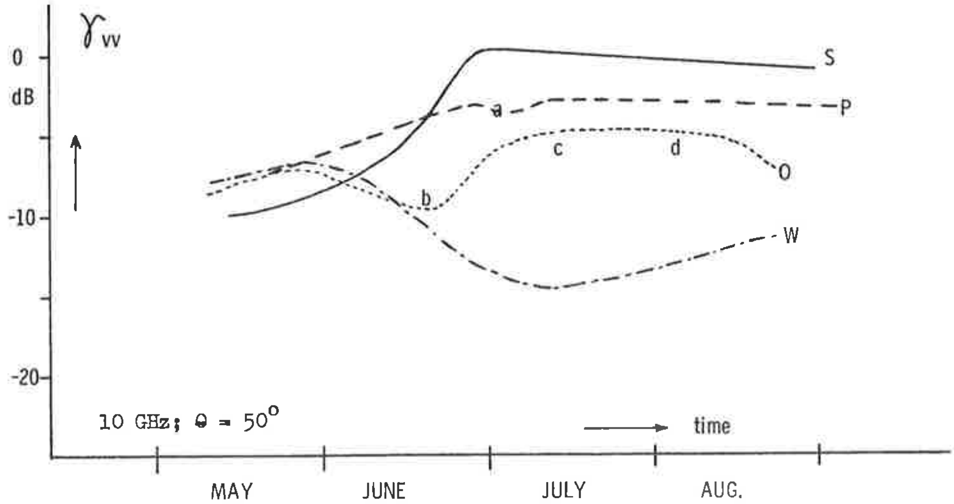

Figure 4. Average shape of the temporal signature of four crops. ROVE data. S: sugarbeets; P: potatoes; W: wheat; O: oats; a: flowering; b: panicles come; c: leaves begin to die; d: lodging begins; 10 GHz; $\theta = 50^0$; VV polarization.

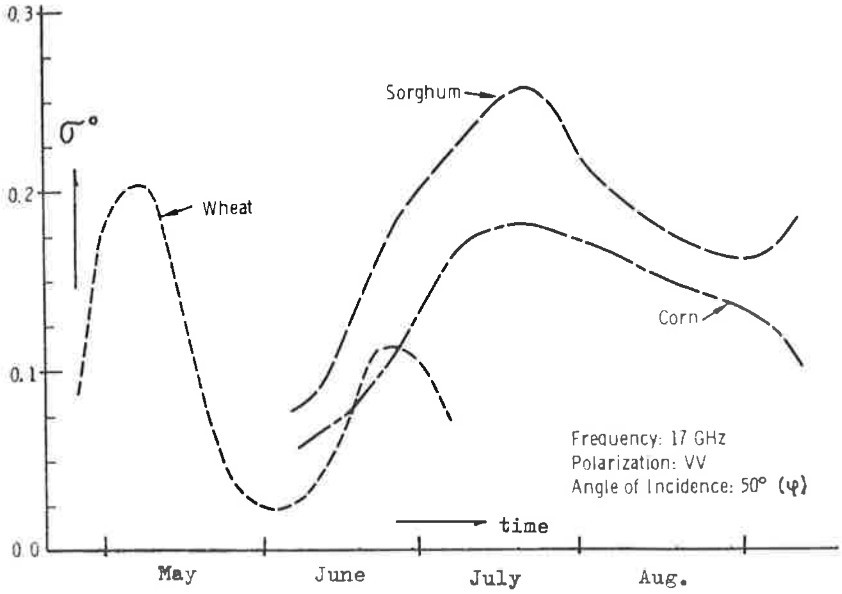

Figure 5. Typical temporal patterns of the scattering coefficient σ^0 (= $\gamma \sin\theta$) for three crops in Kansas (USA) after Ulaby (Ref. 2). 17 GHz, VV polarization, $\theta = 40^0$ ($\phi = 90^0 - \theta$).

		11/7			10/6 + 11/7			11/7 + 12/8			10/6 + 11/7 + 12/8					
croptype	number of fields	cc	nc	ic	cc	nc	ic	cc	nc	ic	cc	nc	ic	% of area cc	nc	ic
sugarbeets	40	40	0	0	40	0	0	40	0	0	40	0	0	100	0	0
potatoes	40	12	28	0	39	1	0	32	7	1	39	0	1	97.1	0	2.9
wheat	58	0	54	4	3	49	6	39	14	5	42	12	4	76.2	18.9	4.9
onions	22	5	17	0	7	15	0	18	4	0	19	3	0	88.5	11.5	0
oats	5	0	5	0	2	3	0	1	4	0	4	1	0	87.3	12.7	0
peas	12	3	9	0	6	6	0	5	7	0	5	7	0	45.1	54.9	0
beans	5	3	2	0	5	0	0	4	1	0	5	0	0	100	0	0
	182	63	115	4	102	74	6	139	37	6	154	23	5	88.0	9.6	2.4

Table 1. Classification results (X-band; HH polarization) for 1, 2, and 3 flights, after Hoogeboom (Ref. 4); cc is correctly classified; nc is not classified; ic is incorrectly classified.

crop rotation for potatoes.

The procedure for such crop type inventories will differ per area in the world due to differences in growing speed at different latitudes as we have seen (fig. 4 and 5). Ulaby et al. (Ref. 2) so developed a completely different procedure for Kansas (USA). They used two time segments per season which they covered each with 4 looks taken 3 to 9 days apart. These time segments were determined by the presence of specific crops in each segment. The first was determined by the occurence of winter wheat (fig. 5) which was harvested in late June or early July and the second by the milo and soybeans. We also give their results as an example in table 2 (Ref. 5). They are for data taken between 1974 and 1976. We give results only for one frequency (14.2 GHz) and polarization (VV) to make comparison possible with the results reported above in table 1.

		after look			
segment 1	A	1	2	3	4
1974	7.1	53.0	75.0	93.0	95.5
1975	2.8	68.7	96.7	99.0	99.8
1976	8.7	49.7	83.5	85.3	88.2
segment 2					
1974	7.1	45.5	70.0	80.5	88.0
1975	2.8	54.7	67.2	75.8	80.3
1976	8.7	82.4	85.1	85.5	88.1

A: average time between looks (days)

Table 2. Percent correct crop classification at 14.4 GHz; after Ulaby (Ref. 5).

The results reported by Hoogeboom and Ulaby are comparable. Seen the fact that these good results were obtained for different procedures, at very different places in the world and different incidence angle ranges justify the hope that radar can be used for vegetation inventories using the temporal variation in the radar return. The final procedures used, however, may depend on the place on earth.

2. PROPERTIES OF THE SOIL UNDER A CANOPY; OTHER PROPERTIES OF THE CANOPY

The measurement series of the radar backscatter versus time also gave an impetus to the modelling of the radar return. Such models are very useful, among others, to investigate the problem of measuring the properties of soils through a vegetation canopy. For this purpose we used the model developed by Attema and Ulaby (Ref. 6) and later extended by Hoekman et al. (Ref. 7).

Since the dielectric permittivity of the dry matter of plant material is at least an order of magnitude smaller than that of water, where this plant material is only in the order of a few percent of the total volume of the canopy and since the volume scattering is the predominant mechanisme for the radar backscatter of vegetation, Attema and Ulaby (Ref. 6) proposed to model a vegetation layer as a cloud of water droplets. For details of this model and its derivation the reader is referred to the references mentioned. The following formula for the radar return is then obtained:

$$\gamma = C[1-\exp(-DWh/\sin\theta)] + G(\theta).\exp(K.m_s-DWh/\sin\theta)$$

or with $\tau = \exp(-DWh/\sin\theta)$ and $M(\theta) = G(\theta).\exp(K.m_s)$

$$\gamma = C\ (1-\tau) + M(\theta).\tau$$

with $M(\theta)$ the return of the soil under the vegetation, approximated by $G(\theta)$, the properties of the dry soil, and a loss term due to the water content m_s of the soil. W is the watercontent of the vegetation in kg/m^3 and h (in m) the measured height. C is a constant representing the backscatter of the vegetation canopy as such and D is the two-way attenuation in $m^3/kg/m$ of the vegetation layer. To express D in dB we must multiply it by 4.343.

Knowing W, h and m_s from observations in situ it is, in principle, possible to determine $G(\theta)$, τ, and the model parameters C and D from measurements

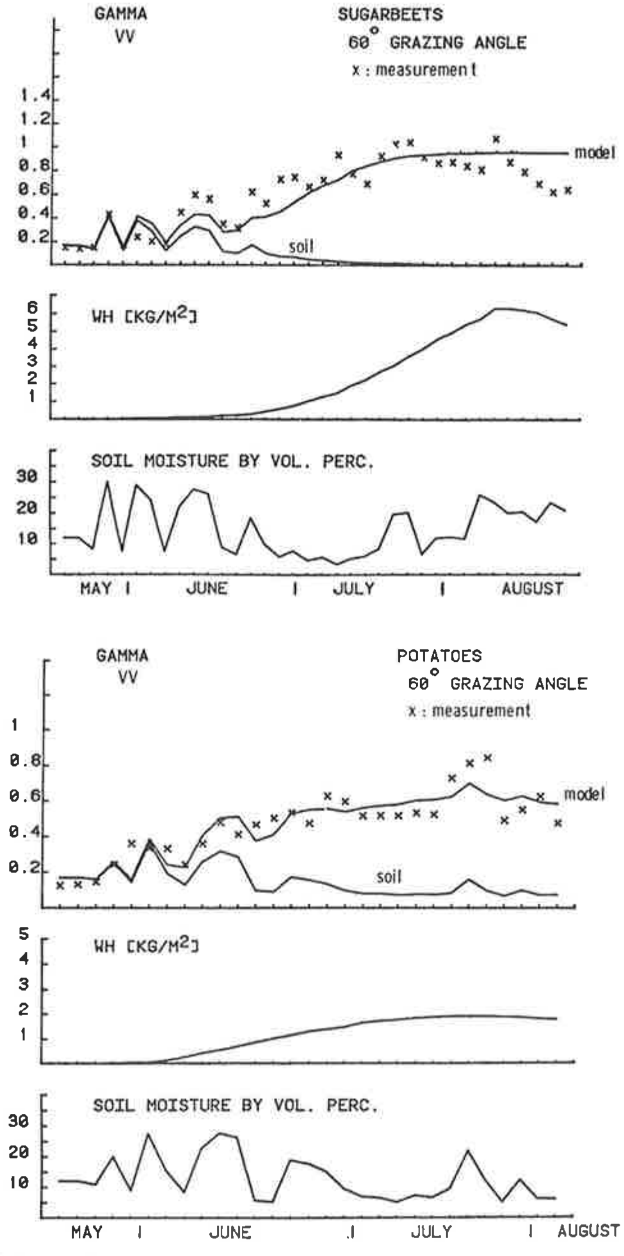

Figure 6. Measured data (crosses) compared with the model of Attema and Ulaby (Ref. 6), after Hoekman (Ref. 8); ROVE data of 1979, X-band, VV polarization.

of γ. Attema undertook such an effort on the data collected by Ulaby's group at Kansas University and Hoekman undertook a similar exercise for the ROVE data of 1979 (temporal data). They both did a regression analysis to the groundtruth supported data mentioned. For details of these analyses the reader is referred to their work (Refs. 6, 7).

In figure 6 we give an example of the results obtained by Hoekman (Ref. 8) on the ROVE data for 1979. It gives the contributions of the soil and the vegetation layer separately, together with the surface data for soil moisture and Wh. G(θ), the radar return of the dry soil under the vegetation, can also be determined and compared with measurements of the same soil, corrected for soil moisture. An example of such a comparison is given in figure 7 (ROVE data of 1980).

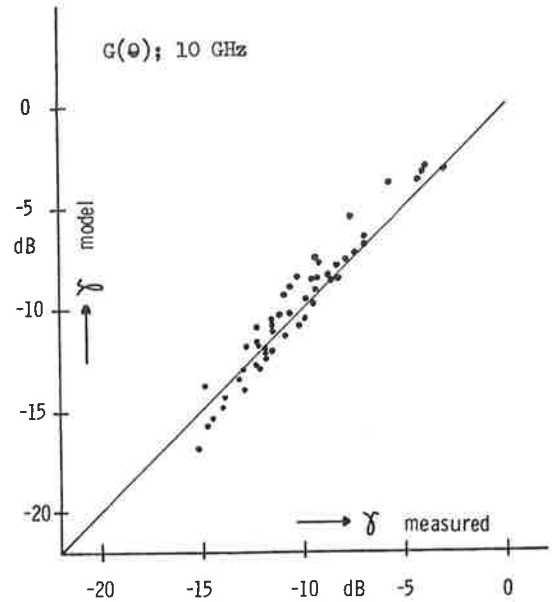

Figure 7. Comparison of the radar return γ of the (dry) soil under a vegetation layer as obtained from direct measurements and through the model.

Knowing D the attenuation [exp(WhD)] of the microwave radiation by a crop can be determined. Table 3 gives an example. It shows that accuracy of the determination of the backscatter properties of the underlying soil will diminish when going to

Attenuation at θ:		15^0	20^0	45^0	80^0
Sugarbeets	τ:	61	46	22	16
Potatoes		28	21	10	7
Peas		21	16	8	6
Winter wheat		47	36	17	12
Summer wheat		55	42	20	14
Oats		32	24	12	8
Barley		55	42	20	15

Table 3. Average attenuations in dB for fully grown crops (ROVE data) as a function of grazing angle; 10 GHz, VV polarization.

lower grazing angles, due to the larger attenuations of the canopies involved. It also means that the backscatter itself is then primarily (and sometimes wholly) determined by the canopy only at these lower grazing angles.

3. CONCLUSIONS

The radar backscatter of crops shows typical temporal patterns depending on species. The place and length in time of this temporal signature can vary with latitude (climate). This means that optimum classification procedures for crops vary depending on the place on earth.

The vegetation model developed by Attema and Ulaby (vegetation modelled as a water cloud) proves to be a useful tool to obtain information about the vegetation canopy and the underlying soil.

4. REFERENCES

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