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RAIN-INDUCED MODIFICATION OF SAR PERFORMANCE

P. Ferrazzoli and G. Schiavon

Dipartimento di Ingegneria Elettronica, Università di Roma "Tor Vergata",
Via Orazio Raimondo, 00173 Roma, Italy

ABSTRACT

The performance degradation suffered by a microwave remote sensing SAR system due to the presence of rain is analysed. In particular, alterations caused by attenuation, backscatter and depolarization due to the presence of a rain cell along a swath is estimated. Furthermore, a global evaluation of the degradation as a function of the rain intensity is carried out by using a proper parameter. Numerical calculations are performed for some typical SAR configurations at 10 GHz; suitable models for the interaction of electromagnetic waves with raindrops are used.

INTRODUCTION

It is known that microwave remote sensing systems are more advantageous than the infrared and optical ones as far as adverse weather capabilities are concerned. In fact, when the dimensions of hydrometeors are small with respect to wavelength (as is the case for clouds) or the water droplets are sparse (as is the case for light rain) the interaction with the propagating microwave field is not so critical as to induce appreciable degradations of the system performance. Nevertheless, when the rain is not weak, as frequently occurs in some climatic zones, also microwave systems may be subjected to non-negligible limitations.

Purpose of the present paper is to analyse the modifications suffered by a SAR system when rain cells are present along a swath. Some concepts which have been introduced for telecommunication systems may be re-used, but some aspects which are peculiar to SAR systems require ad hoc investigation.

THE MODEL

From an electromagnetic point of view, a rain volume may be characterized as an ensemble of scatterers, representing the water drops. When a raindrop is illuminated by a plane wave, the incoming power is divided into three parts:

- a part is absorbed by the raindrop, and is transformed in non-electromagnetic power;
- part of the plane wave remains undisturbed, but the associated field is partially depolarized, since the absorbing effect is not isotropic;
- a part is scattered in different directions.

The latter effect is described by an expression of the kind:

$$\underline{E}_s(\underline{r}) = \underline{f}(\underline{i},\underline{o}) \exp(-j\beta r)/r \tag{1}$$

where $\underline{E}_s(\underline{r})$ is the field scattered at the observation point $\underline{r}$ for unit incident field, $\underline{i}$ and $\underline{o}$ are the directions of the incident wave and the observation point, respectively; the function $\underline{f}(\underline{i},\underline{o})$ is a characteristic of the raindrop, depending on frequency, size, shape, relative orientation and dielectric properties. The global effect of a rain volume is obtained by properly superimposing the single raindrop effects.

In an active remote sensing system the useful electromagnetic power received by the sensor depends on the backscattering coefficient of the illuminated surface. The observation may be copolar or crosspolar, that is, assuming a transmitted linear polarization, the received polarization is the same as the transmitted one or orthogonal to it. When a rain cell is present along the propagation path, the received field is altered. In particular attenuation and partial depolarization of the useful field occur, together with interference backscatter.

The rain cell affects the response of many pixels at the same time, and not in a simple way. With this respect the affected swath can be subdivided into different zones (see Figure 1):
- a zone before the cell in which interfering rain backscatter only is present;
- the cell itself, where both rain backscatter interference and attenuation (accompanied by depolarization) are present;
- a zone beyond the cell where attenuation and depolarization only are present.

To determine quantitatively the alterations that a rain cell induce in the SAR response, first of all the power received by the sensor from the various pixels along the swath has been calculated. The total power is given by the superimposition of the one scattered by the ground modified by rain attenuation and depolarization and of the contribution from rain backscatter. These various components have been estimated for different values of rain intensity.

A "useful backscatter coefficient" σ^o_U and an "interfering backscatter coefficient" σ^o_I have been introduced. The first one is defined as the ground backscatter coefficient lowered by the two-way rain attenuation, while the second one is the total interfering backscatter coefficient due to rain taking also the system threshold into account. For each pixel the ratio $Q=\sigma^o_I/\sigma^o_U$ is regarded as a noise to signal ratio and it has then been calculated. The fraction of the swath in which a given value of Q is exceeded has been calculated. This fraction is a parameter that represents the swath response degradation.

SYSTEM PERFORMANCE ALONG THE SWATH

The performed calculations refer to a SAR system operating at 10 GHz, with an incidence angle θ of 45 degrees, in vertical polarization, at 40 degrees of latitude. The following procedure has been used:

1) Assume a cell of rain rate R to be present along the swath.
2) Compute the cell height H and the cell width W according to the CCIR expressions /1/, /2/.
3) Compute the specific attenuation A_s according to the CCIR expressions /3/.
4) Compute the cell influence zone (Figure 1):

$$W_i = W + H\,(\mathrm{tg}\theta + \mathrm{cotg}\theta) \tag{2}$$

5) Subdivide W_i in N intervals. For each interval:
   - compute the path in rain 1 (Figure 2);
   - compute rain attenuation:

$$A = A_s\, 1$$

   - compute the useful backscatter coefficient:

$$\sigma^o_U(\mathrm{dB}) = \sigma^o_g(\mathrm{dB}) - 2\,A \qquad \text{(copolar observation)} \tag{4}$$

$$\sigma^o_U(\mathrm{dB}) = \sigma^o_{gx}(\mathrm{dB}) - 2\,A \qquad \text{(crosspolar observation)} \tag{5}$$

   σ^o_g and σ^o_{gx} are copolar and crosspolar ground backscatter coefficients, respectively;
   - compute rain XPD (dB) as a function of A according to CCIR /1/;
   - compute interference due to depolarization:

$$\sigma^o_{I1} = 2\ \sigma^o_{gx}\ /\ \mathrm{XPD} \qquad \text{(copolar observation)} \tag{6}$$

$$\sigma^o_{I1} = 2\ \sigma^o_{g}\ /\ \mathrm{XPD} \qquad \text{(crosspolar observation)} \tag{7}$$

   - compute rain backscatter cross section per unit volume σ^b as a function of R, according to the CCIR expressions /2/;
   - compute rain backscatter interference:

$$\sigma^o_{I2} = \sigma^b \,\mathrm{sen}\,\theta \int_{X_1}^{X_2} \exp[-2\ A'_s\ y'(x')]\ dx' \tag{8}$$

   where $A'_s = (\ln 10)\ A_s/10$ and X_1, X_2, x', y' are shown in Figure 2;
   - compute the total backscatter coefficient:

$$\sigma^o_T = \sigma^o_U + \sigma^o_{I1} + \sigma^o_{I2} \tag{9}$$

Figures 3 and 4 report the results obtained for copolar observation with the described procedure for R=30 and 60 mm/h and assuming σ_g^o=-10 dB and σ_{gx}^o=-15 dB. The total backscatter coefficient as seen by the system and the separate contributions relative to the useful signal and to all the interferences are plotted for the swath zone affected by the cell. From the figures it can be noted that the response has different characteristics in the three zones mentioned in the preceding section and shown in Figure 1 (the two vertical dotted lines represent the cell boundaries). The effect of depolarization is negligible compared with attenuation and backscatter and does not appreciably affect the SAR performance. The other two effects cause a stronger degradation, which increases with rain intensity. It should be noted that the interfering backscattered power, which increases the received level with respect to clear-sky conditions, is decreased by the attenuation introduced by the cell. As a consequence the inner part of the cell contributes less than the front.
Calculations were performed for crosspolar observation too. In this case σ_g^o and σ_{gx}^o are assumed to be -5 and -15 dB, respectively. Crosspolar backscattered power in turn is assumed to be 30 dB below the corresponding copolar backscattered power. The linear depolarization backscatter ratio is reported in Figure 5 of /4/ for a horizontal path; a 40 log cos(90°-θ) factor has to be introduced for a slant path, with 90°-θ indicating the elevation angle. For θ=45° this factor results in an enhancement of 6 dB; the resulting -24 dB value corresponds to an average canting angle of about 11° and a canting angle standard deviation of 10°. Both values are conservative with respect to real rainstorm parameters. Results are shown in Figures 5 and 6. It can be noted how the backscattering effect is now negligible compared with attenuation. The effect of depolarization, though is increased with respect to the copolar case, still remains low.

ESTIMATE OF DEGRADATION DUE TO RAIN

The noise to signal ratio Q defined above

$$Q = (\sigma_{I1}^o + \sigma_{I2}^o + \sigma_t^o) \,/\, \sigma_U^o \tag{10}$$

where σ_t^o is the system threshold, has been calculated for the points where the influence of the cell is present, following the procedure described in the proceding section. Q > 1 means that the interfering power exceeds the useful one so that the response of the system may be considered to be totally degraded. A "degraded lenght", that is the lenght of the swath for which Q exceeds Q_m=1 has then been calculated. For particular applications which may require higher reliability of the SAR system, values of Q_m lower than one can be assigned. Figures 7 and 8 report the degraded lenght as a function of rain rate for selected copolar and crosspolar ground reflectivities and for system thresholds equal to -18 dB and -30 dB. It is observed that the degraded lenght is zero for low rain intensities, which means that Q never exceeds Q_m along the swath. This is due to the relatively high value of Q_m that has been considered. Note also the dependence of the response on the system threshold. Indeed, when the main degrading effect is due to attenuation, the lower is σ_t^o the larger is the attenuation that can be standed by the system.

CONCLUSIONS

In order to estimate the degradation suffered by a microwave remote sensing SAR system due to the presence of rain cells, proper models for the interaction of electromagnetic waves with water raindrops have been used. Calculations have been made for some typical SAR configurations at 10 GHz. The obtained results show that rain may produce degradation effects which cannot be neglected, especially for high rain intensities.

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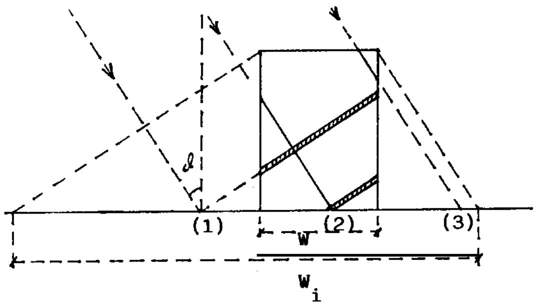

Fig. 1. Paths in rain (-----) and rain backscatter volumes (▨) for pixels allocated before (1), within (2) and beyond (3) the cell.

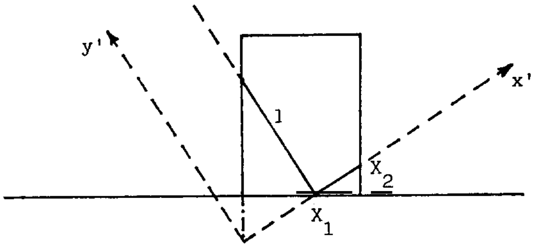

Fig. 2. Reference system and notations.

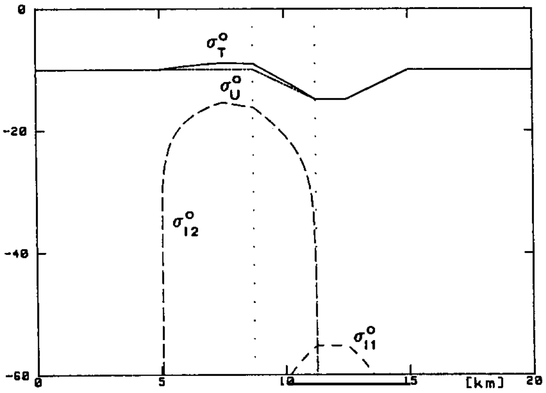

Fig. 3. Contributions to backscatter coef. Copolar observation, R = 30 mm/h

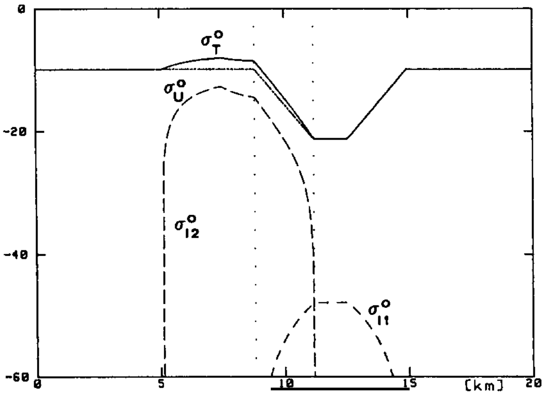

Fig. 4. Contributions to backscatter coef. Copolar observation, R = 60 mm/h

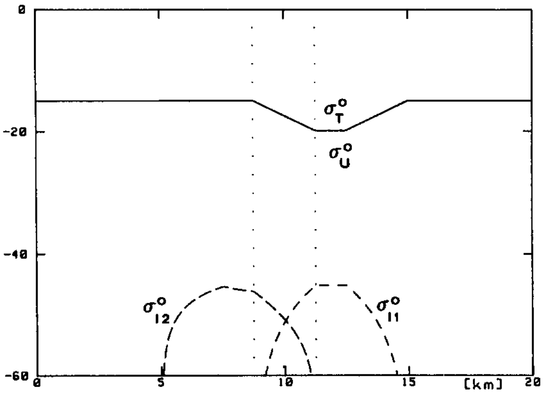

Fig. 5. Contributions to backscatter coef. Crosspolar observation, R = 30 mm/h

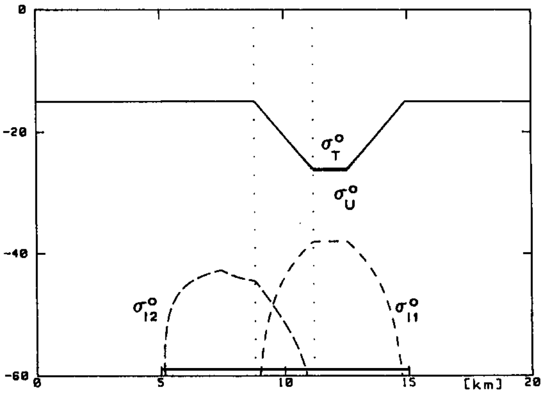

Fig. 6. Contributions to backscatter coef. Crosspolar observation, R = 60 mm/h

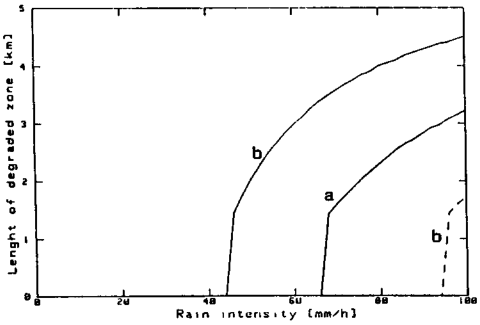

Fig. 7. Copolar obs.; ---: σ_t^o = -30 dB, ——: σ_t^o = -18 dB; a: σ_g^o = -5 dB, σ_{gx}^o = -10 dB; b: σ_g^o = -10 dB, σ_{gx}^o = -15 dB.

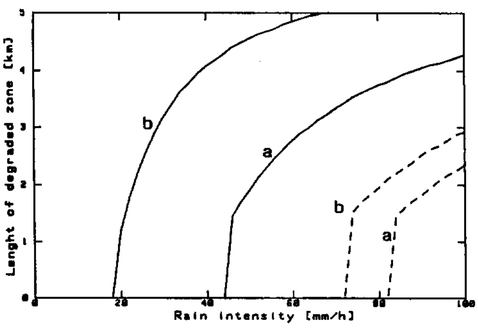

Fig. 8. Crosspolar obs.; ---: σ_t^o = -30 dB, ——: σ_t^o = -18 dB; a: σ_g^o = 0 dB, σ_{gx}^o = -10 dB; b: σ_g^o = -5 dB, σ_{gx}^o = -15 dB