Title

Improving rainfall measurement accuracy in spaceborne rain radar over sea

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Improving Rainfall Measurement Accuracy in Spaceborne Rain Radar over Sea

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Abstract -- In this paper the problem of improving techniques for rainfall intensity estimation over the sea surface through spaceborne rain radars is analysed. In such case, the backscattered signal is composed of a rainfall volumetric contribution and of the sea surface contribution, which gives rise to the problem of extracting the information of interest from the composite echo. In particular, we focus on the problem of deriving a better estimation of the rain perturbed backscattering coefficient of the sea surface from polarimetric measurements, as a means for achieving such improvements. The effects of the additional roughness of the sea surface due to the rainfall have been taken into account and analysed by resorting to an electromagnetic model able to provide a full polarimetric description of the rainfall perturbed sea surface.

INTRODUCTION

Retrieval of rainfall intensity over sea surface by means of spaceborne rain radars [1] is getting increasing importance for monitoring environmental parameters on global scale. Several radar system configurations can be used for this purpose, such as those adopting one or two operating frequencies, or two antennas at two different look angles. Nevertheless, it is not yet evident from the literature which could be the optimal choice of system parameters and data processing algorithms for rainfall rate retrieval through inversion techniques, in order to reduce intrinsic errors in the rainfall estimates.

One drawback of attenuation retrieval techniques is the heavy additional attenuation due to the possible presence of the melting layer, that is not easy at all to predict and model. Surface referenced techniques [2] exhibit in general better performance with respect to the previous ones, but they are based on the knowledge of σ_S (Normalized Radar Cross Section, NRCS, of the sea surface), which is commonly predictable in a very approximate way. Moreover, both kinds of techniques make use of k-Z (specific attenuation-reflectivity) conversion laws, that most times are not well representative of the true relationship between the physical quantities involved. Multiparameter techniques, such as the dual-frequency and the dual-beam techniques, are generally more accurate, but require a more complex system.

In the aforementioned algorithms a quite relevant problem seems to be that of the inherent ambiguity associated with the low number of parameters available and with the uncertainty of the relationships among physical parameters. To bound this problem, more measurement parameters are needed. In addition to that, sea clutter is not negligible when the incidence angle differs from nadir [1],[3]. Indeed, this is the usual configuration for spaceborne rain-radars, for which the typical incidence angle ranges between 0° and 20°. In such a case, volumetric backscattering from several cells above the sea surface is contaminated by the sea return [1]. Furthermore, it has been shown that the influence of the rainfall on the backscattering coefficient of the sea surface is not negligible [4],[5]. The estimation of the rain-perturbed surface backscattering coefficient can be exploited for ambiguity removal in the aforementioned algorithms, and also the surface referenced algorithm could get a substantial improvement. Due to the strong sea return, the modified σ_S alone may permit the rainfall rate retrieval; more realistically, the optimal strategy could be that to utilise the measurement of σ_S in the surface reference technique or, for instance, in a modified version of the algorithm presented in [3]. Some studies aim also at demonstrating that polarisation sensitivity could be exploited, trying to extract, from the composite return, the sea surface contribution (or, inversely, to filter it out) [6].

In order to obtain the filtered component (the volumetric rain return), an optimal polarization is achieved for every incidence angle. However, in that work the sea surface is modelled as corrugated by only wind, and characterized by the Pierson-Moscowitz spectrum for the surface roughness. The additional roughness contribution due to rain is not considered there, and as already shown [4],[5] that assumption seems not to be allowed.

In order to obtain an e.m. formulation that takes into account this additional roughness contribution, while allowing for polarimetric analysis of the sea return, the effects of the raindrop splash are considered and they are introduced in the formulation of the theory for rough surface by Bahar [7],[8]. A full polarimetric description can then be obtained.

E.M. MODELLING

We will consider a sea surface corrugated by wind and by the effects of the raindrop splashes. It has been shown that crown and stalks, arising from raindrop splashes, are important features to be considered for analysing backscattering near grazing incidence angle [9], while ring

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waves are important for backscattering at incidence angles near nadir [4],[5]. In our case, only ring waves have been considered; they have been modeled as a random process with characteristics similar to those of the waves generated by the wind. The treatment of the crown and stalk phases is more particular since these are impulsive effects, and are treated in [9], where the backscattering due to a single ring wave is computed in the time domain. Since our purpose was a complete polarimetric description of the sea radar return, we considered the e.m. model in [7],[8], where it is shown that also the crosspolar components are well predicted by the model itself. We assumed that roughness is due to the superposition of the two random processes due to rain and wind. As a preliminary example, for the sea surface roughened by wind we have taken into account the Pierson-Moscowitz spectrum as in [7], with a zero mean Gaussian surface height distribution. The distribution of the local slope of the surface has also been been assumed as zero mean Gaussian. The same distribution has been used also for the height of the surface roughened by rain, assumed as a random process with Gaussian spatial correlation coefficient.

The height standard deviation h_R(rms) for roughness due to rain is of the order of a few millimeters, and its correlation lenght is of the order of a few tens of centimeters at maximum. Under these hypotheses and considering the values for the wind roughness given in [7] [8], it is easy to verify that the average radius of curvature of the rain roughness is much larger than that of the wind roughness. The NRCS has been calculated by means of a statistical average over the slopes and over the heights.

Indicating with L_R and L_W the correlation lengths of the roughness due to rain and to the wind, respectively; we have $L_W >> L_R$. This stated, and assuming also the two random processes as statistically independent, we can express the total NRCS σ_S as the sum of two NRCS:

$$\sigma_S = \sigma_0 + \sigma_R \qquad (1)$$

where σ_0 is the NRCS contribution of the wind roughness perturbed by rainfall, computed as the statistical average over the slopes and over the heights, both related to the wind roughness. σ_R is the NRCS contribution due to rainfall, computed as the a statistical average over the slopes of the surface roughened by the wind. Under the hypothesis that the standard deviation h_R(rms) of the rain roughness is small respect to the e.m. wavelength, it is also possible to simplify the computation of σ_R using a small perturbation method in the local reference system, averaging then the results over the slopes of the roughness induced by wind.

It is worth noting that we used a Gaussian correlation coefficient for the rain roughness. That was a simplified assumption for a preliminary calculation, nevertheless we think that under the above hypotheses the shape of that correlation coefficient is not so important. Moreover, we have verified numerically that under the hypothesis $L_W >> L_R$ the results depend very slightly on the value of L_R.

NUMERICAL RESULTS

Some preliminary numerical results of the calculation of the NRCS are shown in the following for the frequency of 15 GHz. The wind speed is supposed to be 4.3 m/s as in [7]. Surface roughness due to rain is described in terms of standard deviation h_R(rms). Indeed, h_R is related to the rainfall rate R, nevertheless an accurate description of such relationship is not available in the literature. The relationship given in [4], for instance, is probably limited to that experimental case with that artificial rain. For this reason, we have simply chosen h_R as the parameter describing sea roughness and rainfall intensity.

Results reported in Figs. 1,2,3 have been obtained with a small perturbation solution for σ_R up to the first order, and those shown in Fig. 4 with a solution up to the second order. In Fig. 1 the VV component of the NRCS is plotted versus incidence angle in the absence of rain, and in the case of additional perturbation due to rain for different values h_R(rms) of the surface roughness. When increasing rainfall intensity (increasing h_R(rms)), an increase of the NRCS is correspondingly obtained; this phenomenon can be observed at all incidence angles ranging from 0° to 35°. In Fig. 2 the same comparative results are reported for the cross-polar component. It is interesting to notice from Fig. 2 that the crosspolar return behaves in an opposite way with respect to copolar returns: in fact, NRCS decreases as the standard deviation h_R(rms) increases, and the largest difference is obtained for incidence angles close to nadir. This result deserves some deeper analysis. However, if we keep in mind that the regions perpendicular to the incident field and that a slightly rough surface do not depolarise the e.m. return, such behaviour can be partially understood. In Fig. 3 the same comparison is shown for the HH component and for a wind speed of 15 m/s. It is important to observe that the rain perturbation is relevant also for higher wind speed. In Fig. 4 is shown a comparison between the NRCS calculated up to the first or up to the second order with a standard deviation of 2mm. The second order solution is recommended even for such small standard deviation, even if for a standard deviation of 1 mm the two solution are practically equal.

CONCLUSIONS

Severals models are developed in the literature to characterize the sea surface (roughed by wind) interaction with e.m. waves. In this paper a model that takes into account the additional surface roughness due to rainfall is considered in order to achieve a full polarimetric description of the radar return. Results can be utilised for rainfall rate retrieval or to overcome some of the inherent ambiguities associated with the retrieval algorithms. These preliminary results can already be useful for a more detailed characterisation of the sea surface return. Utilising the same approach a full polarimetric description of the sea radar return is obtained, that can be useful to evaluate performance of polarimetric filtering aiming at suppressing the sea echo from the composite return made up by the volumetric rain contribution added to the contribution of the sea surface. The

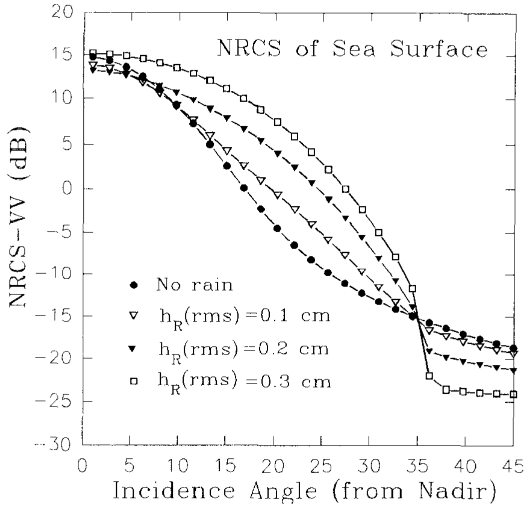

Fig. 1

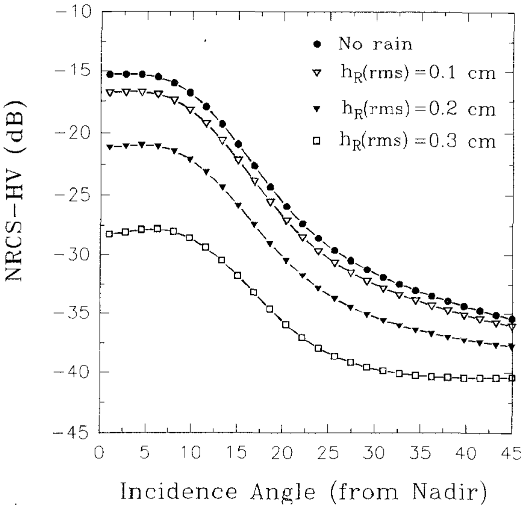

Fig. 2

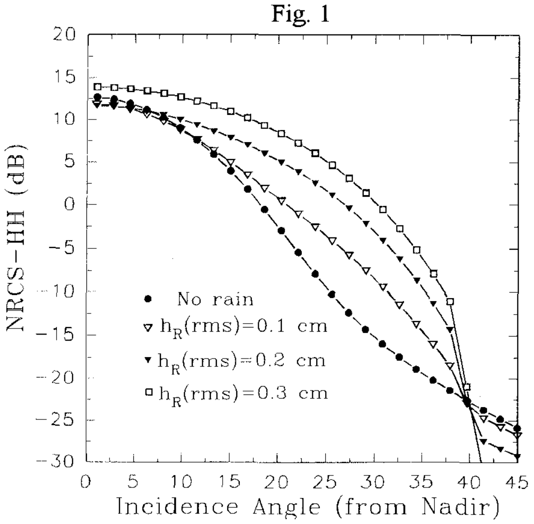

Fig. 3

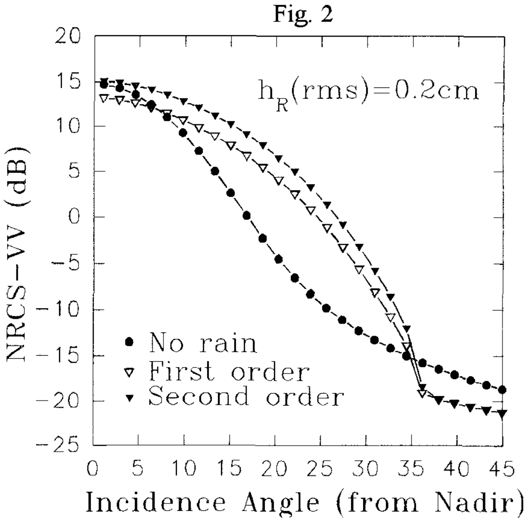

Fig. 4

same model and results can also be exploited to evaluate algorithms for scatterometer wind speed computation, in order to cancel the bias introduced by the rain roughness contribution.

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