CONTRIBUTION OF SMALL-SCALE CORRELATED FLUCTUATIONS OF MICROSTRUCTURAL PROPERTIES OF A SPATIALLY EXTENDED GEOPHYSICAL TARGET UNDER THE ASSESSMENT OF RADAR BACKSCATTER

Boris S. Yurchak
University of Maryland, GEST, MD 20771, USA-yurboris@umbc.edu

1. INTRODUCTION

The study of the collective effects of radar scattering from an aggregation of discrete scatterers randomly distributed in a space is important for better understanding the origin of the backscatter deviations from the theoretical models (e.g., [1, 2]). In the current paper we analyze a mechanism which can cause the backscatter to deviate from the classical (incoherent) estimate because of the collective effects in spatially extended geophysical targets (SEGT). Description of this mechanism is based on so-called "slice" approach firstly suggested for the meteorological SEGT (clouds, rain) in [3, 4], and enhanced by the author [5] for general SEGT (including thick snow cover), taking into account the statistics of its scattering properties. The approach exploits the partial coherence of the backscatter electric field from particles located close to the wavefront of the incident radar irradiance within a radial distance (Δ_s) much less than the radar wavelength (λ). The corresponded radar equation contains parameters that parameterize the irregularities of the SEGT's microstructure. Here we extend that parameterization with a correlative factor that describes the correlation between slices' reflectivity and, in particular, interprets an increase or decrease in the backscatter compared to the expected one for some cases.

2. RADAR CROSS SECTION OF THE SEGT IN A "SLICE" APPROACH

As the author showed [5], the mean volume component of the SEGT's specific radar cross section (RCS) is:

$$\langle \sigma_v \rangle = \langle \sigma_v \rangle_{class} \, devF(\xi_a, \chi) \tag{1}$$

where $\langle \sigma_v \rangle_{class}$ is the mean volume component of the specific RCS in the "classical" (incoherent) approach; and

$$devF(\xi_a, \chi) = \frac{\xi_a^2 + \chi}{\xi_a^2 + 1} \tag{2}$$

is the deviation factor, governed by the Poisson index $\chi = \frac{Var(n)}{\langle n \rangle}$, ($n$ is a random number of particles within a slice), and the variation coefficient of the particle radar equivalent length (PREL) $\xi_a = \frac{Stdev(a)}{\langle a \rangle}$ (PREL ≡ $a = \sqrt{\sigma}$; σ is the random RCS of an individual particle located within a slice). Although the deviation factor (2) describes the plus/minus deviations of the RCS from the classical one, there is also one more additional slice's statistics that can contributes in the backscatter as well.

3. VOLUMETRIC RCS TAKING INTO ACCOUNT THE CORRELATION BETWEEN SLICE SCATTERING PROPERTIES

Equation (1) has been derived in [5] under the assumption of delta-correlated fluctuations of a slice radar equivalent length (SREL) $b = \sum_{q=1}^{n} a_q$. In a general case the SRELs can be correlated due to finite b-disturbances spectrum with inner (l_0) and outer (L_0) scales. The slice size is assumed to be equal to the minimal scale of SREL's fluctuations l_0 (if $l_0 < \lambda$). Applying the methodology [5] and considering a medium with correlated fluctuations, it is possible to obtain a more comprehensive expression for the volumetric RCS:

$$\langle \sigma_v \rangle = \langle \sigma_v \rangle_{class} \cdot devF(\xi_a, \chi) \cdot corrF(\Delta_0) \tag{3}$$

where $corrF(\Delta_0)$ is the correlative factor and Δ_0 is the correlation radius. Assuming the radial distribution of the SREL within the scattering volume as a consequence of adjoining rectangular pulses of width Δ_s with the exponential correlation function $R(\Delta) = \exp\left(-\left|\Delta \cdot \Delta_0^{-1}\right|\right)$, the following expression can be derived for the correlative factor:

$$corrF = \left|\frac{\sin(k\Delta_s)}{k\Delta_s}\right|^2 \frac{1 - \exp\left(-2\frac{\Delta_s}{\Delta_0}\right)}{1 - 2\exp\left(-\frac{\Delta_s}{\Delta_0}\right) \cdot \cos(2k\Delta_s) + \exp\left(-2\frac{\Delta_s}{\Delta_0}\right)} \tag{4}$$

where $k = 2\pi\lambda^{-1}$ is the wavenumber of the incidence radar irradiance. In the case of atmospheric turbulence, $l_0 \approx \sqrt[4]{\nu^3/\varepsilon}$ (ν is the kinematic viscosity of air, and ε is the energy dissipation per unit of mass). The correlative factor for thin slices ($\Delta_s<\lambda/16$) and a small correlation radius (moderate and high turbulence) arises because of the small differences in the distance between slices, which cause a constructive interference, Fig.1.

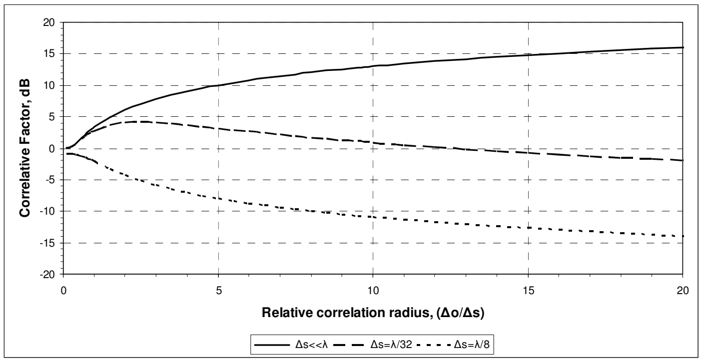

Fig.1. Correlative factor versus relative correlation radius (Δ_0/Δ_s) for different slice sizes. The upper curve is only a theoretical limit that never can be reached in practice because it relates to the infinitesimal scales of fluctuations, which cannot be less than the inner scale (l_0) of SREL's disturbances

Subsequent increases in the correlation interval causes the contribution of the destructive interference, which makes the backscatter decrease. P.L. Smith [4] predicted qualitatively this behavior based on the interference theory. With a slice size of ~$\lambda/8$ suggested in [6] (low turbulence), the correlative factor slows monotonously beginning at 0 dB; *CorrF*≈-10 dB at $\Delta_0 \approx \lambda$, for example. This value is close to the observable deviation of the backscatter from the atmospheric fog [6]. The arising feature of the correlative factor together with the probably high value of the Poisson index [7] can be applied for interpretation of the experimental data obtained during the radar probing of clouds accompanied with simultaneous measurements of the particle size spectra in situ [8]. In this experiment, the estimations of radar reflectivity based on the standard weather equation were found notably higher than expected values calculated according to the spectrometer data.

4. CONCLUDING REMARKS

The radar backscatter features have been considered within the frames of the slice approach taking into account the correlation between slice radar equivalent lengths. The correlation contribution has been evaluated based on the derived correlative factor. In particular, for a stochastic scattering medium with correlation radius less than the wavelength this factor describes the backscatter changes in accordance with an earlier proposed idea based on physics consideration. The slice approach allows interpreting the variety of radar backscatter deviations from the classical model based on the inventory of contribution of the statistical features of the fine-scale microstructural fluctuations. The SREL's statistics, commonly unknown for thick snow cover, should be investigated in future researches.

5. AKNOWLEDGEMENT

This work was supported by NASA's Cryospheric Science Program.

6. REFERENCES

[1] C.R. Noveltis, "Feasibility study of imaging the Antarctic ice using a spaceborne P-band radar," *Electromagnetic Model Review Document*, 2005. ESA Contract Number 18195/04/NL/CB. WP 200.

[2] J.R. Kendra, K. Sarabandi, and F.T. Ulaby, "Radar measurements of snow: experiment and analysis," *IEEE Trans. Geosci. Remote Sens*., vol. 36, no. 3, pp. 864-879, May 1998.

[3] J.S. Marshal and W. Hitschfeld, "Interpretation of the fluctuating echo from randomly distributed scatterers," *Can. J. Phys*., vol. 31, pt. I, pp. 962-994, 1953.

[4] P.L. Smith, Jr., "Scattering of microwave by cloud droplets," in *Proc. 11th Weather Radar Conf*., Sep. 14-18, 1964, pp. 202-207.

[5] B.S. Yurchak, "Radar volume backscatter from spatially extended geophysical targets in a "slice" approach, *IEEE Trans. Geosci. Remote Sens.*, vol.47, no 11, pp. 3690-3696, November 2009.

[6] K. Naito, and D. Atlas, "On microwave scatter by partially coherent clouds," in *Proc. 12th Weather Radar Conf*., Oct. 17-20, 1966, pp. 7-12.

[7] A. B. Kostinski and A. R. Jameson, "On the spatial distribution of cloud particles," *J. Atmos. Sci.,* vol. 57, no. 7, pp. 901-915, Apr. 2000.

[8] F. Pasqualucci, N.L. Abshire, R.B. Chadwick, and R.A. Kropfli, "Cloud observations during the Phoenix experiment," in *Proc. 19th Conf. Radar Meteorol*., April 15-18, 1980, pp. 715-117.