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

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ABSTRACT

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 from spatially extended geophysical targets (SEGT). We consider the microstructure irregularities of a SEGT as the essential factor that affect radar backscatter. To evaluate their contribution this study uses the "slice" approach: particles close to the front of incident radar wave are considered to reflect incident electromagnetic wave coherently. The radar equation for a SEGT is derived. The equation includes contributions to the total backscatter from correlated small-scale fluctuations of the slice's reflectivity. The correlation contribution changes in accordance with an earlier proposed idea by Smith (1964) based on physical consideration. The slice approach applied allows parameterizing the features of the SEGT's inhomogeneities.

Index Terms— Remote sensing, radar scattering

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) that is much less than the radar wavelength (λ). This fictitious thin volume is a "slice", Fig.1.
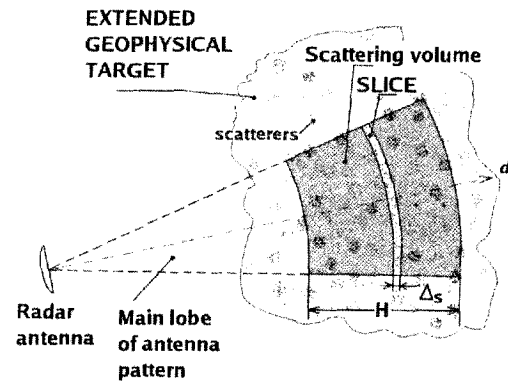

Fig.1. Simplified slice approach scheme. An arbitrary position of a single slice is shown. The scattering volume is shaded

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

The mean radar cross section (MRCS) of the volume component of the backscatter from SEGT under assumption of single scattering by individual particles has the follow general form:

$$\langle \sigma_\Sigma \rangle = \left\langle \left| \sum_{i=1}^{N} a_i \exp(-j2kd_i) \right|^2 \right\rangle \tag{1}$$

where $a = \sqrt{\sigma}$ is the "Particle Radar Equivalent Length" (PREL), σ is the random RCS of an individual particle, N is the total number of particles within the scattering volume, $k = 2\pi\lambda^{-1}$ is the wavenumber of the incidence radar

irradiance of the wavelength λ. Under a "slice" approach the instantaneous sum of PRELS of particles located close to the wavefront at the qth position and within the slice radial size $\Delta_s \ll \lambda$ can be represented as:

$$\sum_{i \in \{q\}} a_i^{(q)} \exp\left(-j2kd_i^{(q)}\right) = b_q \exp\left(-j2kd_q\right) \quad (2)$$

where $b_q = \sum_{i \in \{q\}} a_i^{(q)} = \sum_{i \in \{q\}}^{n_q} a_i^{(q)}$ is the "Slice Radar Equivalent Length" (SREL) which is the sum of all PRELs within a slice; n_q is a random number of particles inside a slice, and $d_q = q\Delta_s$ is a distance of qth slice from the border of the scattering volume nearest to the radar. Thus, the backscattering feature of the radar scattering volume can be represented as the series of $M = H / \Delta_s \gg 1$ adjoining "pulses" (slices) with random amplitude (b):

$$\langle \sigma_\Sigma \rangle = \left\langle \left| \sum_{q=1}^{M} b_q \exp\left(-j2kq\Delta_s\right) \right|^2 \right\rangle =$$
$$= \left\langle \left| \frac{1}{\Delta_s} \int_{-H/2}^{H/2} b(x)\exp\left(-j2kx\right)dx \right|^2 \right\rangle \quad (3)$$

The spatial distribution of the SREL along the radial direction $b(x)$ within the scattering volume can be represented as a sum of a quasi-regular component $b_0(x)$ and a small-scale (compared with the wavelength) fluctuating component $b_f(x)$ [6]:

$$b(x) = b_0(x) + b_f(x) \quad (4)$$

If assume that the process $b(x)$ is stationary, i.e., $\langle b_f(x) \rangle \approx 0$, $\int_{-H/2}^{H/2} b_0(x)\exp\left(-j2kx\right)dx \approx 0$, and $Var(b)$=const, it is possible to show [5] that MRCS can be expressed through the normalized correlation function $R(\zeta)$ of the fluctuating component of SREL:

$$\langle \sigma_\Sigma \rangle = \frac{Var(b)}{\Delta_s^2} \int_{-H/2}^{H/2} dx \int_{-H/2}^{H/2} dy \cdot R(x-y)\exp\left[-j2k(x-y)\right] \quad (5)$$

where $Var(b) = Var(a)\cdot\langle n\rangle + \langle a\rangle^2 \cdot Var(n)$ is the variation of SREL, expressing through the statistics of PREL and particle number within a slice basing on the known theorem about the variance of a sum of a variable number of variable values [7].

In the case of uncorrelated fluctuations of SREL, i.e., when

$$R(x-y) = \begin{cases} 1, & x-y=0 \\ 0, & x-y \neq 0 \end{cases} \quad (6)$$

it was shown by the author [5] that the MRCS is equal to:

$$\langle \sigma_\Sigma \rangle = \langle \sigma_\Sigma \rangle_{class} devF(\xi_a, \chi) \quad (7)$$

where $\langle \sigma_\Sigma \rangle_{class}$ is the MRCS in the "classical" (incoherent) approach; and

$$devF(\xi_a, \chi) = \frac{\xi_a^2 + \chi}{\xi_a^2 + 1} \quad (8)$$

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 by the variation coefficient of PREL $\xi_a = \frac{Stdev(a)}{\langle a\rangle}$. If the fluctuations of particle number is pertaining to the Poisson law when $\chi=1$, then for any ξ_a the deviation factor $devF=1$, and a classical result of incoherent approach takes place. The PREL variation coefficient (ξ_a) can be expressed through the parameters of the particle size distribution function (PSDF) [5]:

$$\xi_a = \xi_r^{-1/3} \frac{\sqrt{\xi_r^{-1} + 2Sk}}{\xi_r^{-3} + 3\xi_r^{-1} + Sk} \quad (9)$$

where $\xi_r = \frac{Stdev(r)}{\langle r\rangle}$ is the particle size variation coefficient, and Sk is the skewness coefficient.

Although the deviation factor (8) describes the plus/minus deviations of the MRCS from the classical one, there is also one more additional slice's statistics that can contributes in the backscatter as well.

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

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 $l_0 < \lambda$). In this case equation (5) can be written in the form:

$$\langle \sigma_\Sigma \rangle = \frac{Var(b)}{\Delta_s^2} H \int_{-H/2}^{H/2} d\Delta \left(1 - \frac{|\Delta|}{H}\right) R(\Delta)\exp\left(-j2k\Delta\right) \quad (10)$$

If assume that the correlation interval is much less than the radial size of the scattering volume, (10) can be reduced to:

$$\langle \sigma_\Sigma \rangle \approx \frac{Var(b)}{\Delta_s^2} H \int_{-H/2}^{H/2} d\Delta R(\Delta)\exp\left(-j2k\Delta\right) =$$
$$= M \cdot Var(b) \cdot corrF \quad (11)$$

where $corrF = \frac{1}{\Delta_s} F(\kappa)_{\kappa=2k}$ is the correlative factor of the normalized spectral function $F(\kappa)$. Since

$$M \cdot Var(b) = M \langle n\rangle \langle a\rangle^2 \left(\xi_a^2 + \chi\right) =$$
$$= N \langle a\rangle^2 \cdot devF \cdot \left(\xi_a^2 + 1\right) = \langle \sigma_\Sigma \rangle_{class} devF$$

the equation (11) can be represented in the form:

$$\langle \sigma_\Sigma \rangle = \langle \sigma_\Sigma \rangle_{class} \cdot devF \cdot corrF \quad (12)$$

Spectral function for process (3) is [8]:

$$F(\kappa)=\Delta_s^{-1}\left|F_s(\kappa,\Delta_s)\right|^2 \sum_{q=-\infty}^{q=\infty} R(q\Delta_s)\exp(jkq\Delta_s) \quad (13)$$

where $F_s(\kappa,\Delta_s)$ is the normalized spectral function of the typical "pulse" of SREL.

Assuming the radial distribution of 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:

$$corrF=\left|\frac{\sin(k\Delta_s)}{k\Delta_s}\right|^2 \frac{1-\exp\left(-2\frac{\Delta_s}{\Delta_0}\right)}{1-2\exp\left(-\frac{\Delta_s}{\Delta_0}\right)\cdot\cos(2k\Delta_s)+\exp\left(-2\frac{\Delta_s}{\Delta_0}\right)} \quad (14)$$

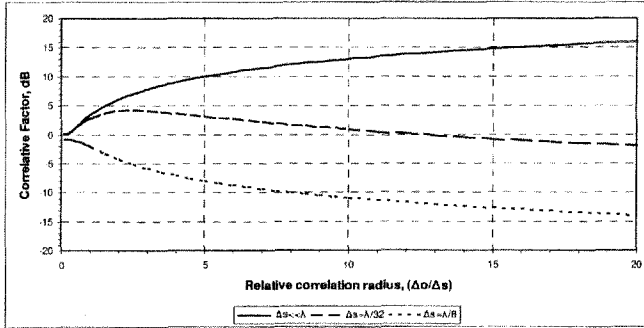The plot of (14) is depicted in Fig.2 for different ratios of (Δ_0/Δ_s).

Fig.2. Correlative factor versus relative correlation radius (Δ_0/Δ_s) for different slice sizes.

As follows from this plot the correlative factor for thin slices $(\Delta_s<\lambda/16)$ and a small correlation radius arises because of the small differences in the distance between slices, which cause a constructive interference. Since in the case of atmospheric turbulence, $\Delta_s=l_0\approx\sqrt[4]{v^3/\varepsilon}$ (v is the kinematic viscosity of air, and ε is the energy dissipation per unit of mass), this case corresponds to the moderate and high turbulence. 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 disturbance.

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; $CorrF\approx-10$ 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 [9] 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 [10]. 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 random scattering medium with correlation radius less than the wavelength this factor describes the backscatter changes in accordance with an earlier proposed idea based on physical consideration [4]. 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 statistics of a slice radar equivalent length (SREL), commonly unknown for spatially extended geophysical targets (SEGT), should be investigated in future researches. The correlative factor obtained together with the deviation factor [5] parameterizes the "rate of inhomogeneity" of a SEGT. The "classical" result (the total RCS is a sum of the RCSs of individual particles) takes place upon 2 conditions: (1) the fluctuations of particle number at small-scale should be pertaining to the Poisson law, and (2) SREL fluctuations should be not correlated. The assessment of these factors and conditions inherent to different kinds of a SEGT will improve the accuracy and reliability of the radar remote sensing.

5. AKNOWLEDGEMENT

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.W. Drake, Fundamentals of Applied Probability Theory. McGraw-Hill, New York, 1967.

[8] V.T. Goryainov, A.G. Zhuravlev, and V.I. Tikhonov. Staistical Radio Engineering: Examples and problems. Textbook, Sov. Radio, Moscow, 1980, 544 pp.

[9] 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.

[10] 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.

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

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Abstract: 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 spatially extended geophysical targets (SEGT). We consider the microstructure irregularities of a SEGT as the essential factor that affect radar backscatter. To evaluate their contribution this study uses the "slice" approach: particles close to the front of incident radar wave are considered to be approximately at the same distance from the radar. Therefore, these particles reflect incident electromagnetic wave coherently. Each slice is much narrower than the radar wavelength in the wave propagation direction. The radar equation for a SEGT, which is based on the slice model of backscatter volume, is derived. The equation includes contributions to the total backscatter from correlated small-scale fluctuations of the slice's reflectivity. The average power of an echo signal is proportional to the sixth power of the particles' size distribution function (classical case), only for the case of Poisson fluctuations of particle concentration within the slices and uncorrelated small-scale reflectivity fluctuations within a backscatter volume. The correlation contribution changes in accordance with an earlier proposed idea by Smith (1964) based on physical consideration. The slice approach applied allows parameterizing the features of the SEGT's inhomogeneities.

1. SLICE APPROACH

1.1. INITIAL CONDITIONS

The mean radar cross section (MRCS) of the volume component of backscatter from the Spatially Extended Geophysical Target (SEGT) is under consideration. The backscattering is assumed to be due the summation of single scattering by individual particles.

$$\langle \sigma_\Sigma \rangle = \left\langle \left| \sum_i^N a_i \exp(-j2kd_i) \right|^2 \right\rangle \quad (1.1)$$

where N is the total number of particles in the scattering volume, d_i is the distance of the ith particle center from the radar, $a_i \sim \sqrt{\sigma_i}$ is the "Particle Radar Equivalent Length" (PREL), σ_i is the radar cross section (RCS) of ith particle, and $k = 2\pi/\lambda$ is the wavenumber of the incidence radar irradiation with the wavelength equal to λ. The Rayleigh approach is assumed to be applicable to the individual scatterers, and, thus, the backscatter occurs with phase change only by $-\pi$. Attenuation within the scattering volume is ignored.

1.2. SEGT REPRESENTATION UNDER A "SLICE" APPROACH

The particles located close to the front of the incident radar wave are considered to be approximately the same distance from the radar, and they reflect the incident electromagnetic wave almost coherently (Marshall and Hitschfeld, 1953). One can consider that these particles are embedded in a fictitious thin volume (a "slice") with its base coincident with the surface of the spherical wavefront, bounded on the side by the main lobe of the antenna pattern, and radial length $\Delta_s \ll \lambda$. Fig. 1. Thus, the scattering volume with the radial size H can be represented by $M = H/\Delta_s \gg 1$ numbers of these slices adjoined.
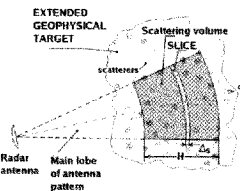
Fig 1. Simplified slice approach schema. An arbitrary position of a single slice is shown. The scattering volume is shaded

Taken into account (1.2), and the number of slices $M \gg 1$, the general equation (1.1) can be written in the integral form

The instantaneous sum of PRELs of particles located close to the wavefront at the qth position and within the slice radial size $\Delta_s \ll \lambda$ can be represented as

$$\sum_{i \in I_q} a_i^{(q)} \exp(-j2kd_i^{(q)}) = b_q \exp(-j2kd_q) \quad (1.2)$$

where

$$b_q = \sum_{i \in I_q} a_i^{(q)} = \sum_{i=1}^{n_q} a_i^{(q)} \quad (1.3)$$

is the "Slice Radar Equivalent Length" (SREL): the sum of all PRELs within a slice, n_q is a random number of particles inside a slice, and $d_q \sim q\Delta_s$ is a distance of qth slice to the radar. The slice size Δ_s can be assumed to be equal to the minimal scale of the SREL's fluctuations l_0. Thus, the backscattering feature of the radar scattering volume can be represented as series of M adjoining "pulses" with random amplitude b_q:

$$\langle \sigma_\Sigma \rangle = \left\langle \left| \sum_{q=1}^M b_q \exp(-j2kq\Delta_s) \right|^2 \right\rangle \quad (1.4)$$

$$\langle \sigma_\Sigma \rangle = \left\langle \left| \frac{1}{\Delta_s} \int_0^H b(x) \exp(-j2kx) dx \right|^2 \right\rangle \quad (1.5)$$

1.3. MRCS AS A FUNCTION OF THE SEGT's STATISTICS

The spatial distribution of SREL along the radial direction $b(x)$ within the scattering volume can be represented as a sum of a quasi-regular component $b_0(x)$ and a small-scale (compared with the wavelength) fluctuating component $b_f(x)$ [Naito & Atlas, 1966]

$$b(x) = b_0(x) + b_f(x) \quad (1.6)$$

For stationary $b(x)$ it is possible to show [Yurchak, 2009] that the MRCS can be expressed through the normalized correlation function $R(x)$ of the fluctuating component of SREL

$$\langle \sigma_\Sigma \rangle = \frac{Var(b)}{\Delta_s^2} \int_0^H dx \int_0^H dy \cdot R(x-y) \exp[-j2k(x-y)] \quad (1.7)$$

where

$$Var(b) = Var\left(\sum_{i=1}^n a_i\right) = Var(a) \cdot \langle n \rangle + \langle a \rangle^2 \cdot Var(n) \quad (1.8)$$

is the variance of a sum of a variable number of variable values [Drake, 1967].

2. UNCORRELATED SREL FLUCTUATIONS

If the fluctuations of SREL are uncorrelated, i.e.,

$$R(x-y) = \begin{cases} 1, & x-y=0 \\ 0, & x-y \neq 0 \end{cases} \quad (2.1)$$

it is possible to show [Yurchak, 2009] that:

$$\langle \sigma_\Sigma \rangle = N \left[Var(a) + \langle a \rangle^2 \chi \right] \quad (2.2)$$

where

$$\chi = \frac{Var(n)}{\langle n \rangle} \quad (2.3)$$

is the so-called Poisson index. If the fluctuation are in accordance with the Poisson law when $\chi = 1$, and taking into account known relationship $\langle a^2 \rangle = \langle a \rangle^2 + Var(a)$, one has a classical result of an incoherent approach

$$\langle \sigma_\Sigma \rangle = N \cdot \langle a^2 \rangle = N \cdot \langle \sigma \rangle \quad (2.4)$$

Basing on (2.2) and (2.4) the MRCS can be expressed through the deviation factor indicated the contribution of the SEGT's inhomogeneities

$$\langle \sigma_\Sigma \rangle = \langle \sigma_\Sigma \rangle_{class} devF(\xi_a, \chi) \quad (2.5)$$

where

$$devF(\xi_a, \chi) = \frac{\xi_a^2 + \chi}{\xi_a^2 + 1} \quad (2.6)$$
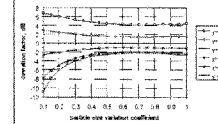
and $\xi_a = \frac{Stdev(a)}{\langle a \rangle}$ is the PREL variation coefficient. In turn, it can be expressed through the parameters of the particle size distribution function (PSDF) [Yurchak, 2009].

$$\xi_a = 3\xi_r \cdot \frac{\sqrt{\xi_r^2 + 2Sk}}{\xi_r^3 + 3\xi_r^2 + Sk} \quad (2.7)$$

where $\xi_r = \frac{Stdev(r)}{\langle r \rangle}$ is the particle size variation coefficient, and Sk is the skewness coefficient.

The deviation factor (2.6) is depicted in fig.2 for the Gamma PSDF (it is valid also for the lognormal PSDF).

Fig 2. Deviation factor versus particle radius variation coefficient for different deviations of Poisson index χ from the Poisson law.

References

Drake, A.W., 1967, Fundamentals of Applied Probability Theory. McGraw-Hill, New York

Goryainov, V.T., Zhuravlev, A.G., and V.I. Tikhonov, 1980. Statistical Radio Engineering. Examples and problems. Textbook, Sov. Radio, Moscow, 544 pp.

Levin, B.R., 1974. Theoretical Foundation of Statistical Radio Engineering, vol. 1, Sov.Radio, Moscow, 550 pp.

Marshall, J.S., Hitschfeld W., 1953. Interpretation of the fluctuating echo from randomly distributed scatterers. Part I, Canadian Journal of Physics, v.31, 962-994.

Naito, K., and D. Atlas, 1966. On microwave scatter by partially coherent clouds. In proc. 12th Weather Radar Conf., Oct. 17-20, 1966, pp. 7-12.

Smith, P.L., Jr., 1964. Scattering of microwave by cloud droplets. In proc. 11th Weather Radar Conf., Sep. 14-18, 1964, pp. 201-207.

Yurchak, B.S. 2009. Radar volume backscatter from spatially extended geophysical targets in a "slice" approach. IEEE Trans. Geosci. and Remote Sens., vol. 47, No.11, pp. 3690-3696.

3. CORRELATED SREL FLUCTUATIONS

If the fluctuations of SREL are correlated, equation (1.7) can be reduced to the form [e.g., Levin, 1974]:

$$\langle \sigma_\Sigma \rangle = \frac{Var(b)}{\Delta_s^2} H \int_{-H}^{H} d\Delta \left(1 - \frac{|\Delta|}{H}\right) R(\Delta) \exp(-j2k\Delta) \quad (3.1)$$

If assume that the correlation interval is much less than the radial size of the scattering volume, (3.1) can be reduced to

$$\langle \sigma_\Sigma \rangle = \frac{Var(b)}{\Delta_s^2} H \int_{-H}^{H} d\Delta \cdot R(\Delta) \exp(-j2k\Delta) = Var(b) \cdot M \cdot corrF \quad (3.2)$$

where $M = H/\Delta_s$, and $corrF = \frac{1}{\Delta_s} F(\kappa)\big|_{\kappa=2k}$ is the correlative factor of the normalized spectral function $F(\kappa)$

For process (1.4) one has [e.g., Goryainov et al., 1980]:

$$F(\kappa) = \frac{1}{\Delta_s} \left| F_s(\kappa, \Delta_s) \right|^2 \sum_{q=-\infty}^{\infty} R(q\Delta_s) \exp(j\kappa q\Delta_s) \quad (3.3)$$

where $F_s(\kappa, \Delta_s)$ is the normalized spectral function of the typical "pulse" of SREL. If assume the rectangular shape of the SREL's "pulses", then

$$F_s(\kappa, \Delta_s) = \Delta_s \sin\left(\frac{\kappa\Delta_s}{2}\right) \left(\frac{\kappa\Delta_s}{2}\right)^{-1} \quad (3.4)$$

For δ-correlated case (2.1), and taking into account that $\Delta_s \ll \lambda$, one has $F \approx 1$, and (3.2) coincides with (2.2). For the exponential correlation function $R(\Delta) = \exp(-|\Delta|/\Delta_s)$ where Δ_s is the correlation interval, the correlative factor can be obtained in the form (3.5) $\rightarrow$ (plot is in fig.3).

$$corrF = \left(\frac{\sin(k\Delta_s)}{k\Delta_s}\right)^2 \frac{1 - \exp\left(-2\frac{\Delta_s}{\Delta_o}\right)}{1 - 2\exp\left(-\frac{\Delta_s}{\Delta_o}\right)\cos(2k\Delta_s) + \exp\left(-2\frac{\Delta_s}{\Delta_o}\right)} \quad (3.5)$$
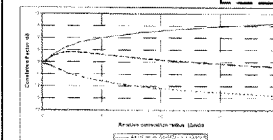
Fig 3. Correlative factor versus relative correlation radius for several selected slice sizes

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 can not be less than the inner scale (l_0) of the SREL's disturbances. In the case of atmospheric turbulence, $l_0 \sim \varepsilon^{-1/4}$ (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 small differences in the distance between slices, which cause a constructive interference. Subsequent increases in the correlation interval causes the contribution of the destructive interference, which makes the backscatter decrease. Smith (1964) predicted qualitatively this behavior based on the interference theory. With $\Delta_s \sim \lambda/8$ (suggested by Naito & Atlas, 1966) (low turbulence), the correlative factor slows monotonously beginning at 0 dB, and reaches a value of ~ -10 dB at $\Delta_o \approx \lambda$.

CONCLUDING REMARKS: Comparing (3.2) with the MRCS for the classical (incoherent) approach we find that the latter should be corrected by deviation (2.6) and the correlative (3.5) factors:

$$\langle \sigma_\Sigma \rangle = \langle \sigma_\Sigma \rangle_{class} devF(\xi_a, \chi) \cdot corrF(\Delta_s)$$

Thus, 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. In other words the factors obtained parameterize the "rate of inhomogeneity" of the Spatially Extended Geophysical Target. An assessment of these factors inherent to different kinds of a SEGT will improve the accuracy and reliability of the radar remote sensing.