Cross-section of coherent radar scattering from nonthermal plasma density fluctuations in the mid-latitude ionosphere

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Methods based on coherent radar scattering yield very important information about nonthermal plasma density fluctuations in the lower ionosphere at different latitudes. In particular the information is helpful for better understanding of the nature of the fluctuations. A noticeable role in producing the fluctuations below the homopause level belongs to neutral air turbulence. The turbulence is especially important in the case when development of plasma instabilities is difficult. A convenient value that describes the process of radio wave coherent scattering from plasma density fluctuations is an effective cross-section σ. An analytic formula of σ for the plasma fluctuations induced by the neutral turbulence is presented in the report. The formula is obtained with the use of the 3D fluctuation spectrum predicted by a quasi-neutral fluid theory of the fluctuations. Using the formula we estimated values of σ for a possible radar backscatter experiment in the case of plasma fluctuations near the 100-km altitude in the daytime and nighttime mid-latitude ionosphere (the magnetic dip angle of $45°$). The local values for the length-scale of the vertical plasma-density gradient L_N of about 7 km, and the average plasma density N_e of $2 \times 10^{10}\,\mathrm{m}^{-3}$ (plasma frequency $f_p \approx 1.27$ MHz) were chosen for the daytime ionosphere and $L_N \approx 3$ km, $N_e \approx 2\times10^9\,\mathrm{m}^{-3}$ ($f_p \approx 0.4$ MHz) at night. The ratio of the ion gyro-frequency to the ion-neutral collision frequency of about 0.035 and the mean rate of turbulent energy dissipation (the main parameter of neutral turbulence) of 0.1 $\mathrm{m}^2\,\mathrm{s}^{-3}$ were regarded as unchanged (from day to night) values. The calculations of σ were made for 10 fixed radar frequencies f_R from 5MHz to 50 MHz, and three possible directions of the antenna beam: (1) perpendicular to the geomagnetic field, (2) along the gradient in mean plasma density (vertical direction) and (3) along the magnetic field. It is shown that in general $\sigma_{\mathrm{day}} > \sigma_{\mathrm{night}}$, in addition the cross-section σ decreases with increasing the radar frequency and with deviation of the antenna beam from the perpendicular direction to the geomagnetic field. Under the daytime conditions σ was changed from about 2.2×10^{-10} to $4.2 \times 10^{-14}\,\mathrm{m}^{-1}$ at the radar frequency of 5 MHz and from about 7.4×10^{-16} to $1.4 \times 10^{-21}\,\mathrm{m}^{-1}$ at $f_R = 50$ MHz. At night σ was changed from 2.2×10^{-12} to $2.2 \times 10^{-15}\,\mathrm{m}^{-1}$ at $f_R = 5$ MHz and from 7.4×10^{-18} to $7.5 \times 10^{-23}\,\mathrm{m}^{-1}$ when $f_R = 50$ MHz. The maximum values of σ were for the case when the antenna beam is perpendicular to the geomagnetic field and the minimum ones for the beam direction along the field.