Multiple Scattering Effects in Ionospheric Radio Sounding

N. A. Zabotin* and J. W. Wright
Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado/NOAA, Boulder, Colorado, 80309-0216

We consider the problem of radio wave reflection from an optically thick, plane, monotonic layer of non-magnetoactive ionospheric plasma containing random field-aligned density irregularities, and investigate numerically the influence of multiple scattering on the averaged intensity and angular distribution of the received signal. Our approach uses a special form of the radiative transfer equation in invariant ray coordinates (Zabotin *et al*., *Waves in Random Media*, **8**, 421-436, 1998). The mid-latitude case is treated in some detail, but we also examine the principal effects of latitude dependence, which result from the varying aspect presented by elongated irregularities. In vertical sounding, multiple scattering in the ionospheric "mirror" produces a diffuse image of the radio point source, with a specific angular-spectrum structure. Three distinct maxima are present: A sharp central peak is oriented along the "magnetic" meridian plane. Laterally, two wider but weaker peaks are located symmetrically relative to the meridian. The effect may be called "astigmatism of the ionospheric mirror" and arise from the orientation of the irregularities.

The case of slightly oblique sounding is also considered. As the distance between transmitter and receiver increases, the side peak closer to the undisturbed angle of arrival gradually becomes dominant; the other one practically disappears, but the former central peak (radiating vertically to the receiver) continues to play a noticeable role. This characteristic two-maxima structure of the obliquely scattered signal may be described approximately in terms of double refraction in some effective medium. Note that this effect is not magnetoionic; it is caused by multiple scattering.

Earlier versions of the theory showed a strong anomalous-attenuation effect; this is now confirmed, with quantitative adjustments. For very typical irregularity-amplitudes in the range $0.002 < \Delta N / N < 0.01$ at the scale length 1 km our calculations produce integral attenuation of the signal intensity between 5 and 22 dB. A special calibration procedure permits estimation of anomalous attenuation in practical dynasonde measurements. We discuss the application of our results to explain the ionogram phenomenon of spread F.

Our results for the polar ionosphere produce a peculiar arc-like shape of the radio reflection. They resemble some optical images of the artificial aurora obtained during heating experiments in Tromsø (M. J. Kosch *et al*., *Proc. of the XXVIIth General Assembly of URSI*, *CD-ROM Edition*, Paper #1321, 2002). This suggests a common origin of the two phenomena, arising from multiple scattering of the heating signal within the ionospheric layer.