A ray-tracing model to account for off-great circle HF propagation over northerly paths

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Off-great circle HF propagation effects are a common feature of the northerly ionosphere (i.e. the sub-auroral trough region, the auroral zone and the polar cap). In addition to their importance in radiolocation applications where deviations from the great circle path may result in significant triangulation errors, they are also important in several other respects: (a) in systems employing directional antennas pointed along the great circle path the signal quality may be degraded at times when propagation is via off-great circle propagation modes, and (b) the off-great circle propagation mechanisms may result in propagation at times when the signal frequency exceeds the MUF along the great circle path.

A ray-tracing model covering the northerly ionosphere is described in this paper. The results obtained using the model are very reminiscent of the directional characteristics observed in various experimentalmeasurement programmes, and consequently it is believed that the model may be employed to enable the nature of off-great circle propagation effects to be estimated for paths which were not subject to experimental investigation. Although it is not possible to predict individual off-great circle propagation events, it is possible to predict the periods during which large deviations are likely, their magnitudes and directions.

azimuth deviations

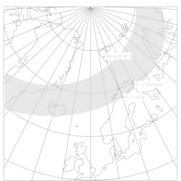

Fig.1 Map showing the Svalbard – Kiruna and Kirkenes – Kiruna paths.

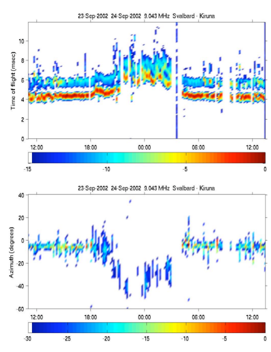

Fig.3 Time of flight (upper row) and azimuth deviations (bottom row) of the 9.04 MHz signal propagating along the Svalbard-Kiruna path.

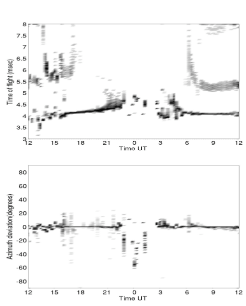

Fig.5 Simulated time of flight (upper row), and azimuth deviation (bottom row) signal propagating along Svalbard-Kiruna path.

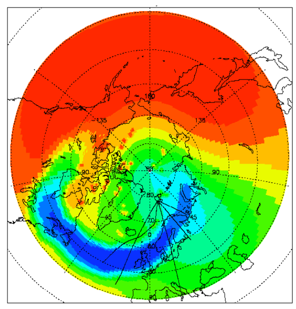

Fig.2 The electron density distributions inside the northerly ionosphere at a height of 300km.The mid-latitude trough and the F-layer patches are shown

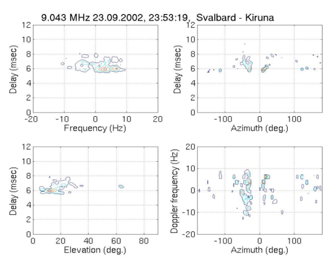

Fig. 4 Scattering function of the 9.04 MHz signal propagating along Svalbard Kiruna path.

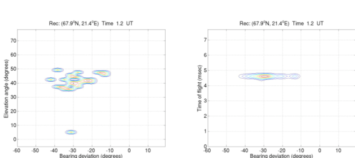

Fig.6 Simulated scattering function, corresponding Figure above

The ray-tracing program requires the electron density (***Ne***) profile and gradient of the refractive index to be continuous. It is convenient to approximate the electron density with analytical expressions that are amenable to mathematical manipulation. For this project, an adjustable model of the background ionosphere electron-density profile was constructed based on the data from vertical soundings.

An analytical approximation defining the location of the trough based on Halcrow and Nisbet model has been used. In the computational model of the auroral precipitations the southern border of the oval is detached from the northern wall of the mid-latitude trough at the value of the north wall scale of the trough.

A quasi-statistical approach has been adopted in modelling F-layer patches and arcs, in which their distributions inside the polar cap were determined by one of a number of different scenarios. The size of the region in which the patches and arcs were distributed is a function of *Kp*. The sun-aligned arcs move slowly across the polar cap in the direction of the IMF *By*, whilst the trajectories of the patches were adopted as a deformed ellipse, with parameters depending on the IMF. These trajectories resemble the convection flow patterns modelled by Lockwood (1993). The resulting electron density distribution is shown in Fig.2

The input parameters of the model are the DATE, operating FREQUENCY, the POSITIONS of the transmitter and receivers. The model allows the simulation of the time history of the direction of the arrival, the time of flight and the intensity of the received signal (see Fig.5). Also the model simulates the angle-delay scattering function shown in Fig.6.

In comparison with observations, the model was found to be capable of reproducing the main features of the directional characteristics of HF signal propagating in high latitude ionosphere. The measured time history of the time of flight and azimuth of arrival are shown in Fig. 3. Different scattering functions of the channel are shown in Fig.4

Further work is required directed towards additional measurements along the trough to investigate differences in the propagation characteristics between solar maximum and solar minimum, and development of the ray-tracing techniques, in particular to include for the prediction of the channel scattering function with Doppler - delay dispersions. A model of the irregularities in the scintillation zone must be developed