THE SIMULATION OF HIGH LATITIUDE OFF-GREAT CIRCLE PROPAGATION EFFECTS

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ABSTRACT

The effects of blobs and arcs in the polar cap ionosphere on the direction of arrival of HF radio signals have been simulated by means of ray tracing. The results of the simulation have confirmed that the presence of blobs and arcs can produce both directional effects and features on simulated ionograms with the precise character of those observed, and, importantly, will allow for the influence of the ionospheric effects on paths and frequencies other than those for which observations were made to be estimated.

INTRODUCTION

Observations over recent years have established that large scale electron density structures are a common feature of the polar cap F-region ionosphere. During periods of southward directed Interplanetary Magnetic Field (IMF) (Bz < 0) and the associated high levels of geomagnetic activity, patches of plasma 100-1000 km across with electron density enhancements of up to a factor of 10 above the background densities have been observed in the high latitude F-region ionosphere. These drift antisunwards across the central polar cap at velocities of a few kilometres per second in the high latitude convection current flows [1, 2]. When geomagnetic activity is low and the IMF is directed northward (approximately 50% of the time), Sun-Earth aligned arcs of plasma with electron density enhancements of a factor of 2-3 above the background can occur. These plasma striations are elongated for thousands of kilometres in the trans-polar noon-midnight direction but are much narrower (around 100 km) in the dawn-dusk direction. These features can persist for periods often in excess of one hour in the background F-region ionosphere [3] and have been found to be approximately twice as prevalent in the morning sector than in the evening sector [4]. They drift across the polar cap at velocities of a few hundred metres per second, generally in a duskward direction [2].

The electron density gradients associated with these large scale electron density structures form tilted reflection surfaces for HF radio waves which allow off great circle propagation paths to be established between the transmitter and the receiver. In order to investigate this type of propagation, a series of experiments [5] have been undertaken in which the bearings and signal characteristics of a number of HF transmissions were measured by means of a wide aperture goniometric direction finding (DF) system located at Alert in northern Canada. Large quasi-periodic bearing variations of up to ±100° from the great circle direction were observed which were attributed to reflection from arcs and blobs of enhanced electron density.

When ionospheric conditions support off-great circle propagation, considerable problems can arise in a number of HF systems. For example, in DF measurements large bearing errors occur resulting in significant errors in the estimates of the location of the transmitter of interest (often many hundreds or even thousands of kilometres). In communications links employing directional antennas, a reduction in received signal strength and SNR occurs since the signals no longer arrive along the direction of the main lobe of the antenna sensitivity pattern. Furthermore, off-great circle propagation often supports communications at times which are not predicted (i.e. when the signal frequency is above the predicted great circle MUF). In over-the-horizon (OTH) radar systems, large positional errors can occur.

In this paper, the preliminary results obtained from a ray tracing simulation of the directional effects of blobs and arcs on HF radio signals are presented.

RAY TRACING SIMULATION

The propagation of the HF radio signals in the high-latitude ionosphere has been simulated through the use of a numerical ray tracing code [6]. The background ionospheric electron density model consists of two Chapman layers, the main parameters of which (critical frequency, critical height, vertical scale height of each layer) are based on values obtained from the international reference ionosphere (IRI) [7]. Some approximation of the longitudinal and latitudinal electron density gradients based on the IRI parameters is necessary in order to improve computational speed. The localised, time varying, enhancements in the electron density which are then applied to the background model to represent the convecting patches and arcs are described below.

The shape of each sun-aligned arc is defined by a small number of three-dimensional Gaussian perturbations in electron density of different spatial scales (altitude, longitude and latitude) randomly distributed near to the centre of the arc. The latitudinal scale is significantly larger than the longitudinal scale to produce plasma strands elongated for several hundreds or thousands of kilometres. Many such arcs can be included in the simulation with their positions being randomly distributed in an area centred on the geomagnetic pole and bounded by the auroral oval. The magnitude of the electron density perturbation of each of the elements forming the arcs is randomly distributed about a specified average value. The temporal development of the structure relative to the propagation path is determined by rotation of the Earth beneath the arcs and movement of the arcs in the dawn-dusk direction.

Patches of enhanced electron density (blobs) associated with high geomagnetic activity are modelled as an arbitrary number of Gaussian distributions with approximately equal longitudinal and latitudinal scale. The temporal evolution of the blobs relative to the propagation path is simulated by means of a twin cell convection flow scheme coupled with the rotation of the Earth beneath the convection flow pattern. The precise form of the convection pattern depends on the value of the y component of the IMF (B_y).

The results of some typical simulations for the Iqaluit to Alert path are now presented. The variations in direction of arrival resulting from the presence of sun-aligned arcs are shown in Fig.1. Large (±40°) positive bearing swings are apparent which are reminiscent of observations [5]. The model also enables ionograms to be simulated, an example of which is presented in Fig.2. Reflections from the background ionosphere can be observed at delays below 1 ms and frequencies below about 10 MHz. The striking features present at frequencies above 10 MHz with fixed delays are similar to those observed experimentally. Two examples of the azimuth deviations produced by the presence of blobs are given in Fig.3. As before, large bearing deviations are evident but it is clear that the nature of the deviations varies with time and is also dependent upon the convection flow pattern (and hence the value of B_y). An ionogram simulated for an ionosphere where enhanced patches were present is given in Fig.4. An example of an maximum useable frequency (MUF) 'nose extension' (i.e. the feature which, in the left-hand panel, is present at frequencies higher than about 6.5 MHz), which are often seen in experimental observations, is clearly present in the simulated ionogram. Good agreement has been obtained between the character of the simulated ionograms and bearing deviations and the experimental measurements [5]. However, given the nature of the polar cap ionosphere, a precise agreement between experiment and simulation should not be expected.

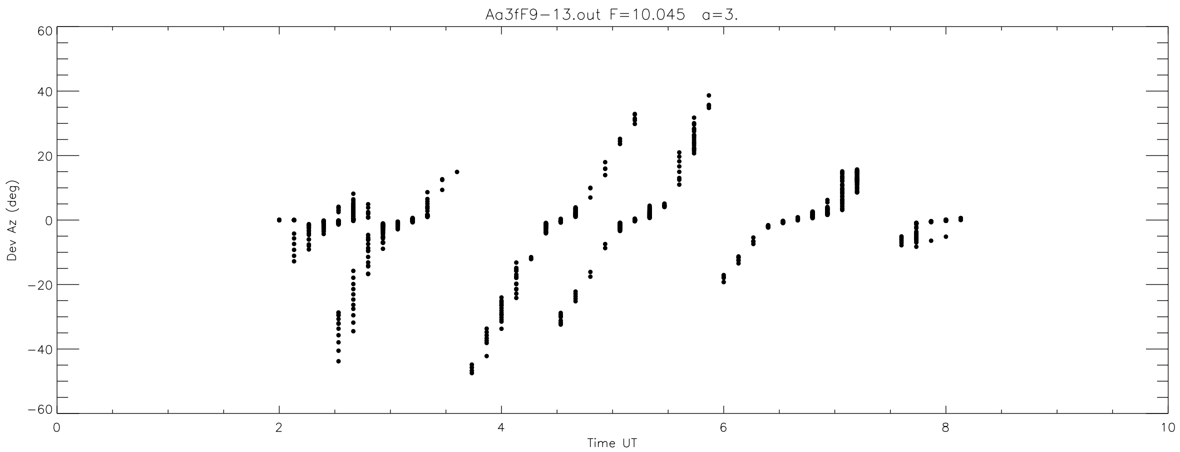

Fig. 1. Time history of the direction of arrival (azimuth only) of a 10.45 MHz signal propagating through a model ionosphere containing arcs of enhanced electron density.

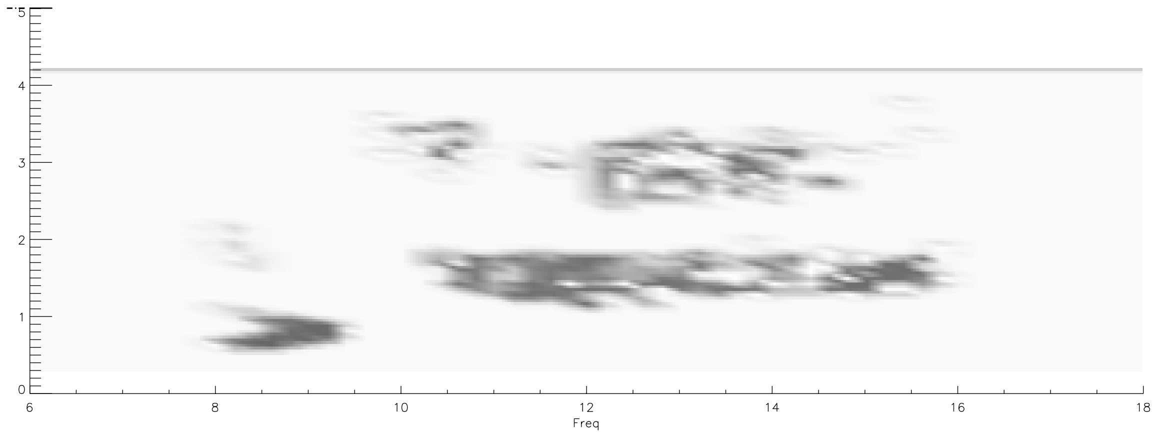

Fig. 2. Ionogram produced by ray tracing simulations through an ionosphere containing arcs of enhanced electron density.

CONCLUDING REMARKS

A wealth of knowledge resulted from the investigations into gross deviations from the great circle path (GCP) outlined in [5]. The magnitude and variances of the deviations from the GCP have been quantified and the associated geophysical conditions and signal characteristics identified. Research is currently being undertaken aimed at incorporating the knowledge gained from the experiments into techniques that will be of direct operational application. The main activities in this area include the development of ionospheric models coupled with ray tracing studies (some preliminary results of which were presented here) both to confirm the cause of the large bearing deviations and to assess the impact of the presence of the high latitude ionospheric features causing the deviations on paths other than those subjected to experimental investigation. Following on from this work, a set of rules (a ‘rule-base’) will be developed through which the influence of the off-great circle propagation mechanisms on specified communications links, radiolocation systems and OTH radars may be estimated. The rule base will then be the incorporated into computer code and its integration with various prediction codes currently in use to allow proper consideration to be given to the off-great circle propagation mechanisms.

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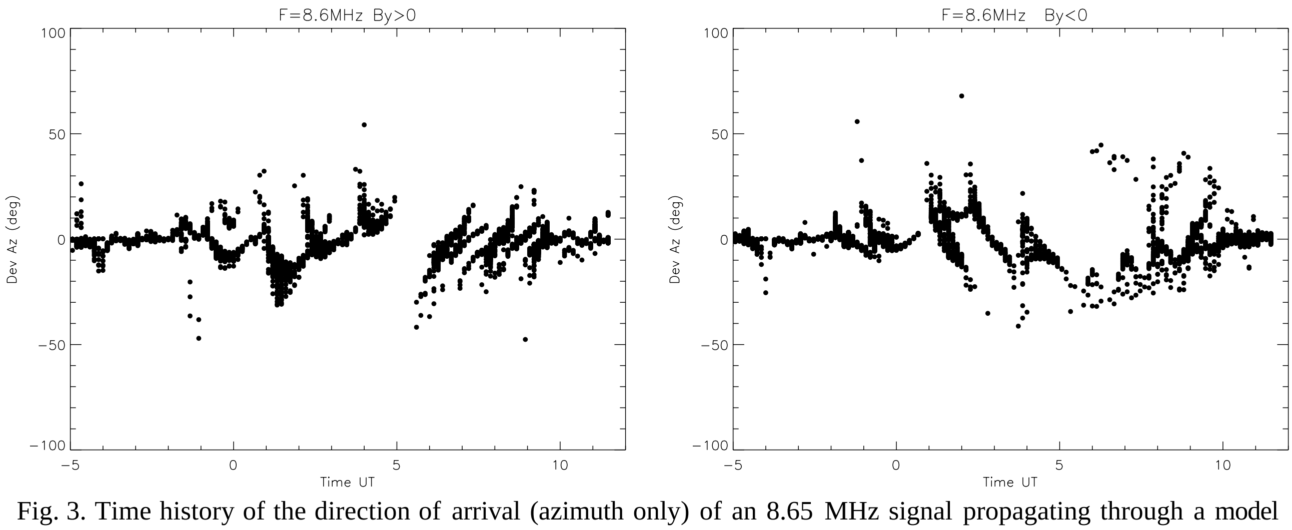

Fig. 3. Time history of the direction of arrival (azimuth only) of an 8.65 MHz signal propagating through a model ionosphere containing patches of enhanced electron density for (left panel) positive B_y, and (right panel) negative B_y.

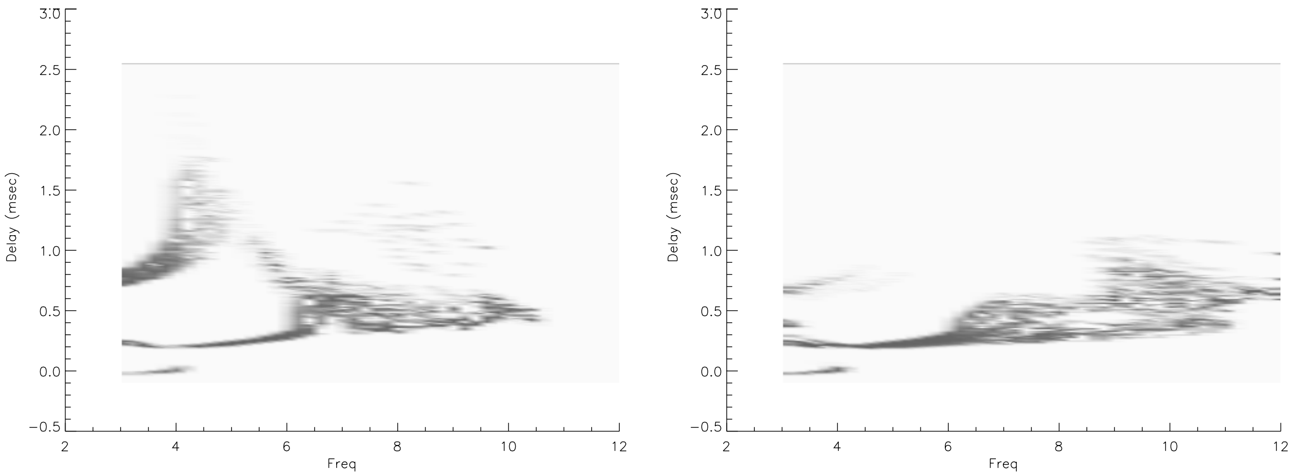

Fig. 4. Ionograms produced by ray tracing simulations through an ionosphere containing patches of enhanced electron density with, (left panel) positive B_y, and (right panel) negative B_y.

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