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Multi-beam sounding ionograms in the polar cap region: Absorption induced by proton precipitations

E.V. Moskaleva *, N.Y. Zaalov

University of Saint Petersburg, Saint Petersburg, Russia

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Abstract

The simulation of the multi-beam ionograms in the polar cap region, assessing absorption effect is performed. It is reasonable to distinguish among four different mechanisms responsible for absorption: regular absorption due to solar UV illumination, absorption associated with energetic particles precipitation, absorption connected with X-rays flare and additional absorption in Auroral oval area. In this paper the absorption attributed to proton precipitations is envisaged. The computational model of the high-latitude ionosphere with irregularities oriented to application for the high frequency wave propagation problem was elaborated (Zaalov et al., 2005). A number of the quasi-vertical ionograms in the polar cap region were simulated on the basis of this model. A well-known algorithm (Sauer and Wilkinson, 2008) is applied for the absorption effects calculation. The simulated high-latitude ionograms with the absorption effect and the measured ionograms exhibit quite a good resemblance. This paper illustrates the importance of the understanding and taking into account the absorption effect in the presence of the various structural features in the polar ionosphere (in particular, patches of enhanced electron density) in interpreting ionosonde data.

Keywords: Propagation HF waves; Ionogram; Polar cap

1. Introduction

The high-latitude ionosphere structure is quite complicated and, generally, is different from the structure of the mid-latitude ionosphere. The presence of the localized regions of enhanced electron density in the F2 region (patches and arcs) is responsible for the complexity and variability of the high-latitude ionosphere structure. The morphology of the polar cap region of the ionosphere is strongly dependent on the interplanetary magnetic field (IMF) and the level of geomagnetic activity. In general, as the geomagnetic activity increases, the size of the polar cap tends to increase and the Auroral oval moves equatorwards. Patches are formed in the dayside Auroral oval and drift in an anti-sunward direction across the polar cap with the speeds of a few hundred meters per second into the night side Auroral oval (Weber et al., 1989; Ma and Schunk, 1997), whereas arcs occur under different geomagnetic conditions and move in a duskwards direction. The size of the patches typically is 200–1000 km in horizontal directions. The electron-density enhancements in the patch exhibit up to a factor of 10 above background (McEwen and Harris, 1996; McDougall et al., 1996).

This change in the morphology of the high-latitude ionosphere can impact on the characteristics of the signals received after propagation through these regions of the ionosphere. Due to the presence of the gradients in the high latitude ionospheric electron density distribution, high frequency (HF) radio signals often arrive at the receiver over paths well displaced from the great circle path (GCP). These large deviations from the GCP in the polar cap

* Corresponding author.
E-mail address: moelvi@mail.ru (E.V. Moskaleva).

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region (with bearings up to ±100° or more) are attributed to the presence of convecting patches and arcs of enhanced electron density (Warrington et al., 1997).

The proton precipitation into the Earth's atmosphere produce significant enhancement in the D-region ionosphere electron density. These electron density enhancements are responsible for an increase in the attenuation of electromagnetic waves being propagated through the ionosphere (non-deviative absorption). In extreme cases the ionosphere may be rendered opaque to HF communication.

The absorption effect caused by proton precipitation is frequently observed in the high latitude of the ionosphere and it is an important factor for formation of the high latitude ionogram structure. It leads to additional complexity in interpretation of the sounding data. The absorption effect attributed to proton precipitation is discussed in this paper. Absorption effect itself is taken into account outside the ray-tracing procedure. The algorithm (Sauer and Wilkinson, 2008) is applied for calculation of non-deviative absorption.

2. Simulation

At present, a number of different models of ionosphere are available. The majority of the existing models are able to describe with sufficient accuracy the mid-latitude ionosphere, while the models of the polar cap region ionosphere are not reliable.

In our background ionosphere model the main E, F1 and F2 layers parameters (critical frequencies, maximum height, half-thickness of the layer) were retrieved from vertical sounding data [http://spidr.ngdc.noaa.gov/spidr/index.html] in order to describe the day-to-day variations of the real ionosphere.

The ray-tracing program (Jones and Stephenson, 1975) is applied to define the mode structure of the propagating signal. Fortran code ray-tracing procedure enables to calculate group and phase path length, geometrical path length for each path. The analytical approximations were made to the longitudinal and latitudinal gradients of electron density because ray-tracing method require continuous refraction index with its derivatives. Further developments of the ray-tracing simulations have included incorporating intelligent 'homing' algorithms into the software to improve processing speed. Another improvement was implemented into the ray-tracing code, where the set of the emitting rays corresponding to any frequency (except for the first) depends on the set of the rays reaching the receiver at previous frequency.

Patches of enhanced electron density associated with high geomagnetic activity are modeled as an arbitrary number of Gaussian distributions with approximately equal longitudinal and latitudinal scale. The temporal evolution of the patches relative to the propagation path is simulated by means of a convection flow scheme coupled with the rotation of the Earth beneath the convection pattern, the precise form of which depends upon the components of the IMF. Intensity of the patches and their spatial scale in both horizontal directions also depend on the time. In practice, the shape, size and number of patches in the convection flow area depend upon many geophysical parameters, not only upon the instantaneous values but also upon their history. A quasi-statistical approach has been adopted in modeling F2-layer patches. Their distributions inside the polar cap were defined by one of a number of different scenarios (set of the parameters of the patches: initial distribution, shape, size, internal structure, speed and number of the patches). This model of the high-latitude ionosphere and 'homing' algorithm details are described in (Zaalov et al., 2005).

The model of the ionosphere is illustrated in Fig. 1 for 23 October 2011, 14:30 UT. The distribution of the plasma frequencies in MHz at the height of 220 km is shown by the gray-scale. Daily average Kp index was 1, sun spot number was 164, the Bz component of the IMF was about −3 nT [http://omniweb.gsfc.nasa.gov].

The assumption that only small number of the patches localized in the vicinity of the sounder can affect on ionogram structure was made in this paper. Consequently, the scenario with a single patch was used in simulations. The intensity of the patches, their size and shape were varied in the simulations. The structure of the ionograms is defined by the choice of the scenario corresponding to the specific set of parameters. In this paper the estimation of the absorption effect in the simulation of the HF wave propagation is performed using a rather simple, but versatile method, which allows including into the model a number of different absorption mechanism. At first, the mode structure of the receiving signal (without absorption effect) is defined by Fortran code ray-tracing procedure in the frame of the model mentioned above (Zaalov et al., 2005). The next step is the recalculation (in MatLab environment) of the signal strength at the receiving point in accordance with the absorption model. The four different mechanisms of the absorption are relevant to differentiate: absorption due to Ultra-Violet (UV) illumination of the Sun, absorption due to X-ray flux events, absorption caused by the proton precipitations in polar cap region and additional absorption in Auroral oval area. In this paper Polar Cap Absorption (PCA) i.e. absorption effect attributed to proton precipitations and regular absorption caused by UV illumination of the Sun is explored. The algorithm presented by *Sauer and Wilkinson* was used for the estimation PCA.

According to this model (Sauer and Wilkinson, 2008) the daytime and nighttime absorption in polar cap region at the fixed frequency 30 MHz is defined by the integral flux of protons above certain energy thresholds. Solar elevation angle greater than 10° corresponds to day condition, smaller than -10° to night condition. Bilinear interpolation is applied for the twilight zone between these bounds. The influence of the geophysical conditions (Kp index) on the extension of the PCA region is determined by the model