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A polar cap absorption model optimization based on the vertical ionograms analysis

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Abstract

Space weather events significantly affect the high frequency (HF) radio wave propagation. The now-casting and forecasting of HF radio wave absorption is important for the HF communication industries. This paper assimilates vertical sounding data into an absorption model to improve its performance as a now-casting tool. The approach is a modification of the algorithm elaborated by Sauer and Wilkinson, which is based on the riometer data. The optimization is focused on accounting for short timescale variation of the absorption. It should be noted that the expression of the frequency dependence of absorption induced by the energetic particle precipitation employed in Sauer and Wilkinson model is based on the riometer data at frequencies of 20, 30, and 50 MHz. The approach suggested in this paper provides an opportunity for expanding the frequency dependence of the absorption for frequencies below 10 MHz. The simulation of the vertical ionograms in the polar cap region uses a computational model designed to overcome the high frequency wave propagation problem in high latitude of the Earth. HF radio wave absorption induced by solar UV illumination, X-ray flares and energetic particles precipitation is taken into consideration in our model. The absorption caused by the energetic particle precipitation is emphasized, because the study is focused on HF wave propagation in polar cap region. A comparison of observed and simulated vertical ionograms enables the coefficients, which relate absorption (day-time and night-time) to integral proton flux to be refined. The values of these coefficients determined from evaluation of the data recorded by any reliable ionosonde are valid for absorption calculation in high-latitude region.

Keywords: Propagation HF waves; Vertical ionogram; Absorption; Polar cap

1. Introduction

HF radio propagation strongly depends on the wave absorption caused by space weather events. A large amount of the attenuation of ionospheric HF radio signals is caused by non-deviative absorption in the D-region of the ionosphere. It is obvious that the electron density enhancements in solar events are responsible for an increase in the electromagnetic wave absorption (especially non-deviative absorption).

The total electron density in the D-region ionosphere is defined by the regular solar UV illumination, X-rays flares and energetic particle precipitation. In the polar cap region the dominating contribution to the electron density enhancements is associated with the energetic particle precipitation. The models of absorption due to different factors are available via Internet. The well-known D-Region Absorption Prediction model (D-RAP) (SPACE WEATHER PREDICTION CENTER http://www.swpc.noaa.gov) includes the empirical models of HF radio wave absorption in D-region induced by X-rays and solar energetic proton precipitation. These empirical models are based on the riometer data (typically at a frequency of about 30 MHz). The D-RAP models

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were validated using the riometer observations from six high- to mid-latitude stations operated at frequencies about 30 and 32.4 MHz [https://www.ngdc.noaa.gov/stp/drap/DRAP-V-Report1.pdf].

The application of the riometer data to the development of the absorption model has some constraints. As a rule, riometers use a fixed frequency (typically about 30 MHz) that results in difficulties in defining the frequency dependence of the absorption. The D-RAP model employs an algorithm related to HF radio wave absorption induced by solar energetic proton precipitation elaborated by Sauer and Wilkinson (2008). In this algorithm the frequency dependence of the absorption is based on the studies performed by Parthasarathy et al. (1963) and Patterson et al. (2001). The riometer data at the frequencies 10, 30 and 50 MHz (Parthasarathy et al., 1963) and at 20, 30, 38 and 51 MHz (Patterson et al., 2001) were examined. The frequencies between 1 and 10 MHz are not covered in these studies, though this range is essential for the modeling of the high-latitude ionosphere and HF channel.

It should be noted that the processing of the riometer data does not distinguish the O and X-mode (left-hand and right-hand wave polarizations) of propagation. As a result the difference in the absorption of the O and X-mode of propagation in D-RAP model is not included. At frequencies about 30 MHz, taking into account the magneto-ionic splitting is not essential. However, the effect of the magneto-ionic splitting on the absorption at the frequencies below 10 MHz is significant.

It is also relevant to note that the algorithm by Sauer and Wilkinson (2008) was based on empirical expressions for absorption as a function of the proton flux. This relationship was acquired from analysis of the riometer observations from Thule operated at frequency 30 MHz (Sellers et al., 1977). It is evident that the formulae for absorption are retrieved from averaging data for a rather long period and are not capable of reflecting variation in geophysical conditions. The optimization of the absorption coefficients is a simple technique to find the correlation between the amount of absorption and the geophysical conditions. It should be noted that an impressive method of the optimization using the riometer data was suggested by Rogers and Honary (2015). In any case, the correction and upgrading of the D-RAP model are required for the modeling of the high-latitude ionosphere and HF channel at frequency range below 10 MHz.

The analysis of the vertical and oblique ionograms is an accessible and effective method for the study of the absorption in the frequency range from 1 to 30 MHz. Typically the vertical sounding data provide the power of the received signal in the frequencies range from 1 to 10 MHz and oblique sounding data from 1 to 30 MHz. The ionogram structure (the lowest observed frequency and number of the hop traces) critically depends on the absorption. The simulation and analysis of the vertical and oblique ionograms can expand the frequency range of the absorption model.

In this paper an expression for frequency dependence of the absorption due to proton precipitation is derived from analysis of the vertical ionograms. The method of the absorption model (Sauer and Wilkinson, 2008) parameters optimization on the basis of ionogram analysis is suggested in this study. The comparison between simulated vertical ionograms and ionosonde data allows the absorption coefficients related to integral proton flux to be redefined. The values of coefficient determined from data corresponding to any specified, reliable ionosonde are suitable for ionogram simulation at any other site that is feasible to model HF channel properly.

2. An approach to the simulation

It is necessary note that approach described in this paper is a combination of fmin method (more exactly, A1 method based on ground-based vertical sounding, (Rawer, 1976)), D-RAP model and high-latitude ionosphere and HF channel model. The lowest frequency (fmin) is the frequency at which echo traces are observed on the ionogram. Usually, these values obtained from ionograms after scaling the traces. Under certain circumstances fmin, which is routinely measured, can work as a qualitatively assessment of the ionospheric absorption.

In general, it is difficult to interpret fmin as an estimation of the ionospheric absorption quantitatively, as it is strongly affected by local radio wave interference and characteristics of the recording system. As result, fmin is not an absolute value (as for example foF2) and comparison between stations, therefore, can be only qualitative. Another serious limitation on the using of fmin as an index of absorption is imposed by the interference with the strong middle wave (MW) signals from the broadcasting station. The signal-to-noise ratio varies depending on frequency and affects the level of the automatic gain control at the receiving site and as result fmin value. To compensate the technique errors the difference between daily mean and daily median fmin values could be calculated (Vergasova and Kazimirovsky, 1996). However, the difficulties related to the implementation of the A1 method impede the performance of similar measurements.

It is helpful to use fmin2, which is defined as the minimum frequency of the second order trace. Because the absorption loss in dB is twice as great for the second order trace as for the first, fmin2 is more sensitive to absorption changes and less to equipment design than fmin. The straightforward next step is taking into account all information containing in ionograms: fmin corresponding next order traces, and echo amplitudes, i.e. whole ionogram structure.

It is clear that in the case of absorption accounting for, the energy characteristics calculation is an important component of HF propagation and proper ionogram interpretation. Currently, the Global Ionospheric Radio Observatory (GIRO http://giro.uml.edu) provides accurate specification of electron density in the Earth's ionosphere