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Simplified empirical model of the auroral D region for the international reference ionosphere

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Abstract

The results published by the author earlier are developed to create an empirical model of the D region within the auroral oval using the rocket measurements of the electron concentrations at high-latitude rocket sites both in the Southern and Northern Hemispheres. To describe the magnetic disturbance degree the daily sum of the 3-h Kp indices is used. The input parameters for the model at each height are the solar zenith angle and the daily sum of Kp. The empirical formulae describing the [*e*] behavior are derived, approximations of the coefficients involved are obtained both in the analytical and digital form and the Fortran programs for electron concentration computation are written.

Keywords: Auroral oval; D region; Electron concentration; Empirical modeling

1. Introduction

The state of the polar (and especially, auroral) lower ionosphere influence significantly the absorption of HF radio waves. So it is important for radiocommunication purposes to know (at least approximately) the state of the auroral lower ionosphere (the D region) where the absorption of radio waves at radio paths crossing the polar region occurs.

There have been attempts to create a model of the electron concentration in the D region. There are specific difficulties in this problem related mainly to the different methods of electron concentration measurements and to a rather complicated photochemistry of the region. However, any review of these problems is out of the scope of this paper. We mention only a series of publications by M. Friedrich and his colleagues (Friedrich and Kirkwood, 2000; Friedrich and Torkar, 1983, 2001; Friedrich et al., 1995) and their attempt to create a model of the auroral D region using both their own rocket measurements by the Faradey rotation method and the results of the EISCAT measurements (Friedrich et al., 2004a,b; McKinnell et al., 2004).

This work was aimed at creation of rather simple model of the auroral D region capable to provide a vertical distribution of the electron concentration in the D region, not very precise but useful for estimations of the HF radio wave absorption conditions at the corresponding radio paths. To describe the geomagnetic situation a very simple index was chosen: the daily sum of the 3-h Kp indices for the given calendar day (designated as SKp) (see below). The author hopes that such a model may be incorporated into the International Reference Ionosphere (IRI) and be useful for the customers needing a simple quick evaluation of the D-region state in the auroral D region for radiocommunication purposes.

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2. Creation of the models

The model should have been created on the basis of the rocket measurements only. Preliminary studies of the approaches to the data analysis: choice of the indices to characterize geomagnetic conditions, the choice of the input parameters etc. have been earlier published by the author and his colleagues in a series of papers (Danilov, 2000; Danilov and Vanina, 2000, 2001; Danilov et al., 2000, 2001, 2002, 2003; and Vanina and Danilov, 1998).

Initially it was planned to try to combine the available results of the rocket measurements of [e] at five rocket sites located in the auroral zone: Andoya, Kiruna, Heiss Island, Molodezhnaya, and Syowa, the three former and two latter being located in the Northern and Southern Hemisphere, respectively. However in the process of the work it became clear that the Andoya and Kiruna data should be considered jointly as one observation point because of their close location. Attempts to use the Heiss Island data failed, because the station during the day shifts from one zone of the polar ionosphere to another (auroral zone, polar cap, subauroral zone, see Tulinov et al. (1975)) and the position of the station depends on local time and the degree and character of the geomagnetic disturbance. The number of flights at Syowa appeared to be too small for attempting to create a separate model, so the data of this station were used only for comparison with the created models (see below). Thus finally two stations were considered for the modeling: Molodezhnaya (M) and Andoya/Kiruna (AK). Actually (as it will be seen below) two models are created, which may be considered separately for each station or in some cases combined.

2.1. Creation of the model for Molodezhnaya station

Two-hundred and seventy-two rocket measurements were used in the creation of the model. The detailed information on the rocket flights, method of measurements and the database obtained may be found in the earlier publications (Vanina and Danilov, 1998; Danilov and Vanina, 2000, 2001). With the experience of looking for the [e] dependence on various parameters (see Danilov, 2000; Danilov et al., 2001; and Danilov et al., 2002) the modeled electron concentration at a fixed height was written in the form

$$\lg[e](\mathrm{mod}) = \lg[e](0) + k(z)\mathrm{SKp}\,g(\mathrm{SKp}), \quad (1)$$

where $k(z)$ describes different sensitivity of [e] to changes in SKp at different solar zenith angles z,

$$k(z) = a_1 + b_1 z \quad (2)$$

and g(SKp) determines a nonlinear character of the [e] dependence on SKp,

$$g(\mathrm{SKp}) = a_2 \lg(\mathrm{SKp}) + b_2. \quad (3)$$

lg[e](0) is the electron concentration under SKp = 0. It is more or less close to the lower envelopes of [e] published earlier (see Fig. 1). The value of lg[e](0) is constant for the given height for $z > 99°$ (nonsunlit conditions). For sunlit conditions ($z < 100°$)

$$\lg[e](0) = -a_3 z + b_3, \quad (4)$$

where a_1–a_3 and b_1–b_3 are the parameters of the model. They have been found separately to different conditions (altitude, sunlit, nonsunlit) and now may be used to calculate lg[e](mod) for any given z and SKp.

Due to the specifics of the measurements at Molodezhnaya the above procedure was possible only for three fixed heights: 75, 80, and 85 km. Though the height interval considered is narrow enough, the most part of the absorption of HF radio waves occurs there, because there is located a maximum of the effective electron collision frequency.

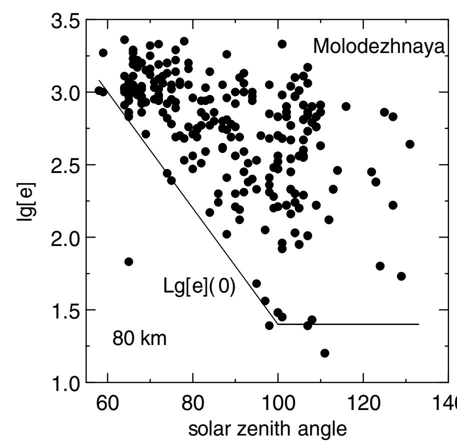

Fig. 1. Electron concentration dependence on the solar zenith angle: points are results of rocket measurements, lines show the lower envelope taken as lg[e](0) in the model.

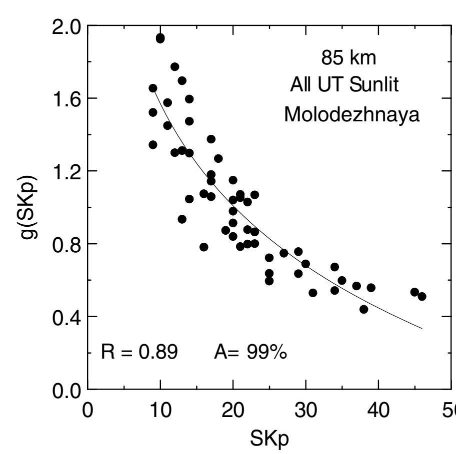

Fig. 2. Example of g(SKp) dependence on SKp for Molodezhnaya: points present the second step of the iteration process, the line show the approximation. R is the coefficient of determination and A is the significance level according to the Fisher criterion.