Dynamics of the Auroral $Es$ Layer during Weak and Strong Disturbances in the Magnetosphere

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Abstract—The paper is dedicated to studying the dynamics of the auroral ionosphere at the level of the sporadic $Es$ layer during magnetospheric disturbances. A new approach to this problem, proposed in the paper, uses the geomagnetic $PC$ index, which is calculated using the magnetic data in the polar caps of the northern and southern hemispheres and manifests the geoefficiency of the interplanetary electric field. It is shown that variations in the sporadic electron concentration in the auroral $Es$ layer could be related to changes in the $PC$ index with a high degree of statistical reliability. However, the character of precipitations of sporadic particles into the ionosphere under high ($PC > 2 \text{ mV/m}$) and low ($PC < 2 \text{ mV/m}$) magnetic activity differs substantially. During strong magnetic disturbances and under intensified electric fields in the interplanetary environment, the intensity of particle precipitation from the magnetosphere into the $E$ region of the high-latitude ionosphere is governed by the values of the $PC$ magnetic index. During weak magnetic disturbances, short-time pulses of an increase in the $PC$ values, caused by the variability in electric field in the magnetosphere, are the main factor in the occurrence of sporadic ionization in the $Es$ layer.

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1. INTRODUCTION

Experimental study of the auroral ionosphere was recently difficult because at high latitudes there was no network of ionospheric vertical sounding ionosondes. Now the situation is changing. In recent years the network of ionospheric observations at high latitudes of the Russian Arctic and Antarctic is being restored. The equipping of high-latitude stations by digital ionosondes makes it possible to obtain ionospheric parameters in real time and use them for comparison with other geophysical parameters. That enhances the interest in studying processes occurring in the ionosphere of high latitudes.

In this paper, the auroral ionosphere dynamics at the level of the $E$ region during magnetospheric disturbances was studied on the basis of the analysis of the vertical ionospheric sounding data at Tromso station (Norway, $\phi = 69.60^\circ$ N; $\lambda = 19.20^\circ$ E; invariant latitude $\Lambda = 66.40^\circ$). The forms of sporadic ionized formations at the level of the ionospheric $E$ layer related to precipitation of particles and detected in dawn, night and dusk hours, except for the daytime side, were considered. None of flat layers were considered in this paper. Global geomagnetic indices $kp$, $AE$, and $Dst$ were used for estimation of magnetic disturbances. Besides, the $PC$ magnetic index calculated using the geomagnetic observations at “Vostok” (southern hemisphere, $PCS$) and Thule (northern hemisphere, $PCN$) was also used.

The $PC$ index was introduced by Troshichev and Andrezen (1985) and Stauning and Troshichev (1988) as an indicator of magnetic activity induced in the polar caps by the geoefficient interplanetary electric field $Em$. Further studies (Janzhura et al., 2007; Stauning and Troshichev, 2008) have shown that the $PC$ index reacts adequately also to pulses of the dynamical pressure of the solar wind. The $PC$ index values are the same being calculated using the data of the northern or southern hemispheres (Stauning and Troshichev, 1988).

The procedure of calculation of the $PC$ index provides a correspondence between the values of the index and $Em$ field independently of the season of the year, time of the day, and observation location (Northern or Southern hemispheres). The advantage of using the magnetic $PC$ index for description of the auroral ionosphere dynamics is that this index is some sort of indicator of the solar wind energy brought inside the Earth’s magnetosphere. The fact that the $PC$ index is obtained in a real-time regime with a very high time resolution (minutes) makes it convenient for diagnostics of disturbances in the auroral ionosphere. The interest in using the $PC$ index as indicator of ionospheric disturbances is currently increasing, in spite of the fact that the high-latitude ionosphere is governed by different physical processes and many external factors are responsible for its formation.

The aim of this paper is to analyze the development of auroral electrojets at the geomagnetic meridian of Tromso using the data obtained at the meridional
chain of ground-based IMAGE magnetometers (geographic latitudes from 54.47° to 75.25°). The main task of the IMAGE system operation is studying auroras and auroral electrojets (Ritter et al., 2004; Palmroth et al., 2009) at geographic latitudes from 58° to 79°, which is especially important for studying the precipitation of charged particles from the plasma sheet of the Earth’s magnetosphere.

2. MEASUREMENT RESULTS AND THEIR DISCUSSION

The analysis of vertical sounding data at stations of the auroral zone shows the presence of sporadic ionized formations at the level of the $E$ region, both at high and weak geomagnetic activity. Studies of the auroral dynamics in the auroral zone showed a strong variability in both time and space, which was especially well pronounced during low level of magnetic activity and which coincides with the occurrence of sporadic layers in these conditions (Hoffman et al., 1988). The study of statistical relation between the value of the critical frequency $f_0E_s$ of the sporadic $E_s$ layer and global indices of geomagnetic activity $kp$ and auroral indices $AE$, $AL$, $AU$, and $AO$ revealed no significant dependence between these parameters. The calculation of global indices of geomagnetic activity was performed by averaging the magnetic data of several stations. The results describe a statistically averaged situation of disturbances in the conductivity, electric field, and field-aligned and horizontal currents on the whole in the auroral zone of the Earth’s ionosphere, which does not correspond to ejections of sporadic particles at local points of the zone. Our study showed that the state of the auroral ionosphere during strong disturbances of the magnetosphere and strong electric fields (when the $PC$ index $> 2 \text{ mV/m}$) differs from the behavior of the ionosphere during weak separated magnetospheric substorms (when the $PC$ index $< 2 \text{ mV/m}$).

We performed also a comparison of the critical frequency $f_0E_s$ of the $E_s$ layer to the value of currents in the auroral electrojets at the geomagnetic meridian of Tromso obtained at the meridional chain of the ground-based IMAGE magnetometers.

During strong magnetic disturbances, values of the electric currents exceed a value of $1 \times 10^9 \text{ A}$. Intensification of currents in the ionosphere depends not only on the concentration of electrons in the sporadic $E$ layer, but on the strength of the electric field as well. So we found no relation between the currents in the electrojets and concentration in the $E_s$ layer during strong magnetic disturbances.

For the analysis of the auroral ionosphere dynamics during weak magnetic disturbances, we used values of the $PC$ index calculated with the 10-minute time resolution and ionograms of the Tromso station insonde. The analysis of ionograms showed that precipitations into the ionospheric $E$ region during weak magnetic disturbances are usually observed when there are pulses of the $PC$ index enhancement. A comparison of the pulse variability in the $PC$ index with a time increment of 10 min to values of $f_0E_s$ was performed.