

ELECTRIC POTENTIAL OF THE IONOSPHERE-MAGNETOSPHERE CONVECTION

E. Y. Feshchenko (*Institute of Physics, St. Petersburg State University*)
Y. P. Maltsev (*Polar Geophysical Institute, Apatity*)

Abstract. In this paper we studied the convection electric field in the high latitude ionosphere using the observations detected by the Dynamics Explorer 2 satellite during one and a half years. The total number of the data was about 10 millions. We have obtained the distribution of the electric field poleward component by averaging the measurements in the spatial latitude-longitude bins in the region from 50 geomagnetic latitude degrees up to the pole. The electric potential isocontours are built in this region by integration of the electric field over longitude. The polar cap potential drop, location of the convective cell centers, and polar cap dimensions are studied depending on solar wind conditions and geomagnetic activity. It turned out that the aforesaid parameters correlate with the *AE* index much better than with interplanetary parameters – *IMF* and solar wind velocity and density. Only the latitude of the polar cap morning boundary correlates with *By IMF* much better. The seasonal effect the as well as the hemisphere asymmetry influence on the potential drop are examined. At the northern hemisphere the potential drop is greater than at the southern one and in winter it is larger than in summer.

1. Introduction

The total polar cap potential difference (henceforth *U* or simply "polar cap potential") is the key parameter for description of the magnetosphere-ionosphere state. It corresponds to ionospheric plasma flowing which is the low-altitude demonstration of the magnetospheric processes.

On average the spatial potential distribution has a two-cell structure [Heppner, 1977; Heppner and Maynard, 1987]. The cell centers correspond to the potential maximum and minimum. They are situated roughly at the polar cap boundary, the maximum being located in the morning, the minimum in the evening. The potential difference between the cell centers is called the polar cap potential.

For successful development of both the magnetospheric theory and the practical applications the knowledge about the polar cap potential is very important. It is the primary boundary condition required by many theoretical and numerical models. In spite of fundamental nature of this parameter so far very few direct measurements of the polar cap potential have been reported, because the measurements of *U* through detection of either electric fields or cold plasma drift velocities require precise knowledge of satellite attitude. Even with an onboard data processing, large amounts of the ground-based analyses are required. An evident simple way out from this situation is to use available *U* measurements to establish the empirical connections with the more routinely measured parameters of the solar wind and IMF. With this purpose Reiff *et al.* [1981], Wygant *et al.* [1983], and Doyle *et al.* [1983] have studied the AE, S3-3, and S3-2 satellite orbits near the dawn-dusk meridian. Unfortunately, only correspondingly 33, 55 and 66 potential measurements were chosen from the all the passes; it is insufficient, of course, for the accurate analysis. Nevertheless the connection between the IMF and polar cap potential had been detected. Boyle *et al.* [1997] using much greater data from the DMSP

satellite have found an approximate formula relating the potential to the IMF and solar wind velocity, and to *Kp* index when the interplanetary parameters were not available. Weimer [1995] have used the data from the Dynamics Explorer 2 satellite for building the potential spatial distribution in the high-latitude ionosphere under various IMF orientations.

The seasonal effect was found by de la Beaujardiere *et al.* [1991]. The radar at the Sonderstrom station, Greenland, observing the electric field in the ionosphere at the latitude from 67 to 82° has found that the polar cap potential was maximum in fall, then in winter, spring, and minimum in summer.

In this work we studied the electric field in the high-latitude ionosphere using the data from the Dynamics Explorer 2 satellite. In contrast to the work [Weimer, 1995] where the same data were processed we used more direct method without expansion into spatial harmonics. Moreover the potential dependence on the solar wind parameters, geomagnetic activity, season, and hemisphere were studied.

2. Data

The data from the Dynamics Explorer 2 satellite during one and a half year period from August 1981 to February 1983 were used. The trajectory was polar, nearly circular, at the altitude of about 900 km, the rotation period being 98 min. The satellite measured two field component only: along its trajectory (either parallel or anti-parallel to the velocity) and a vertical one. The electric field was measured once in a half of second, i.e. approximately through 4 km. The total number of the data was about 10 millions. We averaged the poleward electric field component in the spatial latitude-longitude bins with the size of one latitude degree for two longitude hours in the region from 50 geomagnetic latitude degrees up to 84 degrees. The electric potential was then calculated as an integral of the electric field over distance along the meridian, at the latitude of 50 degrees the potential being supposed

to be equal to zero. The following values have been chosen as the output (convection) parameters: the potential difference ΔU between the polar cap morning and evening boundaries, the latitudes LAT_m and LAT_e of the morning and evening cell centers respectively, and the distance D between the cell centers. The input parameters are taken from the OMNI database. They are: B_x , B_y , B_z IMF, the solar wind number density N , the solar wind velocity V , and K_p , Dst , AE , AL indices. The K_p index is three-hour, the other are hourly averaged. The convection parameters are examined in various ranges of the input parameters.

3. Results

3.1. Convection electric field and its potential under average geophysical conditions

The distribution of the poleward electric field component is shown in Fig. 1. We did not calculate the field at latitudes higher than 84° . The lines at latitudes higher than 84° in the figure are the result of interpolation.

We have obtained this pattern using all available data hence it may be considered as an electric field distribution under average geophysical conditions. The average values of the input parameters are following

$$B_x = -0.3 \text{ nT}, B_y = 0.3 \text{ nT}, B_z = -0.07 \text{ nT},$$

$$N = 10.9 \text{ cm}^{-3}, V = 456 \text{ km/s},$$

$$K_p = 2.9, Dst = -25 \text{ nT}, AE = 276, AL = -169.$$

Now we can calculate the potential as an integral of the electric field over distance along the meridian. The potential contours for the whole data set (under average conditions) are presented in Fig. 2.

The two-cell structure of the potential with the positive values in the morning sector and with the negative values in the evening sector. One can identify the cell centers location with the polar cap boundary. So, the following convection parameters are interesting for us: For the whole data set (for average geophysical conditions) these parameters are equal to $\Delta U = 45 \text{ kV}$, $LAT_m = 73^\circ$, $LAT_e = 75^\circ$, $D = 3430 \text{ km}$.

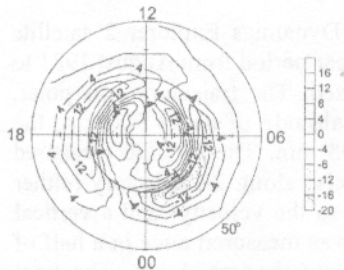


Fig. 1. The high-latitude electric field under average geophysical conditions.

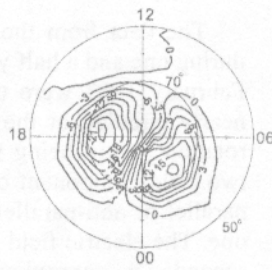


Fig. 2. The high-latitude potential under average geophysical conditions.

3.2. Relation of the convection parameters to the solar wind and geomagnetic activity

In order to understand what solar wind parameters and geomagnetic activity indices mainly affect the convection parameters, we averaged the data under various restrictions.

For example, two ranges, $B_z > 5 \text{ nT}$ and $B_z < -5 \text{ nT}$, are compared in Fig. 3. Then the ranges: $Dst < -50 \text{ nT}$ and $Dst > 0$ are compared in Fig. 4.

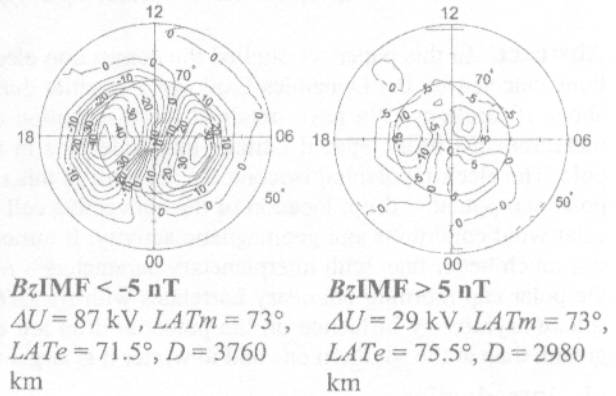


Fig. 3. The comparison of the electric potential and the polar cap parameters under different B_zIMF

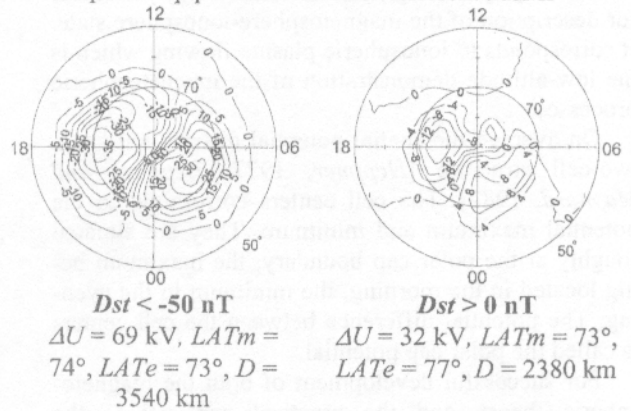


Fig. 4. Comparison of the electric potential and the polar cap parameters under various Dst

One can see that the changes of both Dst and B_z affect significantly the convection parameters, however since Dst and B_z mutually correlate it is quite clear which of the parameters is the most efficient. It is necessary to consider the situation when one of the parameters is disturbed and the other parameter is invariable. We have calculated the potential for a number of pairs: B_zIMF and Dst , B_zIMF and AE , B_zIMF and K_p , Dst and AE , and so on. For example, Fig. 5 shows the following pairs

$$5a: Dst > \langle Dst \rangle, AE > \langle AE \rangle,$$

$$5b: Dst > \langle Dst \rangle, AE < \langle AE \rangle,$$

$$5c: Dst < \langle Dst \rangle, AE > \langle AE \rangle,$$

$$5d: Dst < \langle Dst \rangle, AE < \langle AE \rangle.$$

The values in brackets mean an average. As seen from Fig. 5, the dependence on AE is stronger than that on Dst .

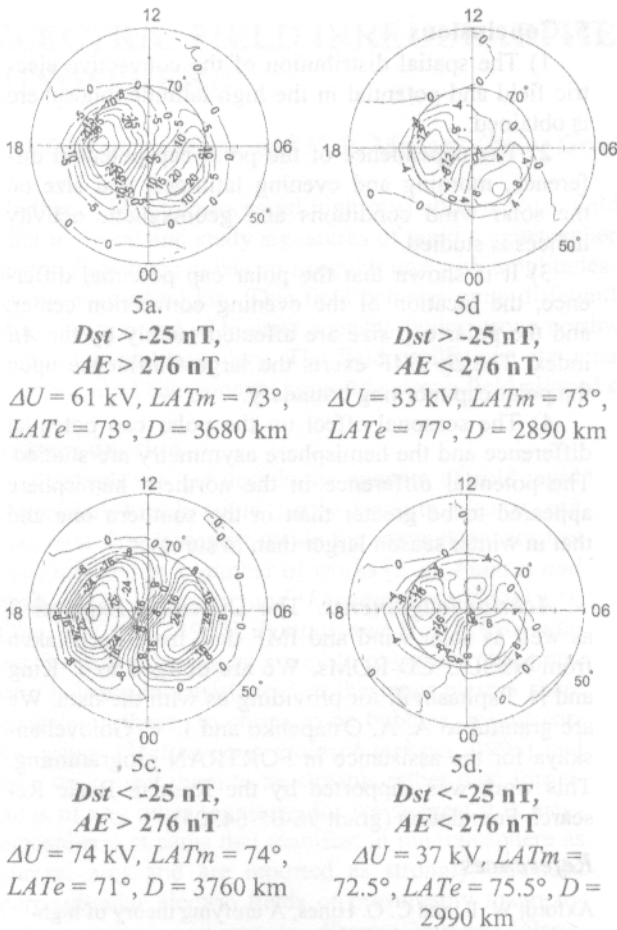


Fig. 5. Comparison of the convection parameters for 4 pairs of Dst and AE .

The influence of By IMF is shown in Fig. 6. One can see that the change of the By sign does not affect the potential difference and polar cap size, instead it influences significantly the cell center latitudes, i.e. when the sign of By changes, the polar cap shifts as a whole to the morning or evening.

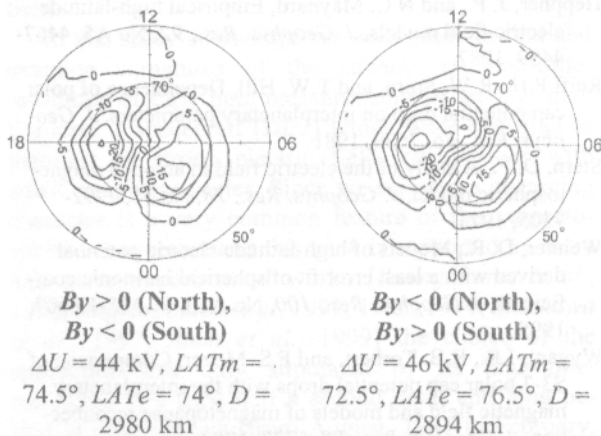


Fig. 6. Comparison of the convection parameters under different directions of By .

Varying the ranges of the input parameters we have obtained more than 20 potential distributions. They permit to carry out the multi-factor analysis and to find parameters affecting most strongly the convection pattern. One must not carry out this analysis taking into account all 9 input parameters because of the large correlation between them. We checked a lot of variants and found that it is sufficient to use the following sets of the input parameters: By , Bz , N , V , or By , Dst , N , V , or By , AE , N , V . The least squares technique yielded the following relationships and residual errors RE :

$$\begin{aligned}\Delta U &= 1.04 AE^- - 0.06 N^- - 0.11 V^-, & RE &= 0.02, \\ LATm &= 0.25 AE^- + 0.44 By^- + 0.01 N^- + 0.23 V^-, \\ RE &= 0.58, \\ LATe &= -0.75 AE^- - 0.16 By^- - 0.01 N^- - 0.3 V^-, \\ RE &= 0.03, \\ D &= 0.84 AE^- + 0.00 By^- - 0.13 N^- + 0.01 V^-, \\ RE &= 0.23,\end{aligned}$$

the most essential parameters being shown with the bold style. The values with the tilde are the normalized parameters. The normalization is convenient since it allows one to see clearly the relative contribution of an input parameter.

The polar cap potential difference, evening boundary latitude and polar cap size appeared to be most strongly related to AE index. The By IMF has the strongest effect on the polar cap morning boundary. It is interesting that the latitude of the polar cap morning boundary changes in the range from 72 to 75° whereas the location of the evening boundary varies wider, from 71 to 77°.

3.3. Seasonal and hemisphere effects

We have studied how polar cap potential difference changes according to the season. As seen from Fig. 7 the potential difference in winter is greater than in summer.

Then we have considered separately the data for the northern and southern hemispheres and compared the obtained potential. It turned out, that the potential difference in the northern hemisphere is greater than in the southern hemisphere as it is obvious from Fig. 8.

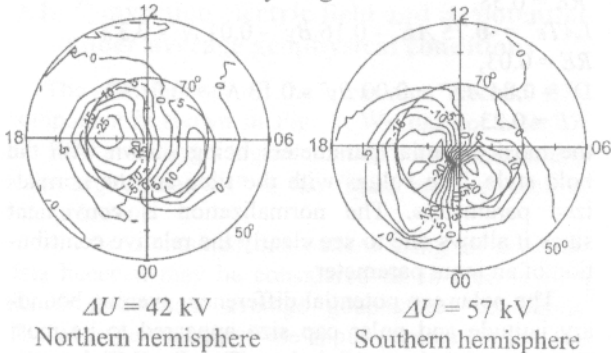
4. Discussion

The data from Dynamics Explorer 2 satellite had been processed earlier by *Weimer* [1995] by another method. *Weimer* supposed that the potential was a sum of several harmonics and found the amplitude of each harmonic by the least squares technique. Our method is more direct but slightly less accurate, because the satellite orbited along a geographical meridian and it did not quite coincide with the geomagnetic one. Thus the values of the electric field in our study are somewhat underestimated at high latitude. Nevertheless our results in many respects are similar to those of *Weimer*. Our study of the dependence of the convective cell center location on different geophysical parameters seems to be more detailed. We

think the center location is not sensitive to inaccuracy of our method.

The dependence of the potential on the IMF orientation is quite natural and can be explained by the theory of the Earth's and interplanetary field reconnection [Dungey, 1961; Stern, 1973]. The dependence of the potential on the solar wind velocity may be connected with the quasi-viscous interaction [Axford and Hines, 1961]. It is much more difficult to explain the hemisphere asymmetry, because it contradicts to the rather conventional opinion about strong electrical conductivity along magnetic field lines.

May-August



November-February

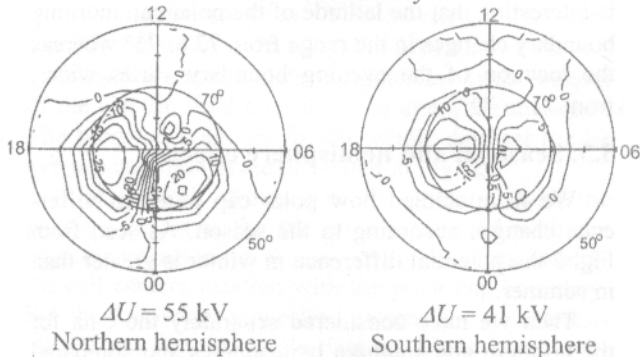


Fig. 7. The electric potential in the summer (top) and winter (bottom).

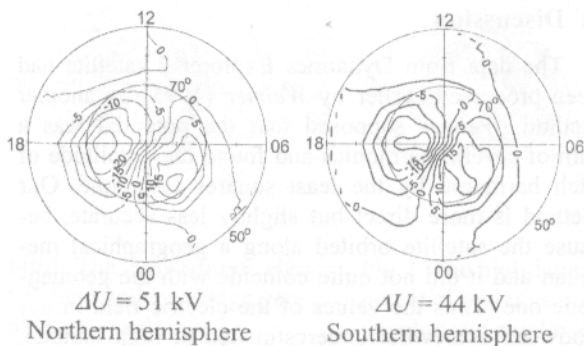


Fig. 8. The electric potential in the northern (left) and southern (right) hemispheres.

5. Conclusions

1) The spatial distribution of the convective electric field and potential in the high-latitude ionosphere is obtained.

2) The dependence of the polar cap potential difference, morning and evening latitudes, and size on the solar wind conditions and geomagnetic activity indices is studied.

3) It is shown that the polar cap potential difference, the location of the evening convection center, and the polar cap size are affected mainly by the *AE* index. The *By* IMF exerts the largest influence upon the polar cap morning boundary.

4) The seasonal effect on the polar cap potential difference and the hemisphere asymmetry are studied. The potential difference in the northern hemisphere appeared to be greater than in the southern one and that in winter season larger than in summer.

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