Polar
Geophysical
Institute

ON THE CONNECTION BETWEEN VARIATIONS OF ATMOSPHERIC ELECTRIC FIELD AS MEASURED AT GROUND SURFACE IN THE CENTRAL ANTARCTICA AND IONOSPHERIC POTENTIAL

A.A. Kruglov [1], A.V. Frank-Kamenetsky [1], G. Burns [2], J. French [2,] V.N. Morozov [3]

1. Arctic and Antarctic Research Institute, Saint – Petersburg, Russia;
2. Australian Antarctic Division, Kingston, Australia
3. Main Geophysical Observatory, Saint – Petersburg, Russia

Abstract. The solar wind generator contributes in a variable manner to the ionosphere-to-ground potential difference at sites in the Polar Regions. It averages ~20% of the contribution of the meteorological batteries at such sites. At times of strong solar wind interaction, much larger contributions to the atmospheric circuit in Polar Regions can occur. Regular measurements of the variations of atmospheric electric fields performed at Vostok Station (φ = 78.45° S; λ = 106.87° E, elevation 3500 m) in Antarctica are compared with the value of solar-wind-imposed ionospheric electric potential above the station (Φi) derived from a Weimer model. Observed positive correlation of ΔEz with Φi affirms the truth of this statement.

Introduction

At high latitudes, the interaction of the solar wind and the Earth's magnetic field imposes on the geoelectric field a variable dawn-to-dusk potential drop of between 20 and 150 kV. Large-scale (>200 km) horizontal electric fields in the ionosphere map into the vertical component of the electric field near the Earth's surface (Park, 1976b, Hays P.B., Roble, R.G., 1979). Frank-Kamenetsky et al., (2001) show that the geoelectric field at Vostok is modulated by the By and Bz components of the interplanetary magnetic field (IMF). Tinsley et al. (1998) compared variations of the surface electric field, ΔEz (the observed electric field at South Pole minus the Carnegie curve scaled to the average of Ez) with variations in the calculated overhead ionospheric electric potential inferred using the Hairston–Heelis model, (Hairston and Heelis, 1990). The authors found positive correlations. Corney et al. (2003) and Burns et al. (2005) shows linear correlation between the variations of Weimer-model (Weimer, 1995) calculated potential above Vostok and variations of near-ground vertical electric field for each hour over bi-monthly intervals, thus demonstrating that Antarctic polar plateau geoelectric field measurements can be used to investigate polar convection.

In this paper we will study the correlations between the electric field variations near the ground measured at Vostok station, Antarctica (geog 78.466S, 106.838E; mag 83.68S, 54.92E) and Weimer -model (Weimer, 2001) ionospheric potential for 1998-2001.

Analytical model

We believe that electric potential in the polar ionosphere can be presented as a sum of external (the solar-wind-imposed potential Φ_{SW}) and internal (thunderstorm imposed potential Φ_0) parts. Similarly, surface electric field can be considered as the sum of the solar-wind-imposed field (E_{SW}) and thunderstorm field (E_{TH}). In order to find the solar-wind-imposed field (E_{SW}) part of the total electric field measured near the earth surface (Ez) we need to subtract the thunderstorm part (E_{TH}) from the measured field.

$$E_{SW} = Ez - E_{TH} \tag{1}$$

For this purpose we solved the problem of downward mapping of the ionospheric field. The equation for electric potential can be written in a spherical coordinates as:

$$l(r)[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\frac{\partial j}{\partial r})+\frac{1}{r^2\sin q}\frac{\partial}{\partial q}(\sin q\frac{\partial j}{\partial q})+\frac{1}{r^2\sin^2 q}\frac{\partial^2 j}{\partial f^2}]+al(r)\frac{\partial j}{\partial r}=0 \tag{2}$$

Where $l(r) = l_0 e^{a(r-R)}$, l_0 - the electric conductivity near the earth surface (Atmosfera. Handbook, 1992), R – Earth radius.

Boundary conditions for solving the equations (2) are the following:

$$j\mid_{r=R}=0 \quad j\mid_{r=r_1}=j(r_1,q,f),$$

where r_1-the altitude of the ionosphere and

$$j(r_1,q,f)=\sum_{i=0}^{8}\bar{A}_{i0}P_i^0(\cos q)+\sum_{i=1}^{8}\sum_{j=1}^{\min(i,3)}(\bar{A}_{ij}\cos jf+\bar{B}_{ij}\sin jf)P_i^j(\cos q) \tag{3}$$

The equation (3) we take from Weimer model (Weimer 1995, 2001). The solution of equation (2) is sought in the form of an expansion in spherical harmonics (Jackson, 1962)

$$j(r,q,f)=\sum_{i=0}^{\infty}\sum_{j=-i}^{i}j_{ij}(r)\cdot Y_{ij}(q,f),$$

$$j_{ij}(r)=\int d\Omega j(r,q,f)Y_{ij}^*(q,f),d\Omega=\sin q\,dq\,df$$

(4). Using this expansion, we obtain for $j_{ij}(r)$ the equation:

$$\frac{d^2 j_{ij}(r)}{dr^2}+(\frac{2}{r}+a)\frac{dj_{ij}(r)}{dr}-\frac{m}{r^2}j_{ij}(r)=0,$$

$$m=i(i+1),i=0,1,2.......... \tag{5}$$

If $r\approx R, a\gg\frac{2}{r}$ the solution of equation (5) with boundary conditions (3) can be written as following:

$$j(r,q,f) = \sum_{i=0}^{\infty} \sum_{j=-i}^{i} \frac{j_{ij}(r_1)(e^{b_1(r-R)} - e^{b_2(r-R)})}{e^{b_1(r_1-R)} - e^{b_2(r_1-R)}} Y_{ij}(q,f)$$

$$b_1 = -\frac{a}{2} + \frac{\sqrt{a^2 + 4m/R^2}}{2},$$

$$b_2 = -\frac{a}{2} - \frac{\sqrt{a^2 + 4m/R^2}}{2} \qquad (6)$$

If $a^2 \gg \dfrac{4m}{R^2}$ the solution of (6) can be simplified:

$$j(r,q,f) = \frac{1 - e^{-a(r-R)}}{1 - e^{-a(r_1-R)}} j(r_1,q,f) \qquad (7)$$

From the expression (7) follows that if $a(r_1 - R) \gg 1 (r_1 - R \approx 60 \text{км})$ the expression for the radial (vertical) component of the electric field will be:

$$E_r = -\frac{\partial j}{\partial r} = -a e^{-a(r-R)} j(r_1,q,f) \qquad (8)$$

For $r = R$ we will get:

$$E_r(r = R) = -a \sum_{i=0}^{8} \sum_{j=0}^{\min(i,3)} \bar{C}_{1ij} Y_{ij}(q,f) = -a j(r_1,q,f) \qquad (9)$$

where:

$$Y_{ij}(q,f) = A_{ij} P_i^j(\cos q)\cos jf + B_{ij} P_i^j(\cos q)\sin jf,$$

$P_i^j(\cos q)$ - associated Legendre functions.

From the expression (9) we can see that the electric field near the Earth's surface is proportional to the potential of the electric field in the ionosphere.

Believing that the potential of the ionosphere (Φ_i) can be presented as

$\Phi_i = \Phi_{sw} + \Phi_0$, where Φ_{sw} – Weimer -model potential and Φ_0, - potential created by thunderstorms, we can rewrite the equation (1) as

Ez = E_{TH} + $\alpha\Phi$sw (10)

If we have the measured electric field (Ez), the calculated Weimer-model ionospheric potential (Φ_{sw}) the simple linear regression analysis can give us the thunderstorm part of the electric field (Ez$_t$) and α – the value proportional to the conductivity of the atmosphere.

The analysis of experimental data

The results of linear regression analysis are shown in fig.1.
Fig.1 represents the diurnal variations of the thunderstorm part of measured electric field for each month of 4 years (1998-2001).
The average diurnal curves for Antarctic summer and winter are shown in fig.2. The classical Carnegie curve (Chalmers 1967) is shown on the right panel.
One can see very good agreement of Antarctic summer (north hemisphere winter) curves with Carnegie curve.
Daily curves of E_{TH} for each month were deducted from the hourly average values of the measured field in order to gain a part of the solar-wind-imposed variations (E_{SW}). Diurnal course of correlation (R)) coefficients between E_{TH} and Φ_{sw} for 1998-2001 are presented in fig.3. One can see positive correlation for all time intervals with a maximum in the

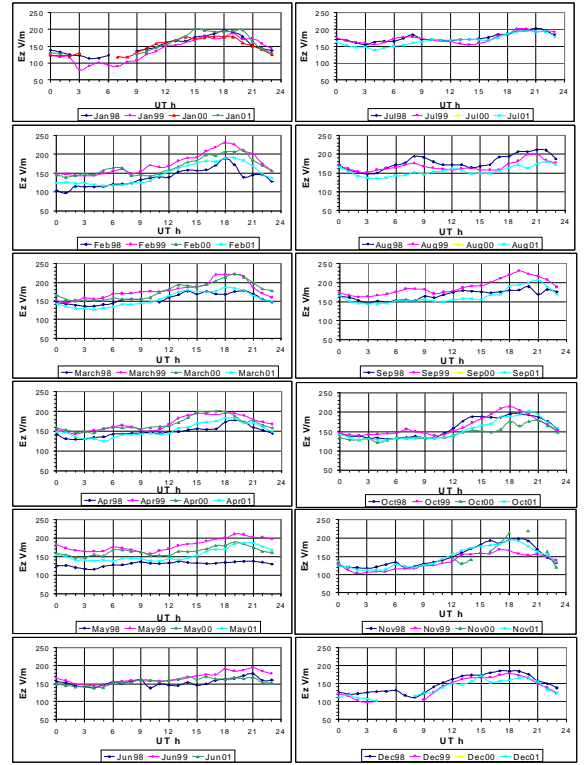geomagnetic morning (03 – 09 UT) and day hours (09 – 18 UT) (for Vostok 00 MLT≈01 UT)

Fig.1 Diurnal curves of the thunderstorm part of atmospheric electric field measured at Vostok st. for every month of 1998-2001
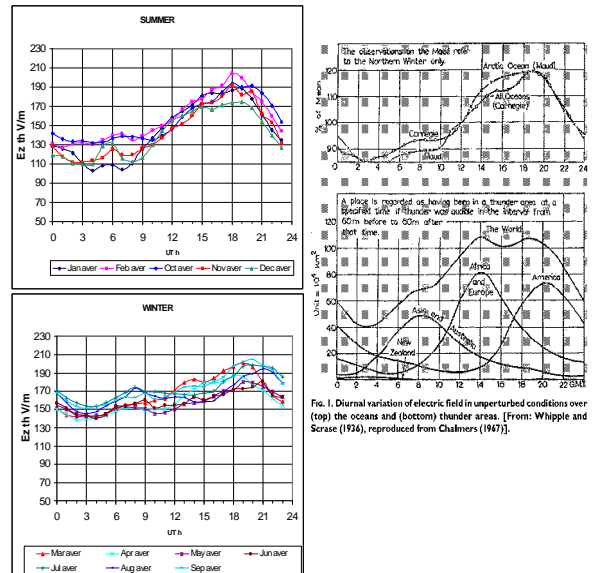

Fig. 2 Daily curves of thunderstorms part of the atmospheric electric field for Antarctic summer and winter (left panel) and Carnegie curve (right panel).
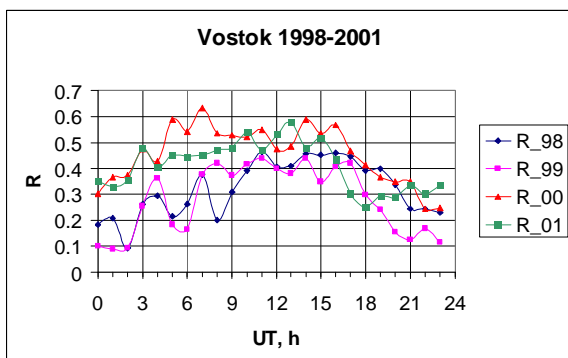
Fig. 3 Diurnal course of correlation coefficient (R) for 1998-2001

The average value of regression coefficient (α) = 0.66. It is less than in Burns et al. (2005), but we used the corrected values of the field, while in (Burns et al. 2005) were used the measured values without correction.

For the case study we used the same reference level (E_{TH}) and calculated Φ_{SW}. Some examples are shown in fig.4.

Fig.4
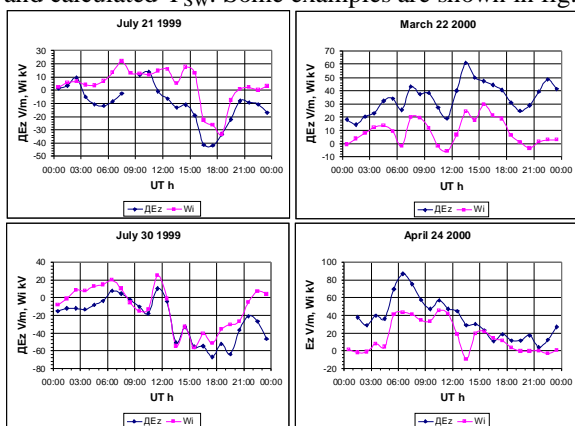
Examples of simultaneous records of variations of the solar wind imposed part of the surface electric field (Ez_i) and the solar wind imposed potential variations of the ionosphere (W_i), calculated by the Weimer model.

We can see that the variations of the near-surface electric field are very close to the variations of the solar wind imposed ionospheric potential.

Conclusions

We have shown that the ionospheric electric fields can penetrate to the earth surface in the Polar Regions and their contribution to the atmospheric electric field can be more than 50 % of the mean value.

Linear regression analysis allows to divide the main sources of variations of surface electric field and to allocate the thunderstorm part of atmospheric electric field.

Diurnal variation of thunderstorm part of near ground field coincides exactly with the famous Carnegie curve for the Antarctic summer (October-February).

Variations of near-surface electric field are in good agreement with variations of the solar wind imposed ionospheric potential calculated by the Weimer model both a statistically and for specific events.

References

Burns, G.B., et al., 2005. Interannual consistency of bi-monthly differences in diurnal variations of ground-level vertical electric field. J. Geophys. Res. 110, D10, doi:10.1029/2004JD005469.

Chalmers 1967. Atmospheric Electricity. Pergamon Press, London, 515 p.

Corney, R.C., et al. 2003. The influence of polar-cap convection on the geoelectric field at Vostok, Antarctica. J. Atmos. Solar-Terr. Phys. 65, 345.

Frank-Kamenetsky et al., 2001 Variations of the atmospheric electric field in the near-pole region related to the interplanetary magnetic field. J. Geophys. Res. 106 (A1), 179.

Hairston, M.R., Heelis, R.A., 1990. Model of the high-latitude ionospheric convection pattern during southward interplanetary magnetic field using DE 2 data. J. Geophys. Res. 95 (A3), 2333.

Hays P.B., Roble, R.G., 1979. A quasi-static model of global atmospheric electricity 1 The lower atmosphere. J. Geophys. Res. 84, 3291.

Jackson J.D. Classical Electrodynamics. New-York – London, 1962, 702 p

Park, C.G., 1976. Downward mapping of high-latitude ionospheric electric fields to the ground. J. Geophys. Res. 81, 168.

Tinsley et al. 1998 South Pole electric field responses to overhead ionospheric convection, J. Geophys. Res. 103, 26,137.

Weimer, D.R. 2001, An improved model of ionospheric electric potentials including substorm perturbations and application to the GEM November 24, 1996 event, J. Geophys. Res., 106, p. 407, Atmosphere. Handbook, 1992 (in Russian).

Weimer, D.R., 1995. Models of high-latitude electric potentials derived with a least error fit of spherical harmonic coefficients, J. Geophys. Res., 100, 19,595.