Dynamical scaling of aeroelectrical field and current at middle latitudes

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ABSTRACT: According to continuous ground middle-latitude [58^0 04' N and 38^0 14´E] observations of vertical electric current density and electric field intensity the main features of dynamics of electrical state of the lower atmosphere are analyzed. Estimates of statistical structure of variations of electric field and current on different of duration time intervals over a period of 1998 - 2013 are obtained. It is shown in most cases during developed convection the short-period aeroelectric field pulsations (frequency band $\Delta f = 0.001–1$ Hz) possess the property of self-similarity. Quasi-periodic daily and annual components in dynamics of fractal dimension and exponent of structural function of the 2nd order of variations of electric field and current are revealed.

INTRODUCTION

Electrodynamics of surface atmosphere is formed by the set of physical processes of generation separation, and transfer of electric charges occurring in a wide range of spatial and temporal scales. The aim of this work was to study the fractal properties of aeroelectric field and current in a wide frequency range, including aeroelectric turbulent pulsations, diurnal and seasonal variations.

DATA ANALYSIS AND DISCUSSION

Digital data of observation, carried out at Borok Geophysical Observatory [58°04 ' N; 38°14 ' E] of 1998 – 2013 were used for analyses. Use of 10 Hz sample-frequency of registration gave us an opportunity to form time-series of observations with duration from hour to decade. In analyses we focused on electric current density dynamics at fair-weather conditions (absence of precipitation, wind speed is not more than 2 m/s, cloudness is not more than 5 balls). Trend absence and a pronounced annual variation observed in series of average monthly values of the vertical

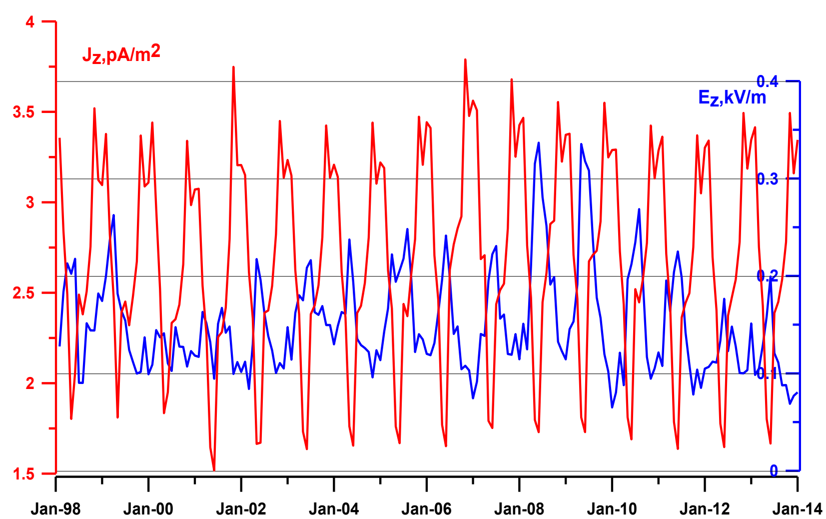

Fig. 1. Dynamics of average monthly values of electric field intensity (blue) and vertical electric current density (red) of 1998 – 2013.

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electric current density (J_z) and electric field (E_z), presented in Fig. 1. The presented series are stationary relatively variance as well autocorrelation function.

The aeroelectric field dynamics are influenced by atmospheric boundary layer turbulence and convection, as well as by changes in the electrical air conductivity, which exposed of a direct impact of radioactive emanations of the earth surface, subsurface and haze aerosols [Hoppel et. al, 1986; Anisimov et.al, 2012; Anisimov et.al, 2013; Anisimov et.al, 2014]. At "good weather" conditions the main factor determining the dynamics of the electrical state of the atmospheric boundary layer is turbulent mixing of air ions, charged aerosols, radon and thoron, which forms the volume space density distribution and aeroelectric field near the earth surface. The energy of E_z multiscale variations distributes on variations scales, following the common law of constant rate of dissipation. The degree of slope of the power spectral density calculated from the series of 4960 days is constant in the range of 4-400 days and is -2.5 (Fig. 2).

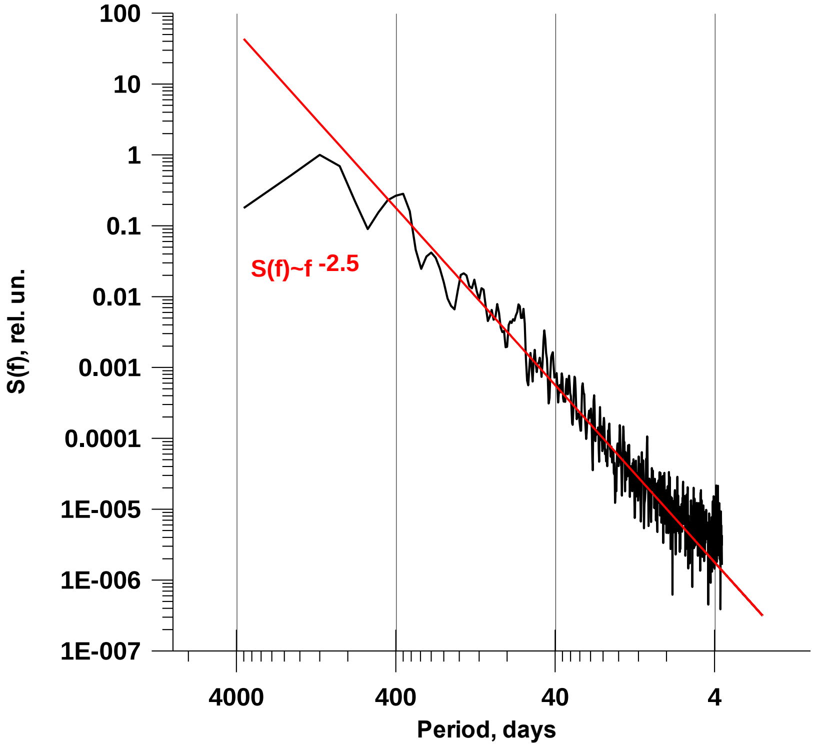

Fig. 2. Normalized spectral density of the daily E_z values on 01.01.1999 - 31.07. 2012 at Borok Observatory.

A more detailed analysis of the intra-annual J_z and E_z variations, calculated using monthly average values for a period of fourteen years observations shows (Fig. 3) that significant global minimum J_z in April is accompanied by significant intra-annual maximum E_z in April-May [Anisimov et.al, 2013]. Presumably, this fact can be explained by a decrease in lower atmosphere

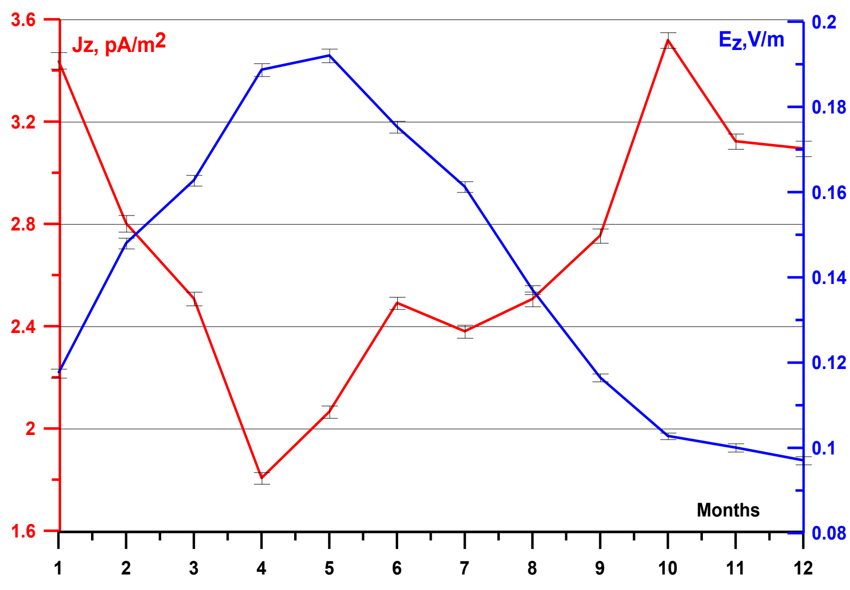

Fig. 3. Annual dynamics of electric field (blue) and vertical electric current density (red) on 1999 – 2013 at Borok Observatory

conductivity of the lower atmosphere resulting from active snow and ice melting in spring.

Fig. 4 presents the results of structural-temporal analysis of an hourly mean E_z dynamics. Structural functions of short-period pulsations ΔE_z were calculated according to the algorithm of stationary increments: $D_E(t,\tau) = \langle|\Delta E(t+\tau) - \Delta E(t)|^2\rangle$ to research the scale τ of self-similarity of E_z [Anisimov, Shikhova, 2014].

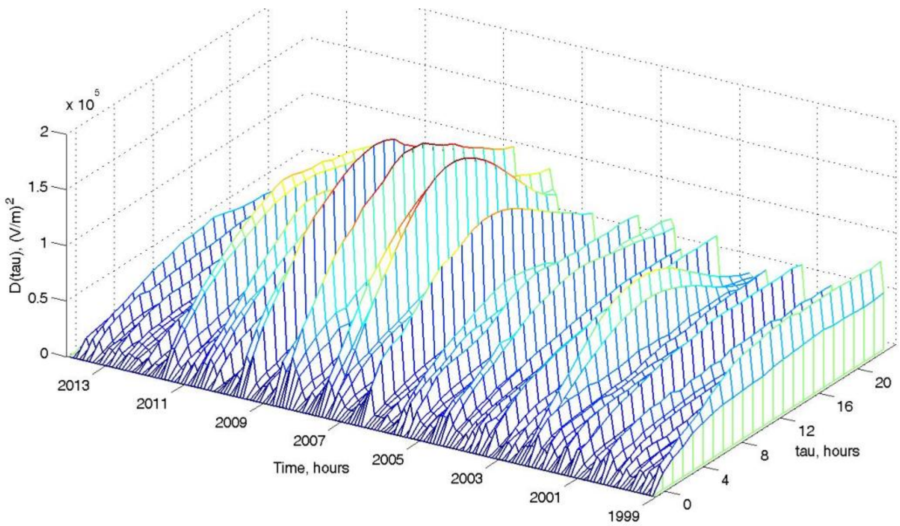

Fig. 4. The second-order aeroelectric structures of E_z hour- average values on 1999 – 2013 at Borok Observatory.

The analysis showed that the interval of self-similarity of energy is multiple to 16-24 hours, and may be due to an influence of global thunderstorm and regional convective generators. The amplitude of the diurnal variation E_z during period of 2007-2011 was much higher than that of the average value for the whole period.

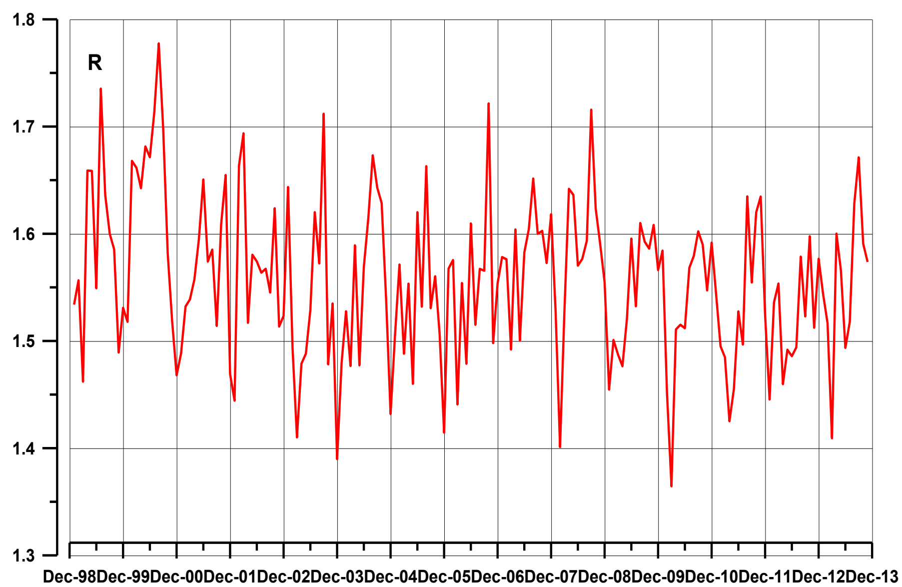

Fig. 5. Fractal dimension of E_z hour-mean data calculated every 720 hours on 1999 – 2013 at Borok Observatory.

The results show that the fractal (self-similar) nature E_z variations are observed on the scales from years to tens of seconds. Figure 5 shows the dynamics of fractal regularization dimension R [Roueff and Vehel, 1998] of aeroelectric field variations for 15 years. Each R-value was calculated for a series of 720 hours (30 days). Fractal dimension of aeroelectric field belongs to the range 1.35 - 1.8, with a mean of 1.56. This result proves fractality of atmospheric electric field, which, while R <1.5 corresponds to the physical process of superdiffusion. Presumably superdiffusion in aeroelecric field is associated with the large-scale energetic atmospheric phenomena, determined by global lightning generator (winter seasons) or regional convective generators (summer seasons).

The presence of long-term digital data of aeroelectric observations and preliminary choise of amplitude-time series with the conditions of "good weather" make it possible to detect the similarity of daily trend of aeroelectric field and unitary variation in continental mid-latitude stations [Anisimov, Mareev, 2008]. As an example, Fig. 6 (a) shows the diurnal variation of hourly mean values of aeroelectric field calculated for winter season. A characteristic of the unitary variation diurnal trend of aeroelectric field with maximum at about 19:00 UT is distinctly traced. Figure 6 (b) shows the diurnal variation of aeroelectric field with some maximums for a summer period of observations.

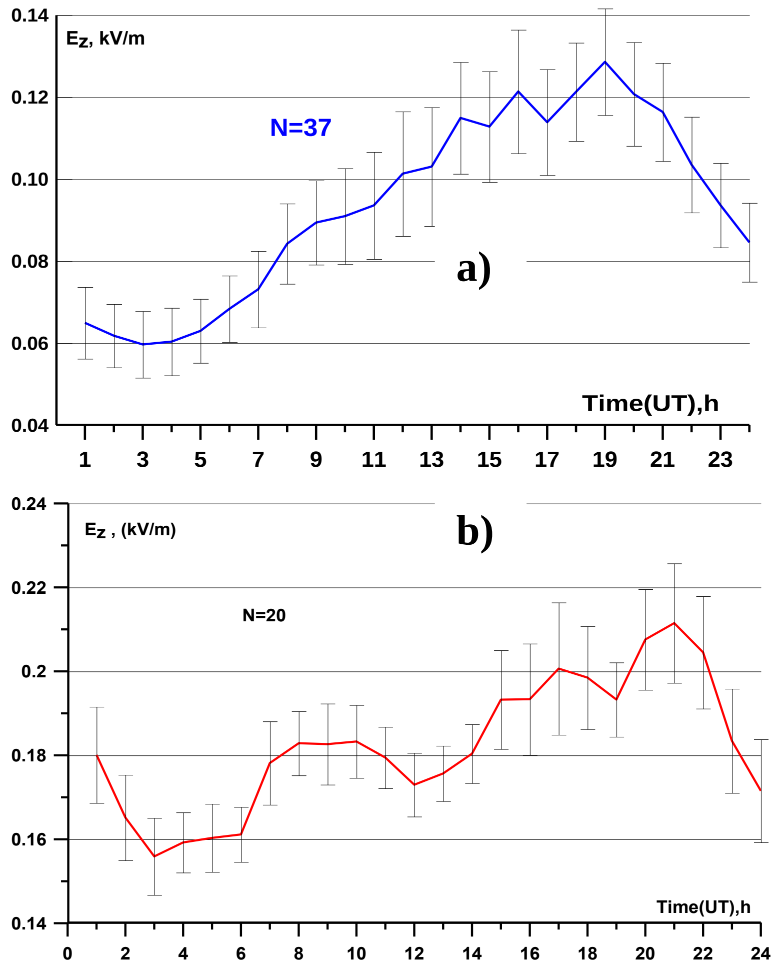

Fig. 6. Daily E_z variation at Borok Observatory calculated for "good weather" conditions on January-February 2012 (a) and on July – August 2012 (b).

In order to obtain statistically significant results in the study of the form of the diurnal variation average daily E_z variation were constructed for each season of the time interval 1998-2012. Results of statistical analysis show that the unitary variation (with minimum in the morning and maximum in evening hours UT) most reliably reproduced in conditions of the unperturbed atmosphere of the northern hemisphere mid-latitudes during the winter months (December, January, February). This finding is consistent with the results have been obtained at the middle-latitude observatory Marsta [Israelsson and Tammet, 2001] , located in Sweden [59 ° 56 'N, 17 ° 35 'E].

One of the goals of investigation was to analyze the relation between atmospheric stratification [Businger et.al, 1971] and the dynamic characteristics of aeroelectric field. Figure 7(a,b) shows a typical daily aeroelectric field registrogramm at Borok Observatory in "good weather" summer conditions and dynamics of sustainability parameter $\zeta = z / L$, where L - the scale of the Monin Obukhov length scale, z-height of meteostation placement usually equals 2m. The important statistical characteristic of the dynamics aeroelectric field is skewness of field values distribution in a fixed time interval. Figure 7c shows typical changes of the skewness A_s calculated as $As = \frac{\sum_{i=1}^{360}(\Delta E_i - \overline{E})^3}{360\sigma^3}$ on series of 10-second average of field strength for each hour of summer day observations. Horizontal lines reflect the boundary of skewness significance at P> 0.9.

At time interval 04:00 - 14:00 UT stratification of the surface atmosphere is close to unstable, during the interval 09:00 - 14:00 UT there are time intervals in which the stratification is close to neutral, in time interval of 16:00 - 00:00 UT is stable stratification (Fig.7b). While significantly positive values of skewness usually correspond to unstable, and significantly negative – to stable stratification (Fig.7c).

To obtain quantitative statistical estimates of daily aeroelectric field dynamics the distributions of aeroelectric field increments for different stratification conditions are considered. It is known that the distribution is close to normal, when the random variable is the result of the combined action of many independent factors and the influence of each factor alone is little.

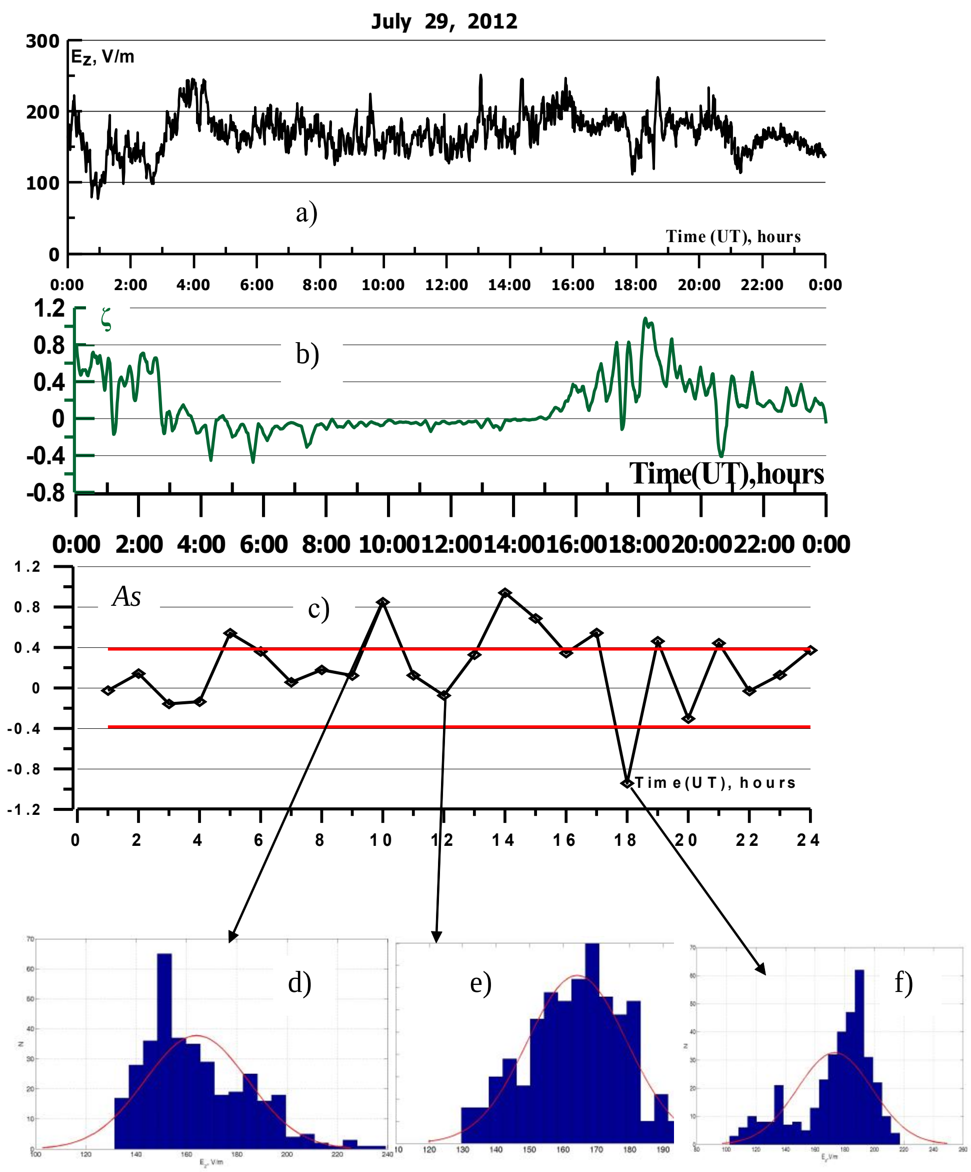

Fig. 7. The daily dynamics of E_z (a), stability parameter ζ (b), mean-hours skewness A_s of aeroelectric ten-sec pulsations (c), distributions of E_z fluctuations for 09-10 UT (d), 11:30-12:30 UT (e), 17-18 UT(f) on July 29, 2012.

Distribution of aeroelectric field increments close to normal is represented on Fig.7e and corresponds to neutral stratification conditions. In time intervals of unstable stratification with a significant positive value of the skewness distribution of the field increments is non-normal (Fig.7d). Distribution of the field increments with a significant negative value of the skewness coefficient shown in Fig.7f corresponds to the conditions of stable stratification.

The spectral density of aeroelectric pulsations characterizes the rate of dissipation of electrical energy (Fig. 8). Note that the dynamics of aeroelectric field in range of periods 10 – 1000 s also demonstrates the property of self-similarity with the average values of the spectral slope α_1 = -3.2 (for pulsations periods of 10-100 s) and α_2 = -1.42 (for pulsations periods of 100-2000 s).

CONCLUSION

The results of statistical analysis of long-term aeroelectric field strength observations and vertical electric current density at mid-latitude geophysical observatory are considered. The dynamics of the aeroelectric field and current demonstrates a fractal properties, fractal dimension of hourly mean series of aeroelectric field is defined. It was found that in the scale range from 10 seconds to a year aeroelectric field variations and current demonstrate self-similarity. It was revealed that the annual aeroelectric field variation during the time interval 1998 - 2013 has maximum on April-May. Corresponding seasonal variation of the vertical electric current density has minimum on April. According to middle-latitude observatory data diurnal aeroelectric field variation for summer and winter seasons of observation are detected. Exponents of slopes of the spectra in ultra-low frequency range of aeroelectric pulsations, having the property of self-similarity are calculated. It is shown that the statistical characteristics of aeroelectric field dynamics reflect changes in stratification conditions of surface atmosphere.

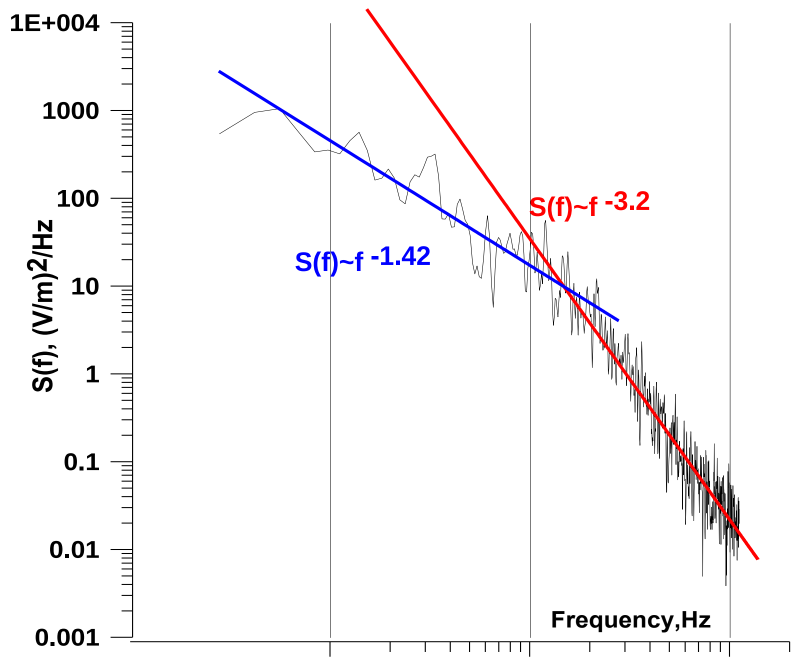

Fig. 8. The spectral density of aeroelectric pulsations on 29.07.2012, 07:00-09:00 UT.

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