EMPIRICAL MODEL OF GEOMAGNETIC FIELD MICROPULSATIONS AT MID-LATITUDES

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An empirical model of the recurrence frequency of Pc1–Pc5-type geomagnetic micropulsations is constructed based on the results of long-term geomagnetic field monitoring at mid-latitudes.

Keywords: geomagnetic field, micropulsations, empirical model, monitoring.

Geomagnetic pulsations transfer to the Earth’s surface information on the physical conditions in the region of their generation in space as well as along their propagation paths to the Earth’s surface. Results of investigations of geomagnetic pulsations demonstrate that the spectral characteristics of electromagnetic background radiation in the environment change due to the interaction of the magnetosphere with the solar wind. One of the first studies of the geomagnetic pulsations were performed by V. A. Troitskaya (1956) [1, 2] who laid foundation for this direction of research. In succeeding years, numerous experimental studies were performed, but they were based on short-term observations occasional in character and mainly at high latitudes [3, 4]. The geomagnetic field components have been monitored at Tomsk State University since 1997. By now, a 13-year continuous cycle of geomagnetic field observations has been accumulated for mid-latitudes; it covers the entire solar activity (SA) cycle. In this period, new methods of separating steady-state micropulsations have been developed [5–7].

The present work is aimed at mathematical description of an empirical model of the spectral characteristics of steady-state micropulsations at mid-latitudes depending on the season, time of day, and solar activity.

To achieve the aim, time series of data on three magnetic induction components \((H, D, Z)\) were considered. Each component was registered from February 1 till April 1, 2010. Data on the magnetic induction were registered with a Quartz-3 EMD digital magnetic variation station. The data on the magnetic induction were filed continuously with a sampling frequency of 20 Hz in 3-min (150 s) time windows; measurements were repeated every 30 s. To separate micropulsations, the data were processed using algorithms described in [5, 6] and smoothed with the help of trends [7].

After spectral processing, the oscillations corresponding to the steady-state \(Pc1\)-, \(Pc2\)-, \(Pc3\)-, \(Pc4\)-, and \(Pc5\)-type micropulsations were subsequently analyzed. By way of example, Fig. 1 shows seasonal-diurnal distribution of the \(Pc5\)-type micropulsations. Our analysis of these distributions has allowed us to describe them empirically.

In the first stage of empirical model construction for each micropulsation type, their seasonal-diurnal recurrence frequencies were calculated for each examined year (1997–2010). The micropulsation recurrence frequency \(X\) is the ratio of the sum of micropulsation periods observed during 1 h to the same period. For the \(D\) component, the recurrence frequency of the \(Pc5\)-type micropulsations for 2007 is shown in Fig. 1. From the figure it can be seen that the micropulsations have diurnal and seasonal behavior.

To describe the diurnal behavior of micropulsations \(X\), the Fourier transform, that is, their series expansion was used considering terms up to the second order:
\[ X_{Pc5}(m,t) = C_{Pc5}(m) + \sum_{i=1}^{2} \left( A_i^{Pc5}(m) \cos \frac{2\pi i t}{24} + B_i^{Pc5}(m) \sin \frac{2\pi i t}{24} \right), \]  

where \( t \) is the time of day, \( m \) is the serial number of the month for the examined 13-year period, \( i \) is the serial number of the harmonic, and \( C_{Pc5}(m), A_i^{Pc5}(m), \) and \( B_i^{Pc5}(m) \) are the coefficient of expansion in the Fourier series, in this case, of the \( Pc5 \)-type micropulsations.

The calculated expansion coefficients describe sufficiently completely the diurnal behavior of the two harmonics – diurnal and semidiurnal. The discrepancy of the initial data series from the data series reconstructed using the Fourier transform did not exceed 3%. This means that the reconstructed data series describes 97% of the initial signal.

For the calculated coefficients of the diurnal expansion in the Fourier series, the first-order trends due to the 11-year SA cycle were calculated. To retrieve a formula for the micropulsation recurrence frequency, the trends so obtained and indices \( F_{10.7} \) being a measure of the solar radio emission flux at a wavelength of 10.7 cm were used. The indices \( F_{10.7} \) were taken from site of the Space Weather Center of the American Meteorological Department NOAA (http://spidr.ngdc.noaa.gov). As a result, we obtained a linear regression dependence between the indices \( F_{10.7} \) and trends by minimization of the squared discrepancy functional \( \Phi = \sum_{i=0}^{n} (Y - y_i)^2 \), where \( n = 155 \) is the number of months. Here \( Y \) is the sought-after function and \( y_i \) are trend values of the expansion coefficients in the Fourier series. The function \( Y \) is described by a linear dependence: \( Y = ax + b \), where \( x \) designates indices \( F_{10.7} \). A minimum of the functional \( \Phi \) means that its derivatives with respect to \( a \) and \( b \) are equal to zero.

Linear regression dependences between \( F_{10.7} \) and trend coefficients differed for increasing and decreasing SA. For the \( Pc3 \)-type micropulsations, these dependences are shown in Fig. 2. For the last 11-year cycle, the solar activity increased from January, 1997 till December, 2001; it decreased from January, 2002 till December, 2009. The time derivative \( \frac{\partial F_{10.7}(m)}{\partial t} \geq 0 \) for the 11-year SA cycle means that the function \( F_{10.7}(m) \) increases; similarly, \( \frac{\partial F_{10.7}(m)}{\partial t} < 0 \) means that the function \( F_{10.7}(m) \) decreases.