PECULIARITIES OF THE ULF EMISSION FRACTAL CHARACTERISTICS OBTAINED AT THE STATIONS OF 210 GM

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Abstract. Magnetic records (1Hz sampling rate) of the 5 stations (Guam, Moshiri, Paratunka, Magadan and Chokurdakh) located from equatorial region to auroral zone approximately along the same geomagnetic meridian (210 MM) have been analyzed using Higuchi method of fractal analysis. The period of 22 months (October 1992 – July 1994) that embodies the date of the strong Guam earthquake of 8 August 1993 has been considered. Comparison of the ULF emission scaling parameters (spectral indexes $\beta$ and fractal dimensions $D$) obtained at different latitudes has been fulfilled. Dependence of $\beta$ and $D$ on Kp index of geomagnetic activity has been separately analyzed for each of 24 local time intervals. The results obtained are considered on the basis of the SOC (Self-organized criticality) concept. A possibility of using the data of the 210 GM stations as reference materials for the Guam seismic active area is discussed.

Introduction

In a series of papers by Smirnova and Hayakawa (see References), the specific dynamics of fractal characteristics of ULF emissions registered at the Guam observatory in relation to the strong Guam earthquake of 8 August 1993 has been reported. Namely the spectral exponents $\beta$ were decreasing and the corresponded fractal dimension $D$ was increasing when approaching the date of the Guam earthquake. It is also revealed that scaling parameters of the ULF time series are influenced by geomagnetic activity. So the local seismo-electromagnetic phenomena are screened by magnetospheric effects, which are of more global character. To distinguish between these effects the data from reference stations are necessary in addition to the Guam data. Here we consider coordinated magnetic records (1Hz sampling rate) of the 5 stations located approximately at the Guam geomagnetic meridian (210 MM stations). The purpose is to compare the fractal properties of ULF emissions along meridian profile and try to answer the question which station could be used as a Guam reference point in seismo-electromagnetic research.

Experimental Data

Magnetic records ($\Delta$H, $\Delta$D, $\Delta$Z – components) used for our analysis were obtained at the 210 MM stations by means of ring-core-type fluxgate magnetometers with sampling rate 1 second. The chain of stations includes Chokurdakh (CHD), Magadan (MGD), Paratunka (PTK), Moshiri (MSR), Guam (GAM) and covers a wide range of latitudes from auroral zone to the equator (see the Table 1).

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>geographic</th>
<th>geomagnetic</th>
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<tbody>
<tr>
<td>GAM</td>
<td>13.58° N</td>
<td>144.87° E</td>
</tr>
<tr>
<td>MSR</td>
<td>44.37° N</td>
<td>142.87° E</td>
</tr>
<tr>
<td>PTK</td>
<td>52.94° N</td>
<td>158.25° E</td>
</tr>
<tr>
<td>MGD</td>
<td>59.97° N</td>
<td>150.86° E</td>
</tr>
<tr>
<td>CHD</td>
<td>70.62° N</td>
<td>147.89° E</td>
</tr>
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</table>

The observation period covers 20 months from October 1992 to July 1994 This period embodies the date of a strong M8 Guam earthquake of 8 August 1993: depth = 60 km, $\Phi$=12.98° N, $\Lambda$= 144.80° E. An example of the typical record obtained at Paratunka is given in Fig. 1. In this study we have analyzed the data in each of the 24 daily 1-hour intervals. In the insertion to Fig. 1, one can see the enlarged 1-hour record (ULF emission) for 16-17 UT. So each analyzed time series, which represents ULF emission in 1-hour interval, contains 3600 points. We apply fractal methods to analyze scaling (fractal) characteristics of ULF emissions and study their dynamics in each location in relation to geomagnetic activity as well as in relation to the strong Guam earthquake of 8 August 1993.
Fractal approach

Now it is recognized that the extended dissipative dynamical systems evolve naturally to the state of self-organized criticality (SOC). The SOC state is characterized by high sensitivity of the system to any external perturbations and a fairly broad energy spectrum of dissipation events. The Earth’s magnetosphere and lithosphere were shown to exhibit this type of behavior. The fingerprints of the SOC state are fractal organization (power-law distributions) of the output parameters in both space and time domains (scale-invariant structures and flicker-noise or 1/f fluctuations). Hence we can use fractal methods for analysis of spatiotemporal scaling characteristics of the magnetospheric and lithospheric emissions.

Three methods of fractal analysis have been considered: 1) PSD method (Feder, 1989; Turcotte, 1997); 2) Burlaga-Klein method (Burlaga and Klein, 1986); 3) Higuchi method (Higuchi, 1988, 1990). Time series can be considered as fractal ones in the chosen frequency range, if its PSD (power spectra density) $S(f)$ follows the power law at those frequencies: $S(f) \sim 1/f^\beta$ Spectral exponent $\beta$, and fractal dimension $D$, characterize the rate of irregularity of the time series. $\beta$ and $D$ are connected via the Berry equation (Berry, M.V., 1979): $D = (5 - \beta) / 2$. The more advanced fractal approach is Higuchi method. It gives more stable values of fractal dimensions. The method is based on the estimation of length of fractal curve $X(N)$. We consider the ULF data with sampling rate of 1s as a time sequence $X(1), X(2), ..., X(N)$. From given time series $k$ new time series are constructed, defined as follows:

$$X'_m = \left\{ X(m), X(m+k), X(m+2k), ..., X\left( m + \left\lfloor \frac{N-m}{k} \right\rfloor \cdot k \right) \right\}$$

(m=1, 2, ..., k)

Then we estimate the length of the curves, which represents the new time series for each $k$:

$$L_m(k) = \left\lfloor \frac{N-m}{k} \right\rfloor \cdot \frac{1}{k}$$

where $\frac{N-1}{\left\lfloor \frac{N-m}{k} \right\rfloor \cdot k}$ is a normalizing factor. Then the total length of curve is defined as follows:

$$<L(k)> = \frac{\sum_{m=1}^{k} L_m(k)}{k}$$

And finally, we plot $<L(k)>$ versus $k$ (ex. $k=1, 2, ..., 10$). If $<L(k)> \propto k^{-D}$ and scales linearly in log-log presentation then we can consider this time series as fractal ones and estimate fractal dimension from the slope of curve (see Fig. 2).

Fig. 2. Examples of the calculation of the ULF emission fractal dimension using Higuchi method.
Results

1. Dynamics of the ULF emissions fractal dimensions at the stations along 210 geomagnetic meridian.

We have obtained 24 sets of the results representing dynamics of the ULF emissions fractal dimensions along the 210 MM profile in each 1-hour daily interval. One example of such dynamics for 11-12 UT interval is shown in Fig. 3.

One can see the following peculiarities:

1) Daily fluctuations of $D$ exhibit chaotic dynamics at each of the 5 stations of 210MM. It is difficult to understand whether such fluctuations are random ones or represent deterministic chaos. Those fluctuations may contain the influence of the magnetospheric, ionospheric, lithospheric, processes as well as effects of the man-made origin.

2) Averaging over ± 5 days (running average values of $D$) exhibits some features of deterministic behavior. Namely the distinct modulation of $D$ with periods near 27 days is outlined, which corresponds to rotation of the Sun around its axes. So it is definitely a magnetospheric effect that is confirmed by the corresponding variations of Kp-index (see the bottom panel).

3) Going to the longer time variations of $D$, one can reach the effect revealed earlier in the reference papers. Namely that is gradual increase of the ULF emissions fractal dimension before the Guam earthquake of 8 August 1993 (marks by an arrow). That may be an earthquake precursory effect. According to our analysis this effect is more pronounced in the H-component of Guam, and it just vanishes in the Moshiri, Paratunka and Magadan data. What about Chokurdakh, lots of gaps in the data do not allow us to trace such a tendency.

4) The modulation by the 27-day period is the most pronounced in the auroral zone (Chokurdakh), where it is manifested in the H, D and Z components. At the other stations, which are situated inside the plasmasphere, the modulation is observed in the H and D components, and never in Z-component. As to the Guam station, which is situated in the region of equatorial electrojet, such a modulation is seen also in Z component.

5) The range of variations of $D$ (see H-component) is wider at the stations of auroral zone (Chokurdakh) and equatorial electrojet region (Guam) in comparison with inside-the-plasmasphere stations (Magadan, Paratunka, Moshiri).

Fig. 3. Dynamics of $D$ along 210 MM. Thin curves - daily values, the thick ones - ± 5 day running average value.
2. Dependence of the ULF emissions fractal dimensions from Kp index of geomagnetic activity

Some results to study the correlations between fractal dimensions of ULF emission time series and the Kp – index of geomagnetic activity are presented in Fig. 4. From the left part of Fig. 4 one can see that fractal dimensions of the ULF emissions time series decrease with increasing of magnetic activity at all stations, but the rates of the decrease are different at different stations and in different time intervals. The dependence of $D$ on Kp is the most pronounced in the auroral zone (Chokurdakh), and it is rather smooth at the middle latitudes (Magadan and Paratunka). Near the equator (Guam) it becomes again sharper. From the right part of Fig. 4 one can see daily variation of the correlation coefficients between $D$ and Kp. This variation is more regular in the middle latitudes (Magadan, Paratunka, Moshiry) with a pronounced maximum near 15 UT and minimum around 4 UT. As to the auroral zone and equatorial region (Chokurdakh and Guam) the maximum is not so pronounced there, and it is spread over the time interval 10-20 UT. But the minimum is also around 4 UT, which corresponds to local time near the noon (14 LT). So we may conclude that the evening, night and early morning hours are preferable for studying magnetospheric effects whereas the noon hours are the most suitable for analysis of lithospheric effects.

Fig. 4. At the left - examples of the plots representing fractal dimensions of the ULF time series (H-component, 11-12 UT) versus Kp-index for all stations. At the right - daily variations of the correlation coefficient between $D$ and Kp along meridian profile (the H-component).
Discussion and conclusions

We have obtained rather pronounced dynamics of the ULF emission fractal dimension $D$ along 210 MM profile, which reflects the global magnetospheric effects as well as some local processes at each of the 5 stations. One can see magnetospheric effects from the thick lines ($\pm$ 5 days running average values of $D$) in Fig. 3 as a modulation of $D$ with the same period near 27 days. That is a characteristic period of the Sun rotation, and it is clearly seen from the corresponding modulation of the Kp index of geomagnetic activity at the bottom panel in Fig. 3. In the horizontal components H and D, this effect is pronounced at all the stations, but in the vertical component Z, it is more visible near the projection of characteristic electrojet locations: auroral electrojet - Chokurdakh station, and equatorial electrojet – Guam station. At the stations situated inside the plasmasphere, which are Magadan, Paratunka and Moshiri, the modulation of the 27-days period is practically disappeared in Z-component. So in order to exclude magnetospheric effects from the horizontal components of the Guam station, all the other stations of 210 MM are appropriate. But to exclude magnetospheric effects from the vertical component of the Guam station, the station Chokurdakh belonging to auroral zone is more recommendable, if there is no other reference station situated near auroral electrojet projection. As to the preferable local hours for analyzing lithospheric effects, the noon hours (near 4 UT or 14 LT) are the most suitable, since influence of geomagnetic activity on the fractal properties of ULF emissions is depressed near the noon hours (see Fig. 4).

The following conclusions have to be done from the analysis fulfilled.

1. Our analysis shows that the results of the fractal analysis of the data from 210 MM chain of stations may give a support to the results of the Guam station data analysis when we attempt to distinguish between magnetospheric and lithospheric effects.
2. Since magnetospheric effects are of global character, they give the correlated part in the results obtained at all the stations. Lithospheric effects could be of individual and local character at each of the station. So we have to manage how to remove the correlated part from the raw 210 MM results. Now we are working in this direction.
3. We understand that our results are of preliminary character, and they need to be checked and confirmed on the other independent materials. Nevertheless we may conclude that the peculiarities revealed can be used as control factors in the forthcoming investigations of the earthquake precursory signatures based on the analysis of scaling (fractal) characteristics of ULF emissions.

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References


