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PLANETARY NUMBER OF LIGHTNINGS DETECTION BY STATISTICAL ANALYSIS OF ELECTROMAGNETIC NOISE IN SCHUMANN BAND CHARACTERISTICS

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1. Introduction

The space between well-conductive spherical surfaces of Earth and ionosphere (at height of ~ 70 km) is a natural resonator for electromagnetic oscillations with frequencies of about 8, 14, 20, 26 Hz and so on (Schumann resonances). The main excitation source of the resonator are lightnings of about 1,000÷2,000 thunderstorms simultaneously running on Earth. The aggregate of these lightning storms is also an electromotive force supplying the planetary electric circuit. Our main interest is concentrated on diagnostics and monitoring methods of planetary thunderstorm activity enhancement. In this paper we report an effort to match statistical characteristics of electromagnetic noise in "Earth-ionosphere" resonator with the characteristics of its excitation source.

2. Experimental data

For the analysis we used electromagnetic noise data in the range of 1÷30 Hz recorded on RRI facility in Novaya Zhizn' (the Nizhniy Novgorod Region) preferably in wintertime to minimize the influence of local disturbance sources including near thunderstorms. For electromagnetic noise registration we used two induction sensors with cosine directional patterns (DP) oriented along (N-S) and across (W-E) the magnetic meridian (magnetic declination was 11.6° East), two amplifiers and a personal computer equipped with 14-bit ADC.

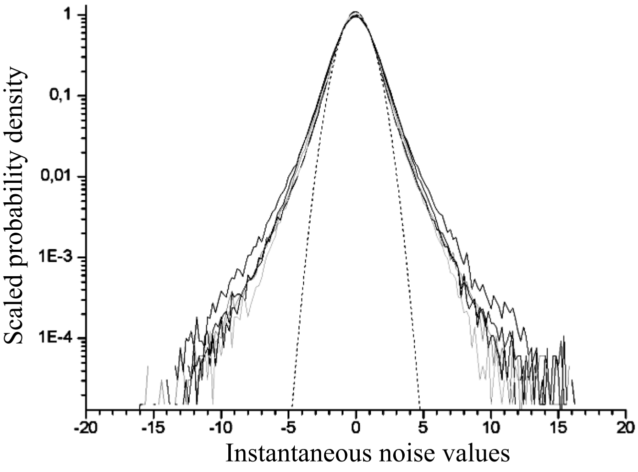

Fig. 1. Experimental instantaneous noise value distributions (in units of standard deviation), dashed curve stands for Gaussian distribution with the same dispersion.

3. Experimental data analysis procedure

We suggest the following analysis technique:

1. a parametric model of noise is defined, the instantaneous noise value probability density is calculated analytically based on the model;
2. the discrepancy between the experimental and the analytical distributions is minimized to determine parameters of the model.

In Fig. 1 the recorded instantaneous noise value distributions for several hourly samples are represented. The difference between these distributions and the Gaussian one corresponding to high pulse density rate (the average distance between the pulses is much shorter then the pulse duration, [1]) is obvious. It gives rise to a supposition that distribution decays contain some information about the pulsed noise component.

Based on the experimental instantaneous noise value probability density with relatively slow decays, the two-component additive noise model is suggested: a Gaussian noise with the dispersion of σ_N^2 and pulsed noise ξ represented as a sequence of exponentially decaying radio pulses:

$$\xi(t) = \sum_{\nu} a_\nu F(t - t_\nu) \sin\left[\omega(t - t_\nu) - \theta_\nu\right],$$

where a_ν are the random amplitudes with $w_a(a)$ probability distribution, $F(t) = \exp(-t/\tau_0)$ is the pulse envelope, t_ν are the uniformly distributed time points, and θ_ν are the random phases, uniformly distributed in ape range of [0..2π]. The effective pulse duration (pulse decay time) τ_0 can be estimated by the resonant width: Δω: $\tau_0 = 2/\Delta\omega \sim 0.1$ s.

The probability density $w(s)$ of two-component noise can be calculated using characteristic function apparatus [1]:

$$w(s) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-ius} \cdot \varphi_N(u) \varphi_\xi(u) du\,,$$

where $\varphi_N(u) = \exp\left(-\sigma_N^2 u^2 / 2\right)$ is the characteristic function of the Gaussian distribution. We used a simple exponential pulse amplitude distribution law $w_a(a) = a_0^{-1} \exp\left(-a/a_0\right)$ with the characteristic function given by

$$\varphi_\xi(u) = \left[2/1+\sqrt{1+a_0^2u^2}\right]^{n_1\tau_0},$$

where n_1 is the average number of pulses per unit time. Thereby there are three parameters in our model: σ_N^2, a_0^2 and pulse density $\nu = n_1\cdot\tau_0$. Two of them are independent, and the third can be defined from the equation

$$\overline{s^2} = \sigma_N^2 + n_1\tau_0 a_0^2/2,$$

where $\overline{s^2}$ is the empirical noise dispersion.

We used "χ^2 minimum method" [2] to optimize parameters of our model. In this approach the most feasible parameter values are the ones that minimize the

$$\chi^2(\sigma_N,\sigma_a) = \sum_{i=1}^{r} \frac{\left[N_i - N_0\cdot p_i(\sigma_N,\sigma_a)\right]^2}{N_0\cdot p_i(\sigma_N,\sigma_a)}$$

function. Here N_0 is the total amount of sampling, r is the number of groups the sampling is divided into, N_i is the empirical number of samples in the i^{th} group ($N_0 = \sum_{i=1}^{r} N_i$), $p_i = \int_{s_i}^{s_{i+1}} w(s)ds$ is the theoretically calculated probability of the noise values getting into the i^{th} group. The χ^2 minimization was implemented by a combination of Newton-Rafson and gradient search methods. Since these methods provide only local extremum search, the technique was supplemented with starting point selection on a rectangular grid in the parameter space.

From time to time a narrow-band radiation with frequencies lower than 8 Hz was present in the recorded signal. It was definitely induced by ionospheric and magnetospheric distortions after a solar flare. There were also occasional monochromatic disturbances at frequencies of 50 and

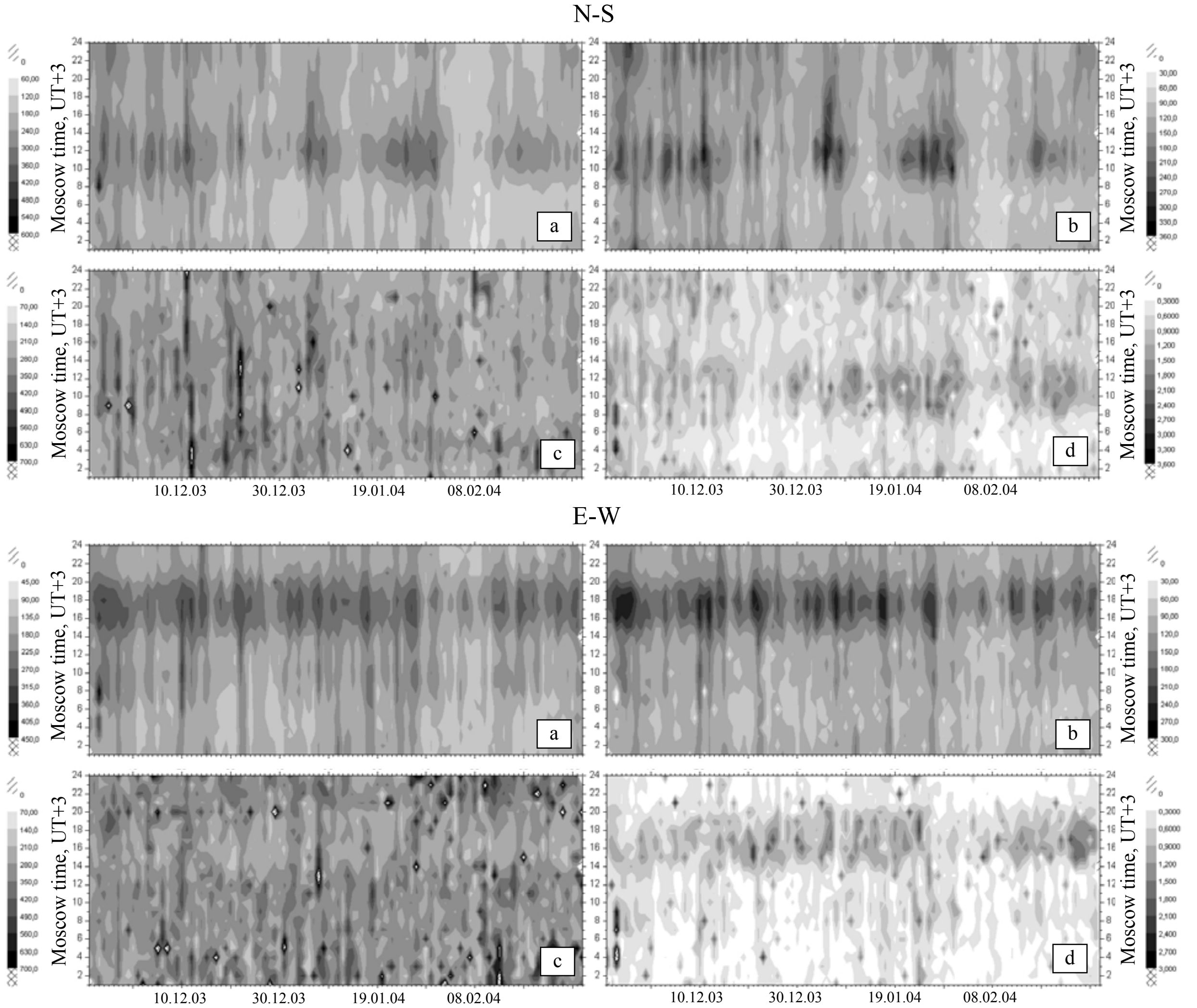

Fig. 2. Noise characteristics as a function of date (horizontal axes) and Moscow zone time (UT + 3 hrs, vertical axes) over a period of November 21, 2003 to March 1, 2004 in N-S (4 top graphs) and E-W (4 bottom graphs) detector signals: a — noise standard deviation ($\sqrt{\overline{s^2}}$), b — standard deviation of the Gaussian component (σ_N), c — mean-square pulse amplitude ($\sigma_a = \sqrt{\overline{a_0^2}}$), d — pulse density ($\nu = n_1\tau_0$).

25 Hz. The lower frequency is virtually equal to the 4th Schumann resonance. Therefore the recorded signal passed through a digital filter to pick out free of disturbances Schumann bands. Hereafter we present the results of the 1st Schumann resonance band (5÷11 Hz) electromagnetic noise investigation.

4. Signal processing results

In Fig. 2 the parameter variations of hourly aggregated signal are presented. The signal was recorded in wintertime of 2003–2004. The ”N-S” detector had a deep minimum of DP in the direction of the African thundery zone and received radiation of the Asian and South-American thundery zones by its Eastern and Western lobes respectively. The “W-E” detector received radiation of the African thundery zone in an almost maximum of its DP.

Noise intensity behaviour can be treated as a daily consecutive activation of thundery zones in Asia at ~ 8 UT (11 Moscow time), Africa at ~ 14 UT (17 Moscow time) and America at ~ 19 UT (22 Moscow time). This daily variation can be observed for all noise parameters except for mean-square pulse amplitude (Fig. 2c), and besides the standard deviations of Gaussian and pulsed noise components are comparable. It is not still clear whether the behaviour of the mean-square pulse amplitude is true to life or is a consequence of analysis technique imperfection. If it is true one can conclude that only quantity of lightnings increases in global thundery zones, but not their average energy.

Both pulse density and the Gaussian component standard deviation demonstrate similar daily variation. In compliance with our model it points to the similarity of their sources’ spatio-temporal location. At the same time on a temporal scale of several days their variations do not match completely.

Noise intensity $\sqrt{\overline{s^2}}$ and its components σ_N and ν fluctuate with a characteristic time of 3÷5 days which is comparable with a typical time of atmospheric fronts and cyclones passage time. The characteristic background rate of pulse density ν is ~ 1, in thundery zones $\nu \sim 1\div3$ and peak fluctuations are characterized by $\nu \geq 4$.

5. Discussion

Assuming pulse length $\tau_0 \sim 0.1$ s one can derive pulse quantity per unit time in global thundery zones as $n_1 \sim 10\div30\ \mathrm{s}^{-1}$. It is similar to the frequency of lightnings observed in the optical range by Earth satellites, but is several times smaller (~ 50 s^{-1}) [3]. This difference is most likely explained as follows. Our detectors record only radiation of strong cloud-to-ground lightning discharges, while the satellites record in-cloud discharges as well. We can also evaluate the results obtained in terms of planetary electrical circuit characteristics and electromotive force supplying it. According to reference data the average current in the global circuit I is ~ 10^3 A while the average negative charge transferred by a lightning ΔQ is $\approx 20\div30$ C. Thus, the average number of lightnings per unit time required to feed the circuit is $n = I/\Delta Q \sim 30\div50\ \mathrm{s}^{-1}$, which is close to the values obtained both by the optical technique and in our radio-wave observations.

The influence of external factors, such as solar activity, on the global electric circuit was investigated in several papers (for example, [4]) During an 11-year solar activity cycle electric current in fair weather zones and the number of sun spots variate with opposite phases. Cosmic rays flow in lower atmosphere also anticorrelates with this number. On the other hand, it was shown by age overlapping technique that the atmospheric current in fair weather zones grows up by ~ 20÷30 % during chromospheric sun flares and remains increased for a few days. If we take into account only variation of atmospheric electric conductivity in fair weather zones (zones of global circuit load), we will face a contradiction. Therefore changes in the zones of electromotive force formation are the subject of certain interest. Unfortunately due to low solar activity during last 2–3 years we have not accumulated a population of events large enough for statistical inference. In Fig. 3 and 4 variations of electromagnetic noise standard deviation during solitary Forbush decreases of cosmic

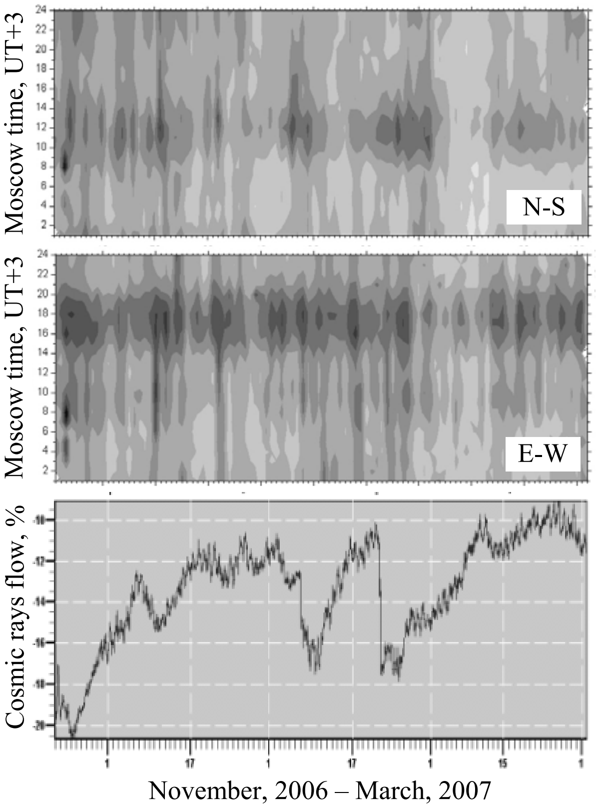

Fig. 3. Temporal variations of electromagnetic noise ($\sqrt{\overline{s^2}}$) in N-S and E-W detectors and cosmic rays flow (IZMIRAN neutron monitor, Troitsk, Moscow region) over a period of November 21, 2003 to March 1, 2004.

rays flow are represented. In Fig. 3 one can see some noise intensity peaks (mainly in “N-S” channel) coinciding with moderate (~ 6 %) cosmic rays flow decreases. In Fig. 4 the same effect can be observed. But we still can not treat these peaks as current increase in fair weather zones reported in [4] because similar fluctuations occur when the cosmic rays flow is stable. Thus, the coincidence of intensity peaks with Forbush decreases may turn out to be accidental.

6. Conclusion

The number of pulses per unit time obtained by the technique suggested is in a good agreement with the number of lightnings registered by Earth satellites and with planetary electromotive force power estimation. It is mainly number of lightnings per unit time that varies in planetary thunder activity zones, but not their energy. The source of the Gaussian noise component is expected to be in-cloud lightning discharges, more numerous but less effective in terms of planetary resonator excitation. This can be illustrated by normalization of the pulsed noise in $\nu >> 1$ specific case due to the central limit theorem [1].

References

1. Rytov S. M. Introduction to statistical radiophysics. Part 1. Random processes. M.: Nauka. 1976. 496 p.
2. Kramer G. Mathematical methods of statistics. M.: Mir. 1975. 648 p.
3. Hayakawa M., Sekiguchi M., Nickolaenko A.P. Diurnal variations of electric activity of global thunderstorms deduced from OTD data // J. of Atmos. Electr. 2005. V.25. N2. P.55–68.
4. Markson R. Atmospheric electricity and problem of relation between solar activity and weather // in «Solar-Earth relations, weather and climate». Ed. B.Mc-Kormac and T.Seliga. M.: Mir. 1982. P.242–265.

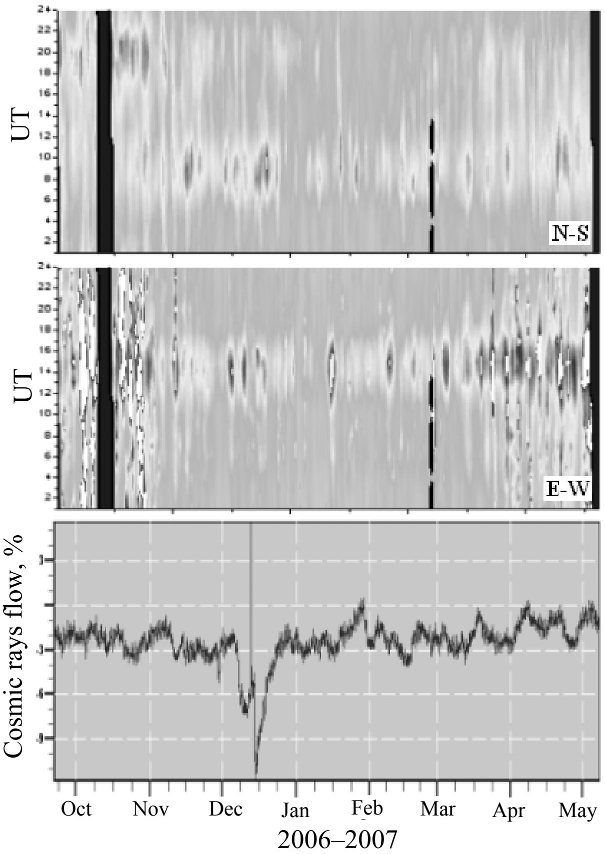

Fig. 4. Temporal variations of electromagnetic noise ($\sqrt{\overline{s^2}}$) in N-S and E-W detectors and cosmic rays flow over a period of September 22, 2006 to May 7, 2007.