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Power spectrum features of the near-Earth atmospheric electric field in Kamchatka

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Abstract

Power spectrum of the diurnal variations of the *quasi*-electrostatic field E_z in the near-Earth atmosphere have been presented for the first time. The E_z power spectrum variations in the period of fine weather have been shown to exhibit two bands of the periods of natural atmospheric oscillations with T = 1-5 and 6-24 h. These oscillations are the modes of the internal gravity and tidal waves in the lower atmosphere. On the days under atmospheric precipitation, the spectral power of E_z increases by an order of magnitude. During the pre-earthquake period, when the diurnal E_z variation had an anomaly, the intensity of harmonics with T = 1.8, 2.2, and 3.8 h increased by an order of magnitude or more in comparison with the E_z spectra in fine weather. Two additional spectral bands with T = 0.6 and 1 h have appeared simultaneously.

Key words *atmospheric* quasi-*static electric field – atmospheric precipitation – atmospheric waves*

1. Introduction

Anomalous variations in the *quasi*-static electrical field E_z in the near-Earth atmosphere before the $M \geq 4$ earthquakes have been recorded in many seismo-active regions of the Earth. They usually occur at an interval of a few hours to a few days before the main shock and prove to be either a bay-like field intensity decrease (even to a sign reversal) or an oscillation train lasting a few hours. These observations were summarized and analysed by Rulenko (2000) and made it possible to establish that both types of E_z anomalies are caused by the deformation processes in the subsurface layers of the Earth's crust during the earthquake preparation phase. The former type of anomalies were observed on Kamchatka for a few years and were referred to the radon (Rn) emission from subsurface gases into the atmosphere, resulting in variations of atmospheric conductivity and, therefore in E_z magnitude (Rulenko *et al.*, 1992, 1996; Buzevich *et al.*, 1998; Smirnov, 2001). These results, as well as the observations in other seismo-active regions, have made it possible to assume that the *quasi*-static electric field in near-Earth atmosphere can be responsible for ionospheric disturbances occurring before seismic shocks (Morgunov, 1988; Pulinets *et al.*, 1998; Mikhailov *et al.*, 1999). Research of electrical field intensity in temporary series has shown that the field value is affected by meteorological characteristics (precipitation, winds) (Smirnov, 2001; Mikhailov *et al.*, 2002). This fact makes it difficult to detect some anomalies in E_z behaviour before the earthquake.

The object of this paper is the investigation of the power spectrum in the near-Earth atmos-

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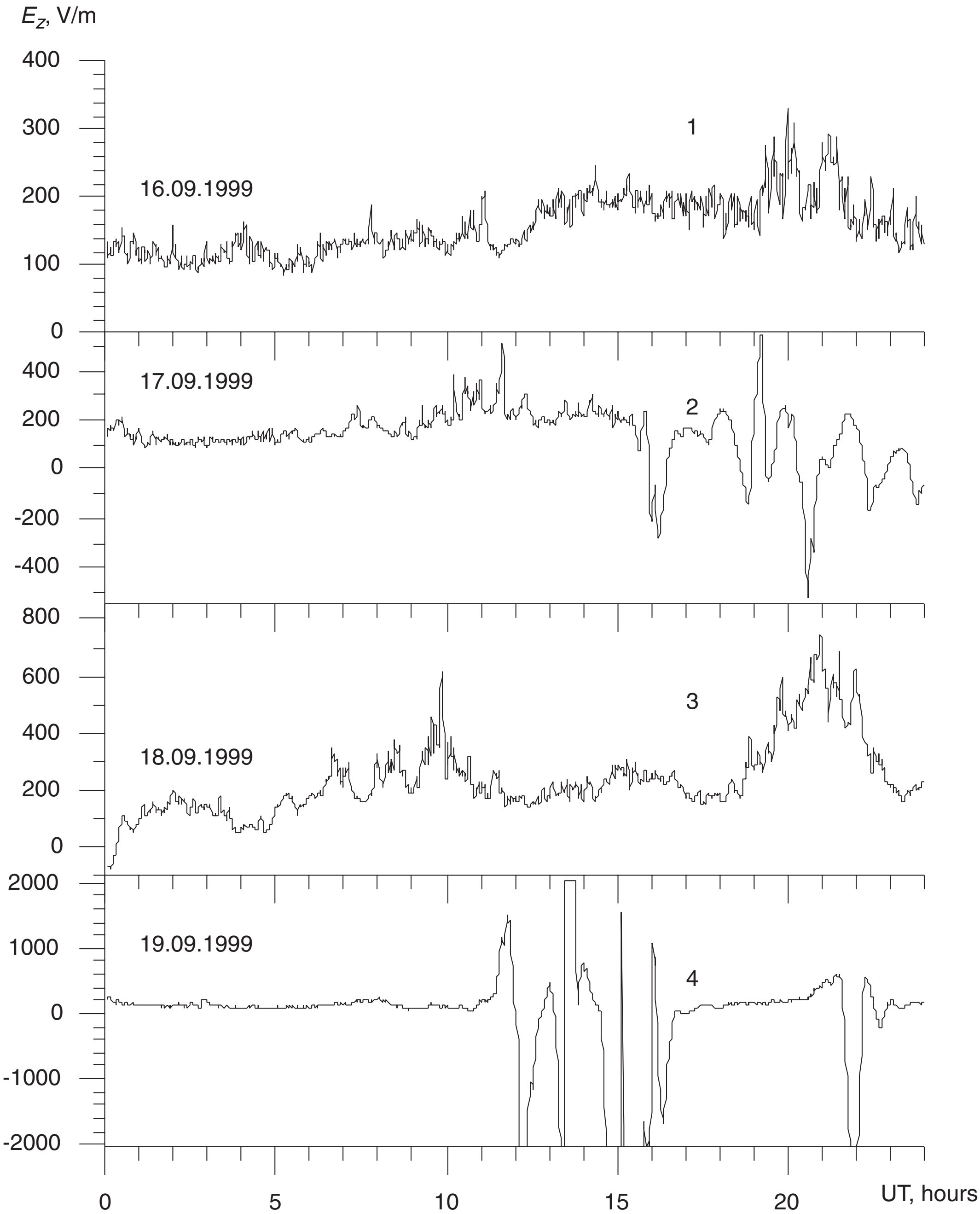

Fig. 1. Typical diurnal variations in a *quasi*-static electric field E_z in the near-Earth atmosphere: 1-3 – days without atmospheric precipitation; 2 – a day before the earthquake; 3 – for the earthquake day; 4 – day with heavy atmospheric precipitation.

pheric *quasi*-static electric field E_z in a period of the fine weather, under atmospheric precipitation and during the pre-earthquake period of anomalous diurnal variations E_z.

2. Experimental data and processing procedure

The Pole-2M electrostatic flux-meter, whose output data are transmitted into the information processing centre in the analogue form, is used at Paratunka ($\varphi = 53°$N, $\lambda = 158.3°$E) to measure the vertical component of the atmospheric electric field (E_z). The E_z values are digitized with sampling rate $\Delta t = 1$ min. The results of the investigations of the power spectrums of the near-Earth atmospheric electric field in September-October 1999 are presented below. Figure 1 shows the typical diurnal E_z variations in the fine weather (curve 1), on the day before the earthquake (curve 2, September 17), on the day of the earthquake (curve 3, September 18, 21.28:33.17 UT, $\varphi = 51.21°$N, $\lambda = 157.56°$E, $h = 60$ km, $M_p = 6.0$) and on the day with intense precipitation (curve 4, September 19). The character of the diurnal E_z variations in the fine weather is described qualitatively by physical processes, occurring in the near-Earth atmosphere. The increase in E_z magnitude at 19-24 UT (06.00-11.00 LT) is related to the convective processes in the atmosphere due to the air temperature variations in the morning. In the fine weather in the daytime and at night the electrical fields are ~ 100-120 V/m, varying in the range ~ ± 20 V/m.

At high and durable precipitation, the electric field value decreased to – 1 kV/m. On the rainy day (September 19), which carries to the Earth's surface volume changes, the atmospheric conductivity increases and E_z decreases, even to a sign reversal. Other examples of the diurnal E_z variations in fine weather and at high precipitation were shown in the paper (Mikhailov *et al.*, 2002).

On the day before the earthquake (curve 2), the bay of decreased E_z magnitude was observed at 15.00-24.00 UT against a background of quiet meteorological conditions. Similar effects were observed in the Paratunka during period 1997-2000 in 1-36 h before earthquakes (Smirnov, 2001).

By example of 29 September 1999, fig. 2 illustrates the spectral processing of the diurnal E_z data. The upper curve 1 represents the diurnal variations E_z. The next curve below 2 is the same data obtained by subtracting the daily average E_z value from curve 1. Curve 2 shows the well-marked semidiurnal wave, whose daytime amplitude is less than the nighttime one. These values have been added by zeros to have 2048 points, needed for using the fast Fourier transform algorithm (FFT). The power spectrum of the augmented E_z time series was computed by the method of periodograms with rectangular time «window» at frequencies of $f_k = k \cdot \Delta f$ with a corresponding frequency step of $\Delta f = 1/2048 \cdot \cdot \Delta t = 8.14 \cdot 10^{-6}$ Hz and with periods of $T_k = = 1/f_k$, where $k = 1, 2, \ldots, 1024$. This spectrum is shown in the panel 4 (solid line, left ordinate axis). The period of the predominant harmonic is $T = 12$ h and less intensive harmonics with periods of 1-5 h are also present. To distinguish them we excluded periods longer than 5 h from the spectrum (the dash-dotted line, right ordinate axis). The time form of these filtered series is shown by curve 3. The spectra labelled 5 are shown in the bottom of fig. 2 as a function of the periods varying to 24 h (on the left) and $T < < 5$ h (on the right).

3. Main results

The method described above was used to make the spectral analysis of the diurnal variations in E_z for September-October 1999. Naturally, the spectrum forms varied from day to day. To obtain statistically reliable spectra and to distinguish stable maximums the data have been averaged over days with specific E_z behaviour. We used days without atmospheric precipitation and earthquakes, when the spectral variations may be caused by global effects in the Earth's crust in the given region and, consequently, in the near-Earth atmosphere. Figure 3 shows the control atmospheric precipitation data for the observation period.

The resulting averaged spectra for the days without (22 days, curve 1) and with (11 days,

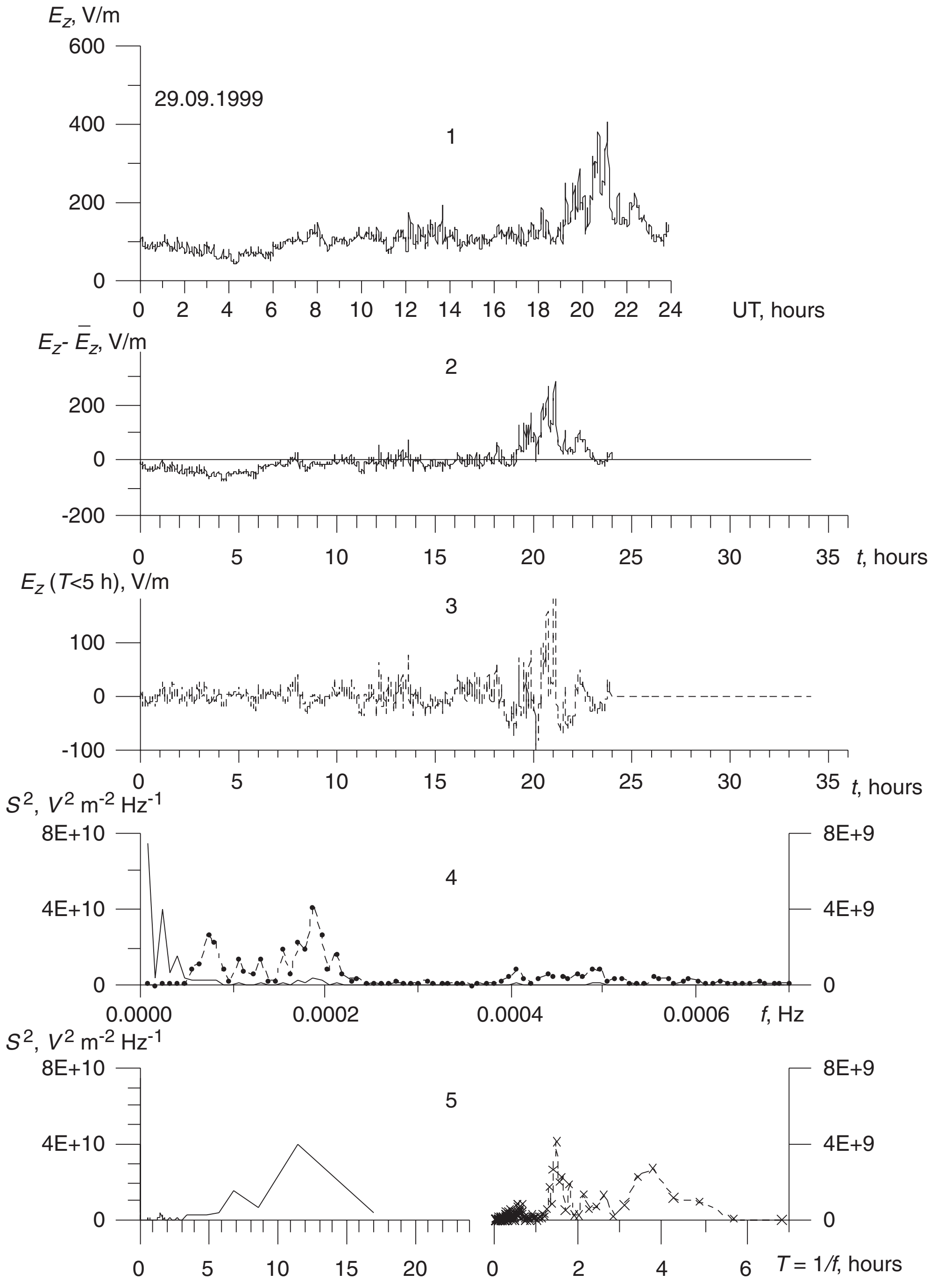

Fig. 2. The method for spectral processing of the diurnal E_z variations.

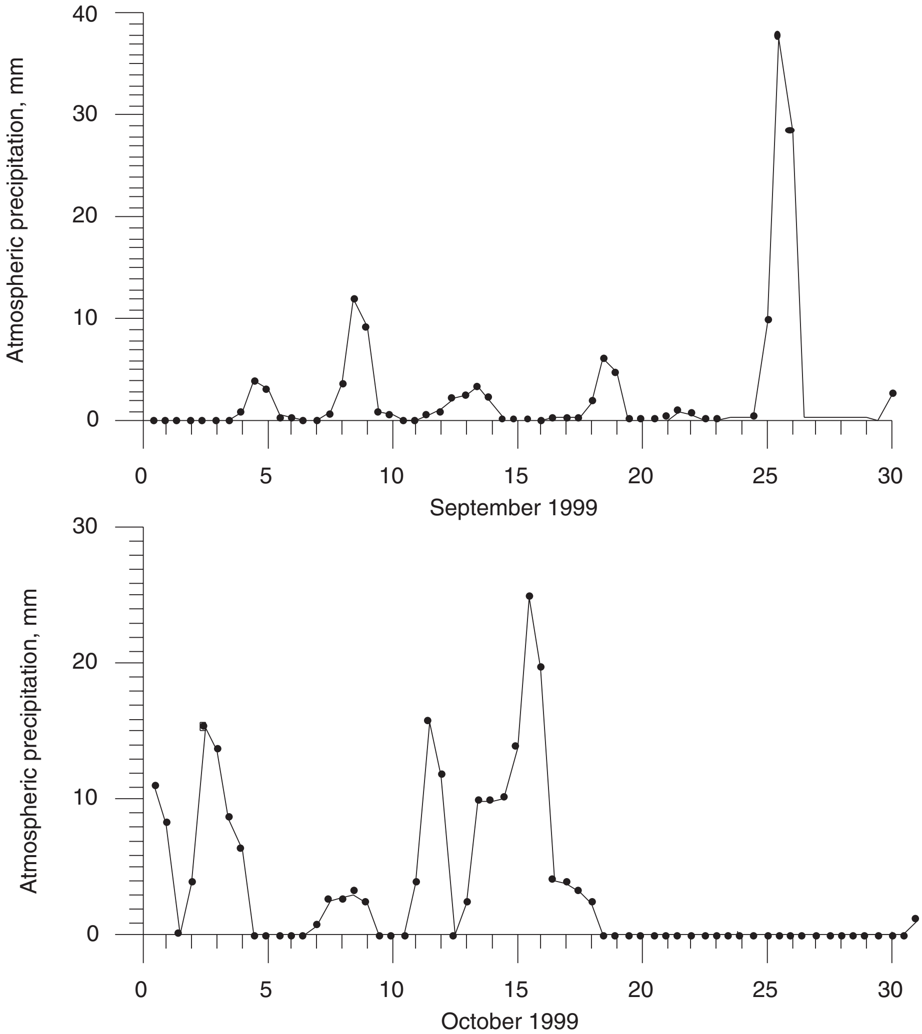

Fig. 3. Variations in the atmospheric precipitation level measured twice a day during September-October 1999.

curve 2) atmospheric precipitation are shown in fig. 4 ($T < 5$ h) together with the individual spectrum for September 17 (curve 3). The vertical bars in curves 1 and 2 are the mean-square deviations. Curve 1 indicates the spectrum weakening from $\sim 2.5 \cdot 10^9$ V^2/m^2 Hz at $T \sim 4$ h to $\sim 2 \cdot 10^8$ V^2/m^2 Hz at $T \sim 1$ h without pronounced peaks at a level of 0.5 relative to the maximum value. The character of the spectrum shown by curve 2 has changed insignificantly, namely, the energy enhancements at $T \sim 4$ h and ~ 2 h, but the power level have increased twofold compared to curve 1, with very large mean-square deviations indicating that individual spectra are widely variable. Finally, curve 3 represents the individual E_z power spectrum for 17 September 1999 without atmospheric precipitation, but with anomalous diurnal variations (see fig. 1).

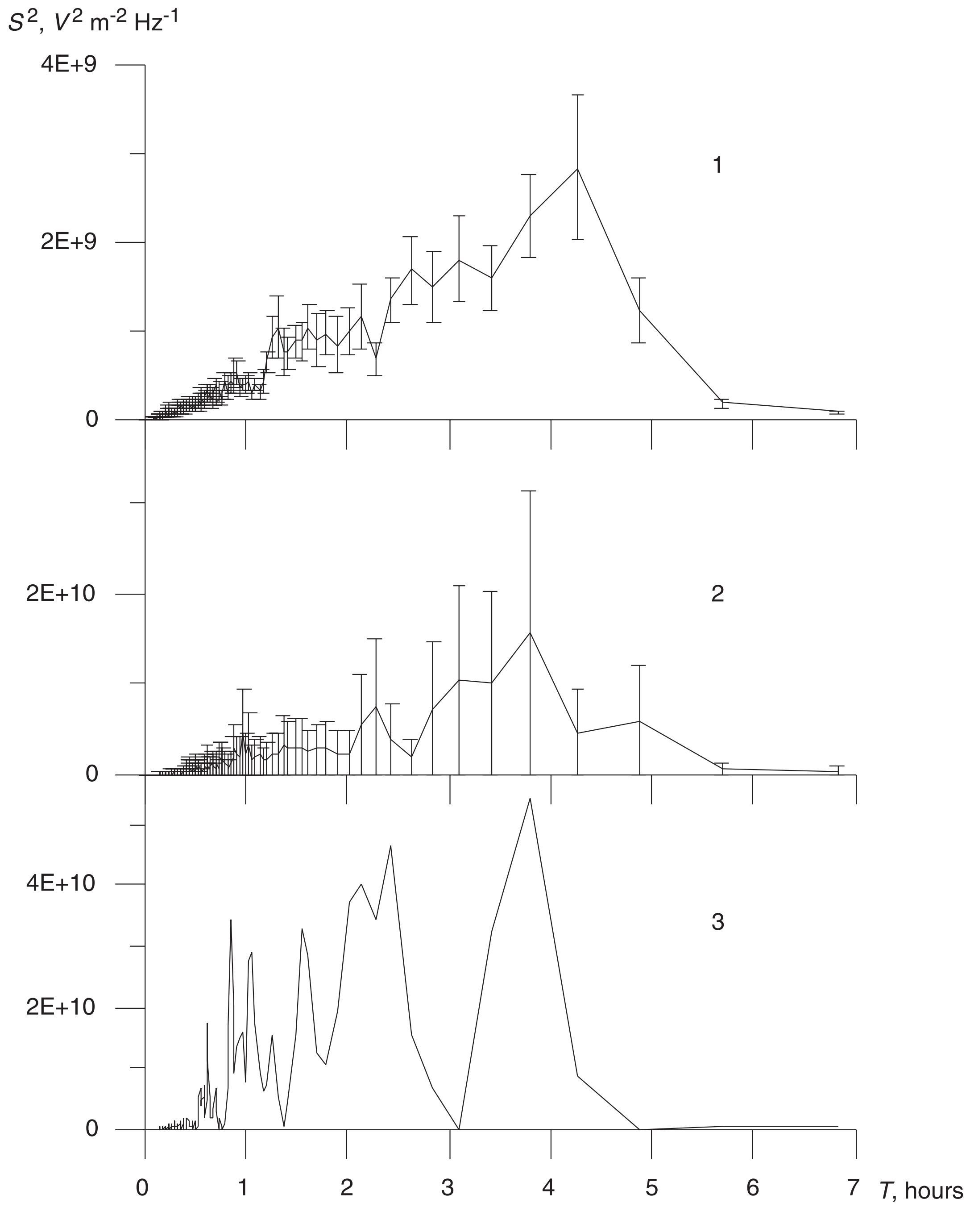

Fig. 4. The averaged E_z power spectrum in the band of periods $T < 5$ h on the days without precipitation (curve 1) and with precipitation (curve 2) and 17 September with the anomalous diurnal variations E_z (curve 3).

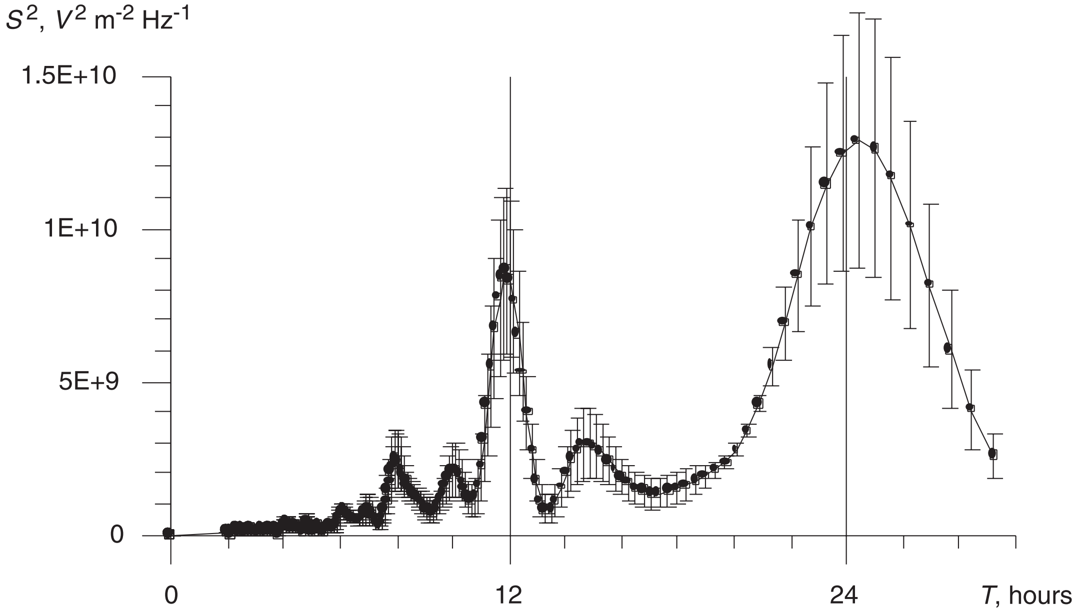

Fig. 5. The averaged E_z power spectrum with periods of 2 h < T < 30 h for the fine weather days from 1 September to 29 October 1999.

The following features are clearly defined in this curve:

i) There are the spectral bands (at 0.5 level of the maximum) at T = 0.6, 1, 1.8, 2.2 and 3.8 h.

ii) The intensity at maxima of these bands exceeds the corresponding values for the days without atmospheric precipitation by an order of magnitude or more.

The T > 5 h harmonics were distinguished by calculating the spectra of longer initial date series with a time step of Δt = 1 h only for days of the fine weather, *i.e.* September 1-4, September 20-24, October 20-24 and October 25-29. Figure 5 represents the resulting spectrum, averaged over these days, which shows the clear maximums with $T \sim 8$, 10, 12 and 24 h.

During September-October 1999 (except September 18), two more Kamchatka earthquakes occurred, whose preparation zone included the E_z measurement point. The earthquakes occurred on October 5 (05.01:35.94 UT, φ = 51.21°N, λ = 157.61°E, h = 76 km, M = 5.6) and on October 18 (20.49:47.92 UT, φ = 51.30°N, λ = 157.12°E, h = 138 km, M = 4.8). From fig. 3 it is seen, however, that rainfalls were recorded during these days, which probably screened the E_z effects caused by other sources.

4. Discussion

The continuous measurements of *quasi*-static electric field E_z with the sampling rate Δt = 1 min have made it possible to study the fine structure of the power spectra with periods from 4 min and longer. Two spectral bands with periods T = 1-5 h and 6-24 h have been found by analysing the E_z diurnal variations for September-October 1999. Under fine weather, clearly defined maximums (at a level of 0.5) were absent, but the intensity trended to weaken when the periods decreased from 5 to 1 h. These periods are known to be the periods of internal gravity waves, which are clearly seen in the seismo-gravitational oscillations of the

Earth and related with pressure disturbances in the near-surface atmosphere (Garmash *et al.*, 1989; Petrova, 1999). The coincidence of the E_z power spectra with those of the Earth's seismo-gravitational oscillations, allows us to state that the E_z variations are of seismic nature. If we accept the «piston» mechanism of generation of air pressure fluctuations by the Earth's surface oscillations (Garmash *et al.*, 1989), then we may expect similar variations in the radon concentration spectra in subsurface gases.

The T = 6-24 h spectral band shows the clear harmonics with T = 8, 12 and 24 h. These are the tidal waves in the lower atmosphere, related to the variations in the temperature of underlying surface. Their intensity is of the same order of magnitude as that of internal gravity waves.

One day before the earthquake on 18 September 1999, the E_z power spectrum showed three distinct maximums (relative to the half-maximum level) at T = 1.8, 2.2, and 3.8 h. Their intensity increased by an order of magnitude and more, especially at T < 3 h, as compared with the E_z spectra during the days of the fine weather. Moreover, spectral components at T = = 0.6 and 1 h appeared too. The similar spectral structures within the T = 1-5 h band were observed by Lin'kov *et al.* (1990) and their enhancement in the variations in the Earth's seismo-gravitational oscillations and in the simultaneous pressure variations in the near-Earth atmosphere before a strong earthquake. The agreement between the E_z spectra and the results of those papers indicate that not only the quiet diurnal variations in E_z, but also anomalies before earthquakes are of the same seismo-gravitational nature.

5. Conclusions

The fine spectral analysis of diurnal variations in the *quasi*-static electric field E_z in the near-Earth atmosphere has been carried out for the first time and has shown the following:

i) In fine weather and on the days with atmospheric precipitation the natural frequencies of atmospheric oscillations have been distinguished in two bands with periods of T = 1-5 h and T = 6-24 h in the E_z power spectrum. The former band corresponds to internal gravity wave modes of the lower atmosphere, while the second band to the tidal waves.

ii) During the earthquake preparation period, the intensity of bands with T = 1.8, 2.2, and 3.8 h increased by an order of magnitude and more compared with spectra obtained in fine weather. During this period, two additional spectral bands with T = 0.6 and 1.0 h were distinguished.

iii) The nature of the E_z spectral anomalies from the Earth's seismo-gravitational oscillations has been confirmed experimentally. However, the question has still to be answered as to whether the pre-earthquake bay-like weakening anomalies of E_z are caused by enhancement of conductivity in the lower atmosphere as a result of the additional ionization by a radioactive gas, or this weakening is a purely seismic electrical signal caused by the rock failure in a hypocenter.

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