Estimation of Geomagnetic Field Disturbance Using the Wavelet Transform[1]

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Abstract– This paper discusses the main aspects of geomagnetic data processing using the wavelet transform. The wavelet transform is shown to be efficient for automatic extraction of unperturbed level of the horizontal component of the Earth's magnetic field. As a result, it becomes possible to significantly reduce the errors arising during automatic calculations of the local geomagnetic activity index (local K-index) in comparison with adaptive smoothing (KAsm is Adaptative Smoothing method) recommended by INTERMAGNET. It has been found that prior to magnetic storms, we can observe a weak rise of geomagnetic activity in different frequency bands connected with the development of an approaching storm.

Keywords: magnetic storm, geomagnetic data processing, wavelet transform, Earth's magnetic field, geomagnetic activity index

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1. INTRODUCTION

During the periods of magnetic storms, geomagnetic data contain variations distributed over different frequency bands. Local features formed in these periods are determined by the field disturbance and these features provide information about the intensity and type of a magnetic storm [1]. The complex structure of geomagnetic variations puts certain restrictions on spectral analysis techniques since their application does not make it possible to obtain information about local changes in a physical process nor the scaling characteristics of these processes [2–9].

The authors suggest the wavelet transform as a mathematical tool for geomagnetic variation analysis [10, 11]. Currently the wavelet transform is widely exploited for the following tasks:

• analysis of local features arising in the geomagnetic field during strong solar flares [5, 8];

• search for periods of the initial phase of a magnetic storm [9];

• signal denoising;

• extraction of the periodic component caused by the Earth's rotation [6, 7].

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The authors applied the wavelet transform for automatic extraction of unperturbed level of the horizontal component of the Earth's magnetic field [2, 3]. As a result, it has become possible to dramatically reduce the errors arising during the automatic calculation of the local geomagnetic activity index (local K-index) in comparison with adaptive smoothing (KAsm is Adaptative Smoothing method) recommended by INTERMAGNET.

The new technology is now used by the magnetic observatories "Paratunka" (Institute of Cosmophysical Research and Radio Wave Propagation of the Russian Academy of Sciences, Paratunka village, Kamchatka region, Russian Far East) and "Yakutsk" (Shafer Institute of Cosmophysical Research and Aeronomy of the Russian Academy of Sciences, Yakutsk, Russian Federation). This paper familiarizes us with spatiotemporal analysis of magnetic storms using the magnetic field data, this analysis being based on the wavelet transform. The new method includes extracting components of the registered variations of the magnetic field in different frequency ranges, estimating the perturbation intensity, and constructing a dynamic spectrum of variations. This method also allows us to discover the time points when geomagnetic activity starts growing prior to and during the periods of extreme

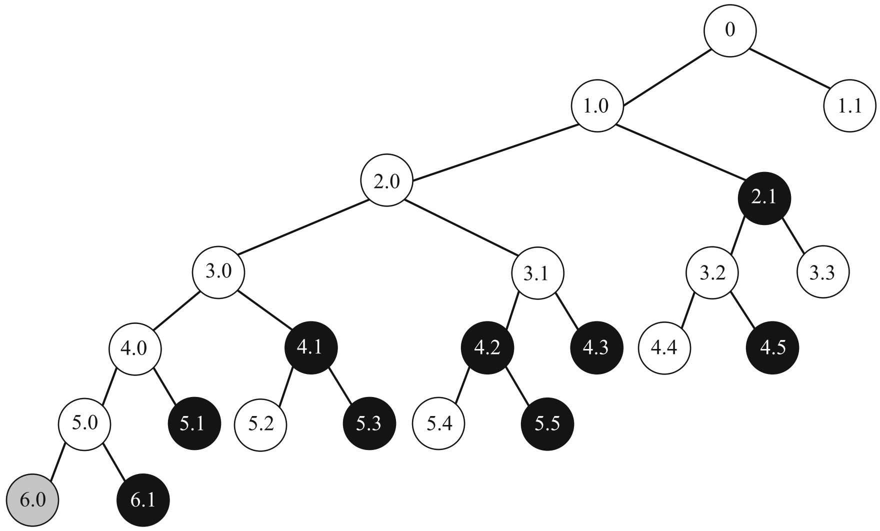

Fig. 1. Variation components of the geomagnetic field (the first digit denotes the level of the wavelet decomposition, the second digit denotes the number of the component). The grey color indicates the quiet component f_{trend}, the black color indicates the perturbed component g_j.

solar events and to localize activation areas. The suggested algorithms can be performed in the automatic mode (close to real time) and adapted for various magnetic observatories.

The suggested mathematical tools have been used for processing data from magnetic observatories in the north-eastern region of Russia. Local increases of perturbation intensity have been extracted in the geomagnetic field; these perturbations arise in different frequency bands during and prior to the development of the main phase of a magnetic storm.

2. GEOMAGNETIC FIELD VARIATION ANALYSIS BASED ON WAVELETS

Consider $f_j(t)$ as the time variation of the horizontal component of the geomagnetic field. We will assume $j = 0$, i.e., $V_0 = \text{clos}_{L^2(\mathbb{R})}(\phi(2^0 t - n))$ for the original data [10, 11]. The wavelet-packet transform can be used to obtain the following presentation of $f_0(t)$ [2, 3]:

$$\begin{aligned} f_0(t) &= \sum_n c_{-m,n}\phi_{-m,n}(t) + \sum_{j\in I}\sum_n d_{j,n}\Psi_{j,n}(t) \\ &+ \sum_{j\notin I}\sum_n d_{j,n}\Psi_{j,n}(t) = f_{\text{trend}}(t) + f_{\text{pert}}(t) + e(t), \end{aligned} \tag{1}$$

where I is the set of indices.

In [3, 4] it is shown that during the period of quiet geomagnetic field the Kamchatka and Yakutsk regions have the component $f_{\text{trend}}(t) = \sum_n c_{-6,n}\phi_{-6,n}(t)$ characterizing unperturbed level of the horizontal component of the Earth's magnetic field and the component $f_{\text{pert}}(t) = \sum_{j\in I} g_j(t)$, where $g_j(t) = \sum_n d_{j,n}\Psi_{j,n}(t)$ characterizing perturbations during the periods of increased geomagnetic activity. The component $e(t) = \sum_{j\notin I}\sum_n d_{j,n}\Psi_{j,n}(t)$ characterizes noise. The measure of magnetic disturbance of the component $g_j(t)$ on the scale j is determined as $A_j = \max_n(|d_{j,n}|)$ [3, 4]. The extracted components of a wavelet tree characterize variations of the geomagnetic field in the wavelet domain and are shown in Fig. 1.

3. ESTIMATION OF THE FIELD ENERGETIC CHARACTERISTIC VARIABILITY AND EXTRACTION OF PERIODS WITH INCREASED GEOMAGNETIC ACTIVITY

The continuous wavelet transform is expressed by the following formula [11, 12]:

$$(W_\Psi f)(b,a) = |a|^{-1/2}\int_{-\infty}^{\infty} f(t)\Psi\left(\frac{t-b}{a}\right)dt,$$

$$f \in L^2(\mathbb{R}), \quad a,b \in \mathbb{R}, \quad a \neq 0. \tag{2}$$

Since the wavelet Ψ has zero mean, when the scale a tends to zero, the coefficients $(W_\Psi f)(b,a)$ charac-

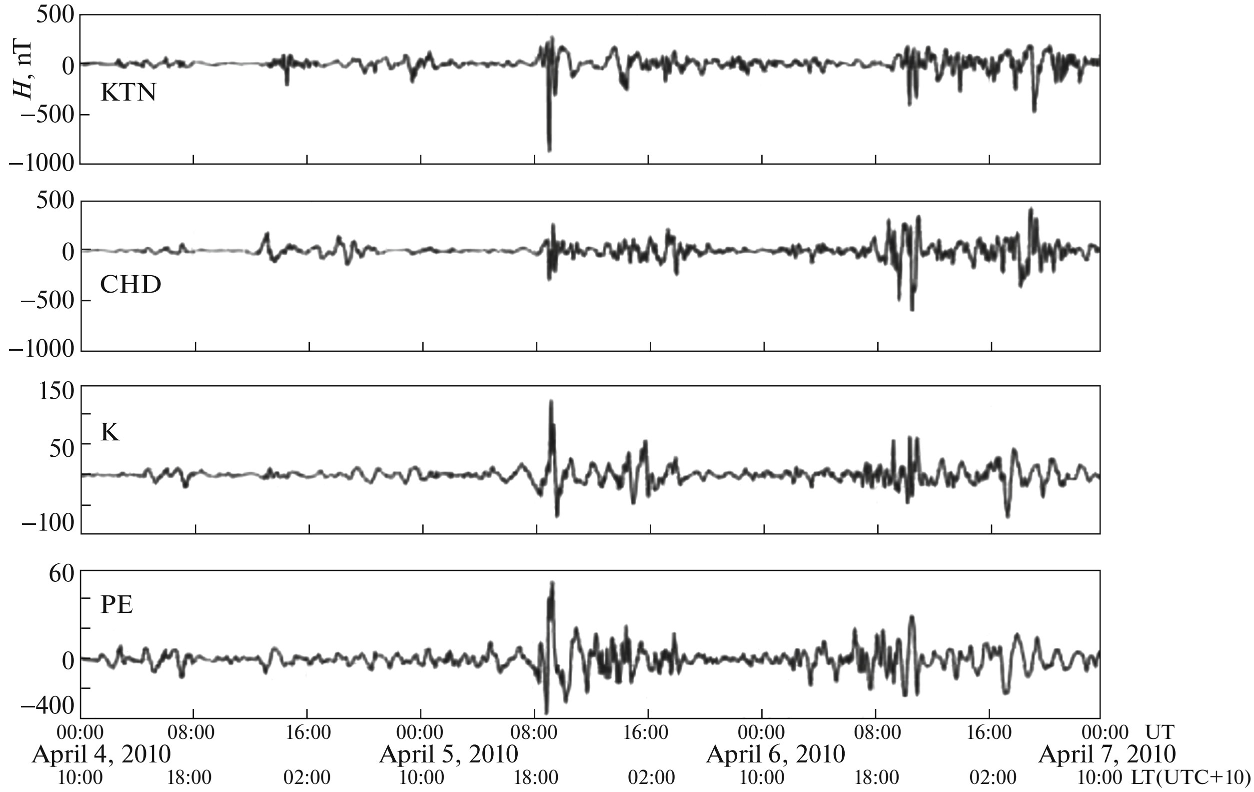

Fig. 2. Perturbed components of the geomagnetic field variations (minute values of the horizontal component).

terize the properties of f in the vicinity of b. This property allows us to obtain detailed information on local properties of the function f. The time-frequency window of the wavelet transform is [12]:

$$[win_t] = [b + a\langle t\rangle - 2a\Delta_\Psi, b + a\langle t\rangle + 2a\Delta_\Psi],$$

$$[win_\omega] = \left[\frac{\langle\omega\rangle}{a} - \frac{1}{a}\Delta_{\hat{\Psi}}, \frac{\langle\omega\rangle}{a} + \frac{1}{a}\Delta_{\hat{\Psi}}\right],$$

where win_t is the time window, win_ω is the frequency window, $\langle t\rangle = \frac{1}{\|\Psi\|^2_{L^2(R)}}\int_{-\infty}^{\infty} t|\Psi(t)|^2 dt$, $\Delta_\Psi = \frac{1}{\|\Psi\|^2_{L^2(R)}}\left[\int_{-\infty}^{\infty}(t-\langle t\rangle)^2|\Psi(t)|^2 dt\right]^{1/2}$, $\|\cdot\|_{L^2(R)}$ is the norm in the space $L^2(R)$.

The connection between the discrete and continuous wavelet transforms [10, 12] and the suggested measure of the magnetic disturbance make it possible to estimate the intensity of geomagnetic perturbations at the time point $t = b$ and scale a:

$$e_{b,a} = |(W_\Psi f)(b,a)|. \quad (3)$$

By applying threshold functions to $e_{b,a}$ on the analyzed scale a, we can estimate the condition of coefficients and find time-frequency intervals that contain weak and strong geomagnetic perturbations:

$$P_{T_{a,1}}(e_{b,a}) = \begin{cases} 0, & \text{if} \quad e_{b,a} < T_{a,1}, \\ e_{b,a}, & \text{if} \quad e_{b,a} \geq T_{a,1}, \end{cases}$$

$$P_{T_{a,2}}(e_{b,a}) = \begin{cases} 0, & \text{if} \quad e_{b,a} < T_{a,2}, \\ e_{b,a}, & \text{if} \quad e_{b,a} \geq T_{a,2}, \end{cases} \quad (4)$$

where the threshold $T_{a,1}$ makes it possible to find weak and strong perturbations and the threshold $T_{a,2}$ is used for finding strong perturbations. The perturbation intensity E_b at time point $t = b$ can be estimated as

$$e^{\pm}_{b,a} = (W_\psi f)(b,a),$$

$$E_b = \sum_a e^{\pm}_{b,a}. \quad (5)$$

4. EXPERIMENTAL RESEARCH AND DISCUSSION

The authors performed the analysis of data from a number of magnetic observatories located in the north-eastern region of Russia (the data were regis-

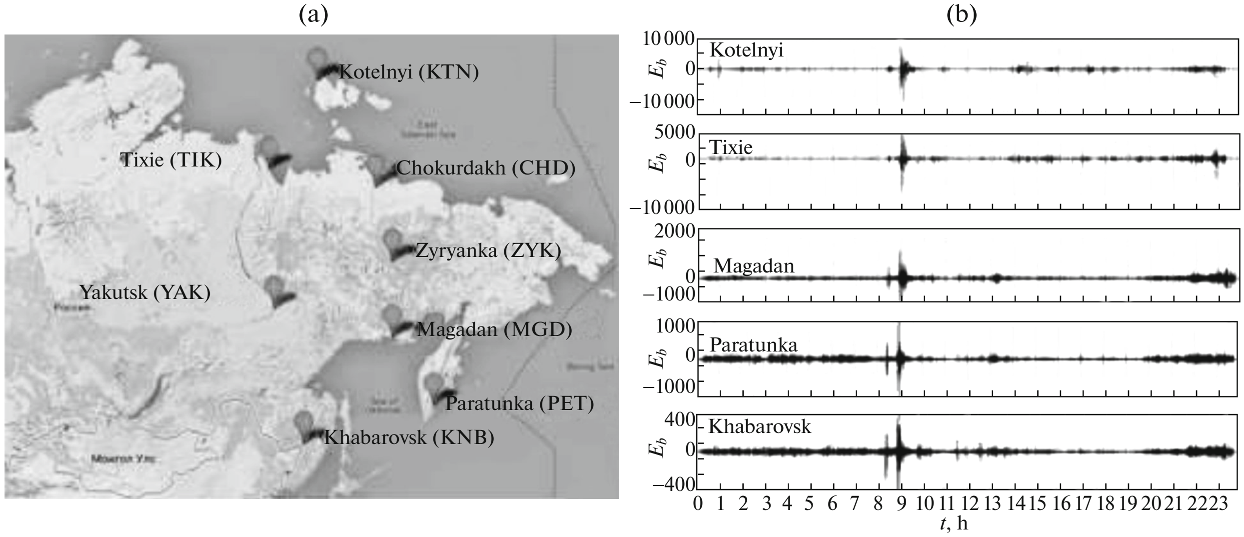

Fig. 3. (a) Location of the analyzed magnetic observatories in the north-eastern region of Russia; (b) estimation of geomagnetic perturbation intensity in the range of Pc3 pulsations (oscillation periods 10–45 s) on April 5, 2010. The processing was performed using second values of the horizontal component.

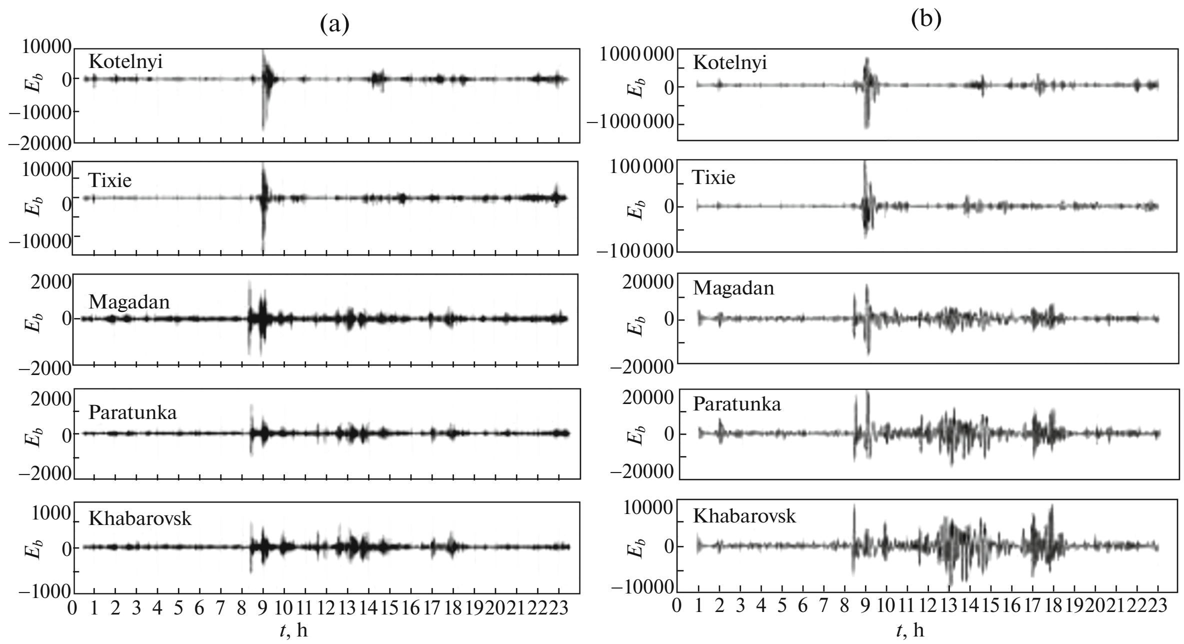

Fig. 4. (a) Estimation of geomagnetic perturbation intensity in the range of Pc4 pulsations (oscillation periods 45–120 s) on April 5, 2010. (b) Estimation of geomagnetic perturbation intensity in the range of Pc5 pulsations (oscillation periods 120–600 s) on April 5, 2010. The processing was performed using second values of the horizontal component.

tered by the Institute of Cosmophysical research and Aeronomy of the Siberian Branch of the Russian Academy of Sciences and the Institute of Cosmophysical Research and Radio Wave Propagation of the Far-eastern Branch of the Russian Academy of Sciences; both institutes are mentioned above) shown in Fig. 1 (upper plot). The analysis was compared to the data of interplanet magnetic field and solar wind parameters (the data are available at ACE Science Center, http://www.srl.caltech.edu/ACE/ASC). The decomposition was based on the Daubechies wavelet of the 3rd order [11] determined by minimizing the error in the class of orthonormal functions (we used the criterion suggested in [12]).

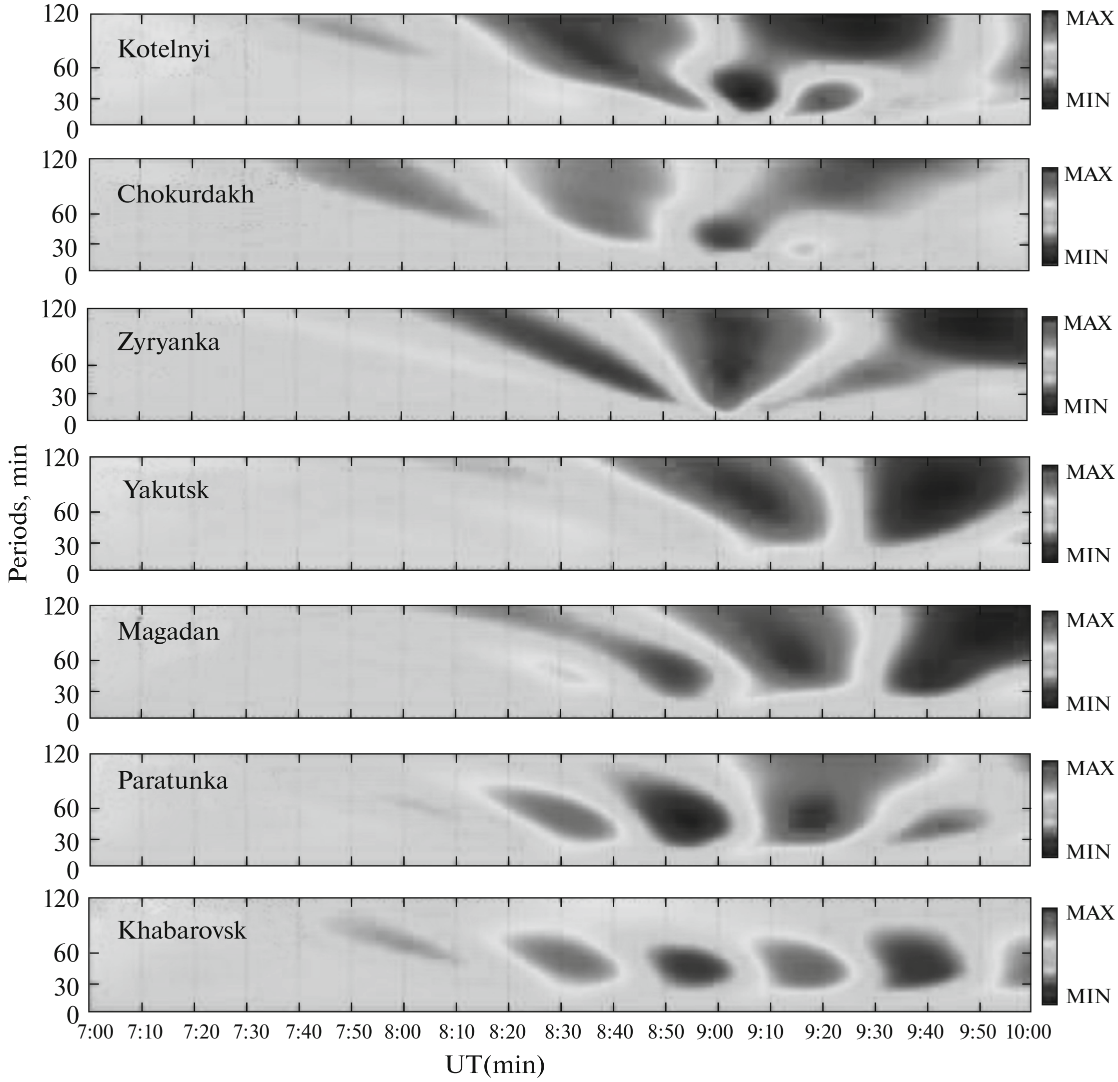

Fig. 5. Dynamic wavelet spectrum of the magnetic storm on April 5, 2010.

The magnetic storm we are analyzing occurred on April 5, 2010 and was registered on the Earth at 08:26 UT. The extracted perturbed components of the geomagnetic field variations $f_{\text{pert}}(t)$ (see (1)) are represented in Fig. 2. The amplitudes of the components $f_{\text{pert}}(t)$ at the analyzed stations reached maximum values at the initial phase of the magnetic storm in the period from 8:55 UT till 9:08 UT.

Estimation of geomagnetic perturbation intensity using (5) shows substantial local intensity rise at the storm onset at 08:26 UT in "Magadan," "Paratunka," and "Khabarovsk" observatories (Figs. 3, 4). Nearly half an hour later there was an intensive sub-storm in the Earth's magnetosphere. During the development of the sub-storm (approximately at 09:00 UT) the intensity of geomagnetic perturbations increases dramatically in all the observatories under study.

The wavelet spectrum of the intensity of geomagnetic perturbations (Fig. 5) reflects the dynamics of the event and allows us to localize the concentration areas and perturbation distribution of the geomagnetic field in the analyzed domain. During the rise of the solar wind speed (from 7:22 UT till 8:03 UT the speed of the solar wind reached 750–800 km/s according to the information from http://www.srl.caltech.edu/ACE/ASC) we can find large-scale negative anomalies at high-latitude stations (Kotelnyi island, village Chokurdakh). These anomalies are shown in blue in Fig. 5 and they illustrate gradual increase of negative perturbations. It is possible to notice abrupt spectrum non-stationarity of these perturbations and spectrum spreading in

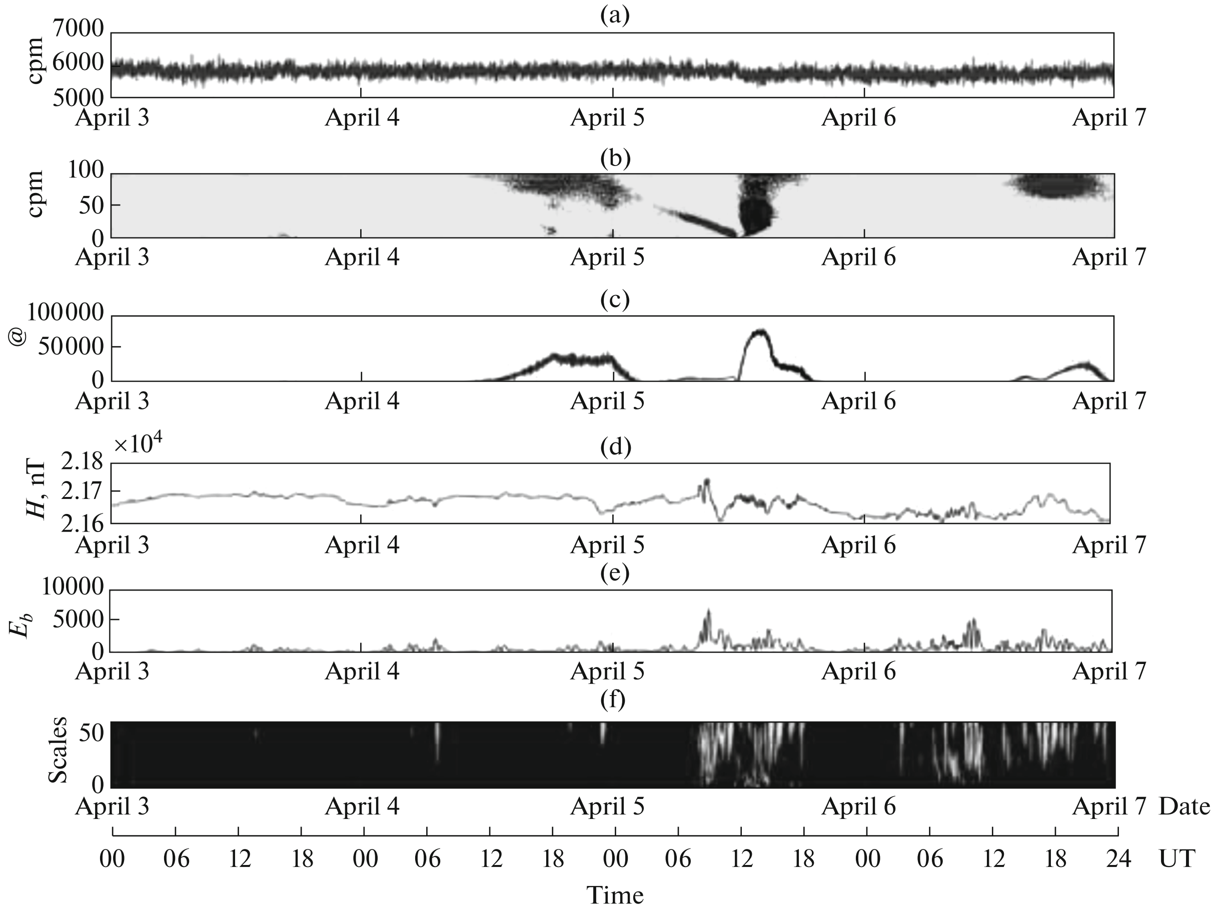

Fig. 6. Data processing results for the period from April 3 till April 7, 2010; (a) data of a neural monitor of the station Cape Shmidt; (b) local increases (black colour) and decreases (white colour) of cosmic rays; (c) resulting intensity of increases and decreases of cosmic rays; (d) H-component of the geomagnetic field, Paratunka station (see (3)); (e) estimation of geomagnetic perturbation intensity (see (3)); (f) periods of increased geomagnetic activity (see (4)).

the high-frequency domain. At 8:10 UT at the station on the Kotelniy island and at 8:20 UT at the station in Chokurdah we can observe perturbation transfer in the positive area (positive perturbations are shown in Fig. 5 in black) and spectrum spreading towards the high-frequency domain (spectrum spreading took place towards the activity periods at these stations). The observatories closer to the north (Fig. 5, Kotelnyi island, Chokurdakh, Tiksi, and Zyryanka) have the strongest perturbations at 09:00 UT. The multiscale local feature coincides with the onset of a sub-storm. The observatories closer to the south (Fig. 5, Magadan, Paratunka, Khabarovsk) have a clearly visible local feature at the moment of a storm onset at 08:26 UT, which agrees with the results of geomagnetic pulsation processing (Figs. 3b, 4).

Cosmic array data help us obtain important information about the condition of circumterrestrial cosmic space in the periods of extreme solar events [13, 14]. Figure 6 demonstrates data processing results for the geomagnetic field together with the processing results of cosmic rays. Cosmic ray processing was performed using the algorithm suggested in [15] and based on the wavelet transform. The analysis of Fig. 6 shows that nearly 1 day prior to the onset of a magnetic storm there was a local increase of cosmic rays lasting nearly 1 day (Fig. 6b; in black) and there are weak perturbations in this period in the geomagnetic field (September 4 – 04:35–04:41 UT, 06:55–07:15 UT, 19:37–19:47 UT, 22:38–23:06 UT). At the initial phase of the storm the level of cosmic rays decreased (Fig. 6b; in white) and there were the greatest perturbations of the geomagnetic field. These results confirm the efficiency of the suggested computational solutions and the possibility of their use for fast estimation of the disturbance degree of the geomagnetic field.

CONCLUSION

The analysis provided in this paper has shown that during the periods of increased geomagnetic activity the suggested mathematical tools allow us to determine time points when geomagnetic perturbations arise and to obtain estimates of the disturbance degree of the geomagnetic field. It has been found that prior to magnetic storms we can observe a weak rise of geomagnetic activity in different frequency bands connected with the development of an approaching storm. Our comparison with cosmic ray data confirmed the fact that there are weak perturbations of circumterrestrial space in the geomagnetic field prior to the arrival of a shock wave (time point SSC).

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REFERENCES

1. N. I. Budko, A. N. Zaitsev, A. T. Karpachev, A. N. Kozlov, and B. P. Filippov, *Cosmic Environment around Us* (Troitsk, 2006) [in Russian].

2. O. V. Mandrikova, I. S. Solovjev, V. V. Geppener, R. T. Al-Kasasbehd, and D. M. Klionskiy, "Analysis of the Earth's magnetic field variations on the basis of a wavelet-based approach," Digital Signal Processing **23**, 329–339 (2013).

3. O. V. Mandrikova and I. S. Solovev, "The method of the extracting disturbance and estimates of the Earth's magnetic field is based on the wavelet-packet," in *Proc. 11th Int. Conf. on Pattern Recognition and Image Analysis* (Samara, Sept. 23–28, 2013).

4. O. V. Mandrikova, V. V. Bogdanov, and I. S. Solovjev, "Wavelet analysis of geomagnetic field data," Geomagn. Aeron. **53** (2), 268–276 (2013).

5. N. Rotanova, T. Bondar, and V. Ivanov, "Wavelet analysis of secular geomagnetic variations," Geomagn. Aeron. **44**, 252–258 (2004).

6. A. Jach, et al., "Wavelet-based index of magnetic storm activity," J. Geophys. Res. **111**, a09215 (2006). doi doi 10.1029/2006ja011635

7. Zhonghua Xu, et al., "An assessment study of the wavelet-based index of magnetic storm activity (WISA) and its comparison to the Dst index," J. Atmos. Solar-Terr. Phys. **70**, 1579–1588 (2008).

8. S. R. P. Nayar, V. N. Radhika, and P. T. Seena, "Investigation of substorms during geomagnetic storms using wavelet techniques," in *Proc. ILWS Workshop* (Goa, Feb. 19–24, 2006).

9. A. G. Hafez, E. Ghamry, H. Yayama, and K. Yumoto, "Systematic examination of the geomagnetic storm sudden commencement using multi resolution analysis," Adv. Space Res. **51** (1), 39–49 (2013).

10. S. Mallat, *A Wavelet Tour of Signal Processing* (Academic Press, London, 1999).

11. I. Daubechies, *Ten Lectures on Wavelets* (SIAM, Philadelphia, 1992).

12. C. K. Chui, *An Introduction in Wavelets* (Acad. Press, New York, 1992).

13. M. I. Tyasto, O. A. Danilova, V. M. Dvornikov, and V. E. Sdobnov, "Strong cosmic ray cutoff rigidity decreases during great magnetospheric disturbances," Bull. Russ. Acad. Sci. Phys. **73** (3), 367 (2009).

14. I. N. Toptygin, *Cosmic Rays in Interplanetary Magnetic Fields* (Nauka, Moscow, 1983) [in Russian].

15. T. L. Zalyaev, "Algorithms for anomaly extraction in cosmic ray variations during heliospheric perturbations," Izv. "LETI," No. 10, 25–32 (2015).

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