ORIGINAL ARTICLE

The monitoring of the irregular disturbances in the arctic on the basis of the processing data of the distributed network of the geophysical observatories

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Abstract

Background and Objective: The article discusses a data processing method for geomagnetic field of the earth on a distributed network of geophysical observatories. **Method:** The proposed method allows to detect and monitor irregular disturbances of the geomagnetic field, evaluate their options, determine the epicenter of the occurrence of disturbances and to estimate the parameters of the epicenter. For monitoring irregular disturbances in the Arctic the application of the developed method would prevent the effects of strong magnetic storms and substorms: Failure of cable lines, railway, accidents and damage to transformers, electronic equipment, and other ground-based technological systems. The article the effect of magnetic substorms on technical objects and biosphere of the Arctic area also examines, the organization of monitoring of geomagnetic disturbances describes, the mechanism of advanced and distributed processing irregular disturbances describes. **Results:** The results of approbation of the proposed methods and algorithms on a real example are this article. **Conclusion:** The application of the developed approaches allowed to increase the precision of determining the epicentral zone, the direction of the propagation and the intensity of geomagnetic disturbances. In addition, the ambiguity of the definition of the epicenter is completely gone, all other local extrema of the value of the correlation coefficient are not >0.78. At the same time, in the processing, the possible loss of the measuring point is due to a preselection of informative areas on them, by the primary processing of geomagnetic waves.

Key words: Arctic, distributed processing, irregular pulsation, monitoring, forecasting, the magnetosphere

INTRODUCTION

The Arctic – the single physical geographical region of the earth that occupies an area of about 5.3% of its entire area. A very long time the Arctic was considered not suitable for life because it has a harsh climate, a difficult terrain, a poor adaptation of the standard of living in the modern civilization. Nevertheless, by its climate, natural resources, Arctic has always influenced the livelihood of the mankind. With it, every year its role is increasing in the economic, political and social levels of the regional and of the global scales.[1-4] Thus, there is a gradual development of the Arctic region: The development of the fuel and energy complex and the development of the natural resources, of the transport routes and the military presence, of the communication systems and the navigation.

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However, the exploration and exploitation of the Arctic are complicated by many processes that occur in it, and that increase the likelihood of accidents significantly, the time and effort to eliminate them. A special place among the negative factors, that affect on the life of mankind, are the geophysical processes that occur over the Arctic, in particular, changes of the geomagnetic field, geomagnetic storms, substorms, and auroras.[5,6]

METHODS

The magnetic storms and the substorms are the result of the action of the solar plasma (charged particles) on the earth's magnetosphere [Figure 1]. The stream of the charged particles is shifted by the solar wind and invaded in the earth's atmosphere in the places between the closed and the "open" magnetic field lines. In result atmospheric gases are ionized, atmospheric currents are increased, and geomagnetic perturbations are created.[7] The formation of the substorms [Figure 2] begins to occur in the auroral oval [Figure 2], which is located in the high latitudes of the both hemispheres of the earth, and which has a diameter of more than 3000 km during the quiet sun. During an active solar activity, the auroral oval can expand to latitudes on 25°° south or north of their usual boundaries. Currently, in the magnetosphere studying of the spatial-temporal dynamics of active forms of auroras on the night side and their sources are carried in the framework of the model of the magnetospheric substorm.[8]

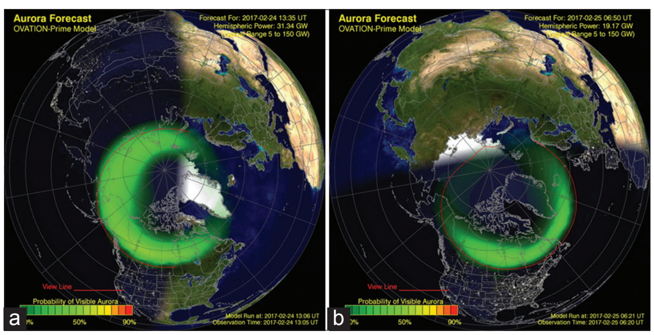

Figure 1: (a and b). The change of the location of the auroral oval in the Arctic by the data of the solar monitoring (solarmonitor.org)

In various spheres of life, the use of the Arctic is not possible without the organization of a reliable system of the communication and the direction finding. However, in practice a number of problems occur by deployment systems of the communication and of the direction finding:

- The anomalous absorption of the polar cap can lead to the weakening of radio signals up to 100 dB with a duration of 10 days after the solar flares;
- The auroral absorption with probability up to 0.4. There are individual cases of the auroral absorption with duration of up to 2 h, and there are a series of events. In these cases the passage of radio waves are violated with the weaker signals up to 60 dB;
- The random absorption by sporadic layer (about 110 km), which contributes to the formation of the waveguide channels and the leap of radio waves in the auroral zone of the absorption (which can also be used to provide radio communications).[9]

In addition to this, the disturbances of the geomagnetic field cause telluric currents to 100 A and more, and the electric field of the intensity more than 10 V/m,[10,11] that occur in the surface layers of the earth. These induced currents are very dangerous for conductive communications, cable lines (main, high voltage, communication, telephone, and telegraph), railway and other equipment.[12,13] The strongest perturbations of the geomagnetic field lead to disasters and failure of transformers, electronic equipment, and other ground-based technological systems.[14-17]

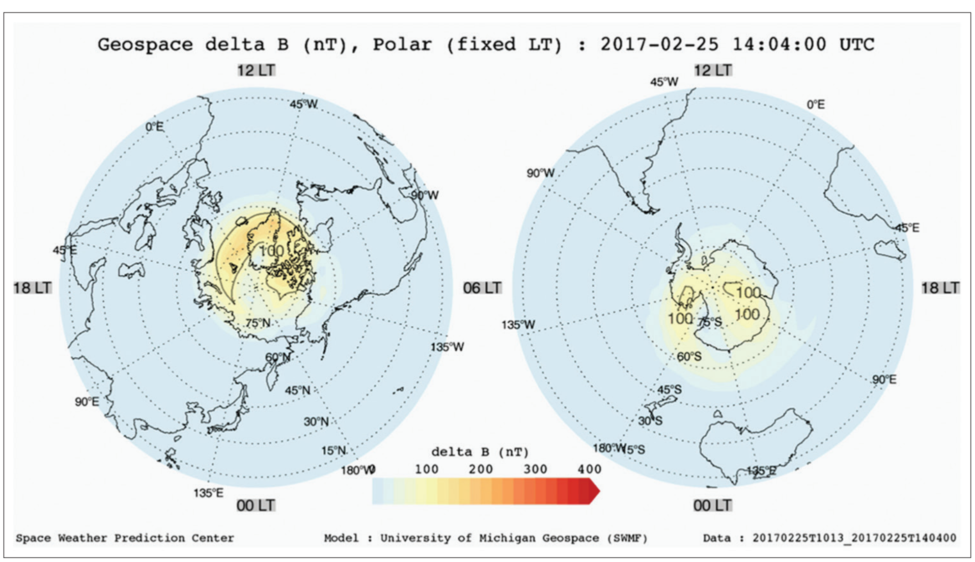

Figure 2: The map of magnetic disturbances by the date of the space weather prediction center (swpc.noaa.gov)

Furthermore, disturbances of the geomagnetic field can significantly affect human health and the biosphere as a whole.[18-20]

However, some type's geomagnetic perturbations can play a positive role in the sphere of communication, and in-depth sensing of the earth, and prediction of earthquakes.[21,22]

Thus, these problems cause more actively to explore the physics of such geophysical phenomena with the aim of the developing of the means of the monitoring, detection, prediction, and prevention of the occurrence of the geomagnetic disturbances and protection against these perturbations of the technical systems and the biosphere.

The spatial-temporal pattern of the distribution of geomagnetic disturbances problematic to determine and the epicenter of their occurrence and characteristics of the epicenter problematic to estimate by only one measurement station and is often not possible. Therefore, on a network of stations the simultaneous monitoring is conducted, i.e., the distributed system of the collection and of the processing is used.[23,24] In this case, the location of stations is the most optimal along the geomagnetic meridian and the geomagnetic parallel, which corresponds to radial and azimuthal cross-sections of the magnetosphere.

Currently, there are several research projects,[25] that implement the distributed recording of the geomagnetic field: SAMNET, INTERMAGNET, SuperMAG, PGI, IMAGE, EURIGIC, BGS, etc. In the Arctic region, the number of observatories is very minimal because there harsh climatic conditions are shown in Figure 3.[26] In addition to ground-based observatories the satellite, monitoring of the earth's magnetic field is by programs: SAC-C, CHAMP, and OERSTED.

However, in real time (1 s's measurement) the measurement of the magnetic field of the earth do not guarantee the accuracy of predictive assessments, estimates of the parameters of the geomagnetic disturbances and the epicenters of their occurrence, that leads to the acceptance of late and/or erroneous decisions, and as a consequence accidents at technical objects, and loss of life.

Currently, to improve the efficiency of the systems of the monitoring and of the prediction of the geomagnetic disturbances, the creating of new methods of the primary and the distributing processing of the signals of the geomagnetic field is necessary.[27,28]

In the local point (on the measurement of the complex of the geophysical observatory) the preprocessing is proposed to perform by the algorithm, which is shown by the block diagram on Figure 4.

The optimal filtering of the irregular perturbation is performed with help at blocks of detectors by the amplitude envelope of

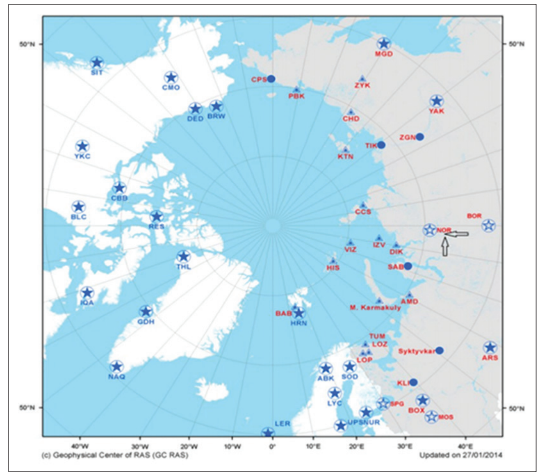

Figure 3: Climatic conditions in the Arctic region

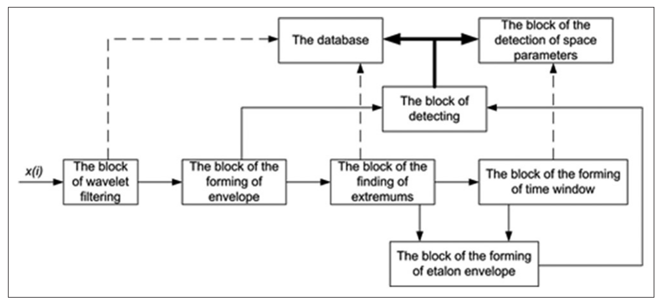

Figure 4: The algorithm of the preprocessing

the useful signal. At that, the recording data pass the frequency filtering in the block of the wavelet filter for enhancing the frequency range of the irregular disturbances.[29]

The maternal wavelets for filtering of signals are proposed to use the following wavelets: Daubechies of the 3th order, Symlet of the 3th order, and Coiflet of the 1st order.

To selection from the recording combination of the useful signal and of the noises the irregular disturbances are proposed to use an optimal detector that works by the criterion of Bayes. The criterion of the minimum of the sum of the provisional probabilities of the mistakes is proposed to use as the criterion of the optimality.

Thus, in the result of the proposing algorithm of the preprocessing is defined: The type of envelope, the duration of the perturbation, the time of their appearance, the spectral-temporal structure, the amplitude envelope, the peak amplitude, the modifying of the phase of each spectral component.

After the determining of all parameters of irregular disturbances of the local point the distributed processing is executed in the center of the monitoring and of the predicting where on the basis of the received data the localization of the epicenter of irregular disturbances, the estimation parameters of the epicenter and the formation of predictive estimates is determined.

The location of the source of geomagnetic waves is executed on the basis of their phase delays, which are obtained on the measuring points:

$$n_i = \left[(\hat{\phi}_i - \phi_{0i} + b(\omega_i) r + \omega_i \hat{\tau}) / 2\pi \right], \quad (1)$$

Where, $b(\omega_i)$ - the coefficient, that takes the dispersion of the phases speeding, φ_{0i} - the reduced phase to the epicentral area of the geomagnetic disturbances, $\hat{\tau}$ - the summary delay of the geomagnetic wave, - the phase of geomagnetic waves i, r – the distance.

In this case, the estimate of the summary delay of the geomagnetic wave can obtain:

$$\hat{\tau} = \frac{1}{M} \sum_{i=1}^{M} \{ \frac{1}{\Delta\omega_i^2 T} \int_{-T}^{T} \frac{dy(\omega_i, T)}{dT} [\hat{A}(\omega_i) y(\omega_i, T) + \xi(t) \cos(\hat{\phi}_i)] dt \} - T, \quad (2)$$

Where, $\xi(t)$ - the random stationary signal (white noise that is passed through the corresponding wavelet filter), M – the number of analyzing spectral components, $\hat{A}(\omega_i)$ - the amplitude of the geomagnetic wave, r_i – the distance from the measuring point to the proposing epicenter.

To locate epicenters of geomagnetic waves the regression expressions can use, that are proposed by the authors.[30]

Because the heterogeneity of the geomagnetic field suggests a spectral-spatial heterogeneity of the source, characteristics of the source of geomagnetic waves possible to determine only for individual spectral components by regression analysis by the method described in Kuzichkin and Tsaplev.[31] On the basis of the study authors, the spatial point estimate of the source possible to execute with a certain statistical accuracy. The elimination of the subjective component is performed by statistical methods of determining the phase of the amendments after the regression processing.[32]

The value of the half width of the confidence interval of the determining of phase characteristics is calculated by the standard deviation in accordance with the following ratio:

$$\Delta\phi = t_p (1 - R_\phi^2) \sum_{i=1}^{k} \frac{F_{0i}(\omega) - \overline{F_0}}{\sqrt{k}(k-2)}, \quad (3)$$

Where, k - the number of observation stations, t_p – the Student's coefficient, $R\varphi$ - the correlation coefficient of the phase, F_{0i}(w) – the value of the major axis of the ellipse of polarization of the phase.

Thus, the estimation of the confidence of the radius of the circle of the epicenter zone is obtained from the expression:

$$\Delta R = \sqrt{1 + \frac{n(\bar{r})^2}{D_r}} \Big/ b(\omega), \quad (4)$$

Where, D_r - the variance of the distances from the observation stations to the epicenter.

In case of ambiguity of the obtained results (the getting the number of possible epicenters) on the measuring points, you must use the method of the separation of geomagnetic waves on partial in relation to the alleged epicenter and consider adjacent paths as belonging to the same wave packet.

In this case, the regression coefficients are determined by the formula:

$$\alpha(\omega_j) = \frac{\sum_{i=1} [\overline{\ln(A_{0i})r} - \overline{\ln(A_{0i})} \cdot \bar{r}] \omega_j \delta_{ij}}{\sum_{i=1} [\overline{\ln(r^2)} - (\ln(\bar{r}))^2] \omega_j \delta_{ij}},$$

$$b(\omega_j) = \omega_j^{\beta} \frac{\sum_{i=1} [\overline{F_{0i} r} - \overline{F_{0i}} \cdot \bar{r}] \omega_j \delta_{ij}}{\sum_{i=1} [\overline{r^2} - (\bar{r})^2] \omega_j \delta_{ij}}, \quad (5)$$

Where, β - the dispersion coefficient, that considering features of the distribution of types of geomagnetic waves; δ_{ij} - the weighting coefficient, that considering measurement mistakes of geomagnetic waves be the i^{th} path on j^{th} the measurement point.

Thus, the reducing method of the statistical estimation of the epicenter zones of irregular geomagnetic waves estimate phase corrections and errors of the algorithmic processing. The proposed method gives the chance to remove the disambiguate the localization of the epicenters of geomagnetic waves and to improve the mistakes of the results of preprocessing.

RESULTS

The proposed methodology was tested in the monitoring system of pulsed geomagnetic sources of the natural origin to predict precursors of substorms in the Arctic zone on the basis of the modular approach to the distributed recording and processing signals of the geomagnetic field of the earth.

In accordance with the discussed methods as a test example the data of the registration of the geomagnetic field was processed, that obtained in the framework of the project SAMNET in the time interval UT: 2006-05-10 20:31:40 – 20:48:20. In three observation stations Oulujarvi (Finland 64.52 N 27.23

E), Uppsala (Sweden 59.90 N 17.35 E), and Crooktree (UK 57.09 N 2.64 W) analyze signals shown in Figure 5 that presented in a unified time scale and normalized with the corresponding scale factors.

To individual components of the wave packet, point estimates of the epicenters show that the wave packets are arranged in the form of some of the lines with the highest correlation coefficient by the phases in the center of the line, that accordingly the central path and decreasing values toward the edges of the line [Figure 6]. As can be seen from the figure, offset is from the western E-jets to the pole during the substorm, and it is not smooth, but a series of discrete jumps lasting a few minutes at intervals up to 10 min. The discrete shift of the epicenters of geomagnetic pulsations shows to the North West that they are grouped after the eruption of charged particles from magnetic flux tubes; the lines of force which have experienced reconnection and depositario, and then the reconnection occur the lines of force of the overlying tube.

On Figure 7 graphs of the dispersions of the phase, velocity shows from periods of the frequency tracks. As can be seen with increasing period, the phase velocity tends to decline. This fact is in good agreement with numerous works devoted to the analysis of phase and group velocities of Pi 2 perturbations.

The identification analysis of the mathematical model of the local descriptions of the field of the Pi-2 may be do by the recording data of the processing of wave packets.

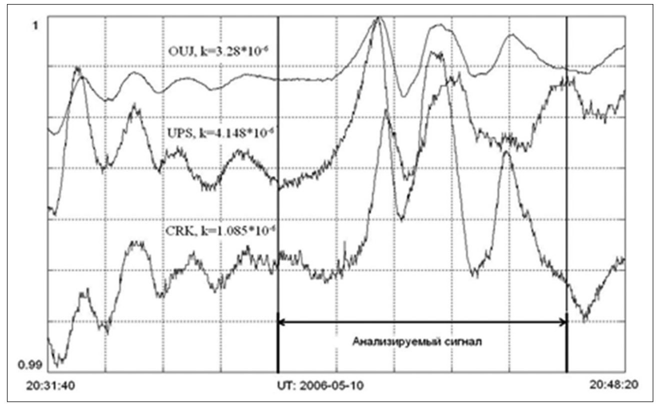

Figure 5: Analyze signals of the disturbance of the geomagnetic field

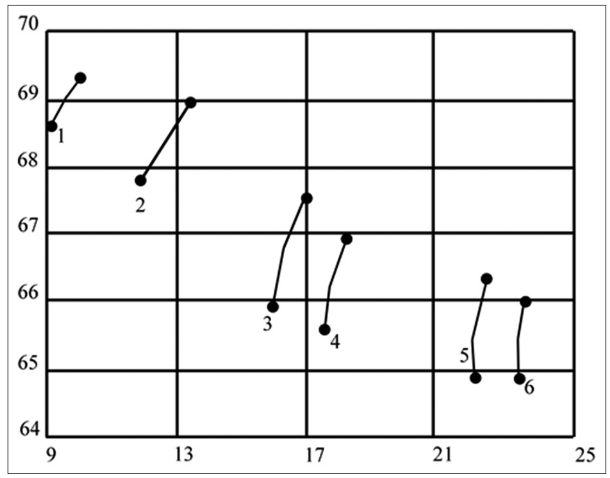

Figure 6: The evaluation of the epicenters of wave packets

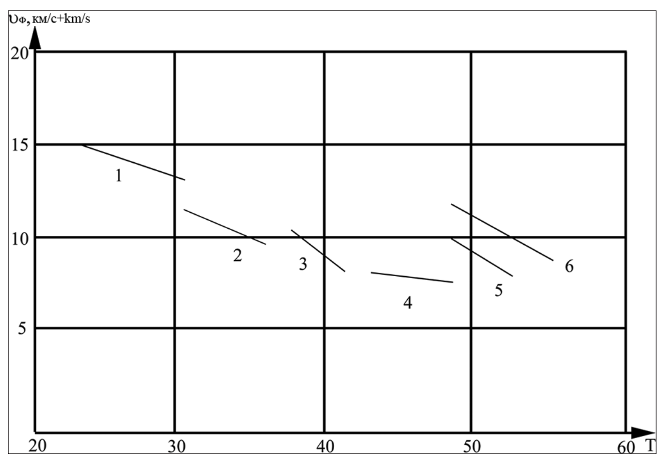

Figure 7: The dependence of phase velocities from the period

CONCLUSION

The application of the developed approaches allowed increasing the precision of determining the epicentral zone, the direction of the propagation and the intensity of geomagnetic disturbances. In addition, the ambiguity of the definition of epicenter is completely gone, all other local extrema of the value of the correlation coefficient are not >0.78. At the same time, in the processing, the possible loss of the measuring point is due to a preselection of informative areas on them, by the primary processing of geomagnetic waves.

Thus, applying the developed algorithms and methods in practice the places with the greatest geomagnetic activity possible to predict and measures to take for prevent of accidents at technical sites.

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