Lightning discharge bearing by monitoring of dangerous geological processes with a system based on Earth's natural pulsed electromagnetic field parameters

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Abstract. This paper describes an application of an Earth’s natural pulsed electromagnetic field (ENPEMF) method for thunderstorm tracing in the atmosphere. It is shown that an estimation algorithm of dangerous geological processes can exclude massive thunderbolt discharge interference in estimating the stress-strained state of rocks using the ENPEMF method over a distributed network of recorders.

1. Earth’s pulsed electromagnetic field sources
There is a widespread development of research and methodological framework for the new information and computing technologies and measuring systems to advance the current environmental research: lithosphere, atmosphere, hydrosphere, and biological objects with an ability to identify and monitor the current state of a variety of parameters and systems. Among these there is a promising branch of radiowave methods using new electromagnetic radiation frequency bands, including a very low frequency band (VLF, 3-30 kHz). In the recent years IMCES SB RAS has been rapidly developing a method of passive radiowave monitoring of lithosphere structures, irregularities, and dynamic processes based on spatiotemporal analysis of the Earth’s natural pulsed electromagnetic field (ENPEMF) structure in the VLF band [1-5].

Recording of the VLF emission of these fields allows developing methods for geophysical survey, mapping of Earth’s crust faults, monitoring of the stress-strain behavior, and forecasting of geodynamic processes [2]. Dynamoelectric conversions caused by stress-related waves from the lower mantle, tidal forces, microseisms, wind, and manmade load lead to the emergence of pulsed electromagnetic fields on these sources, which constitute a natural background lithosphere ENPEMF [3]. Multiyear measurements in various regions have demonstrated that the ENPEMF has an explicit robust diurnal and seasonal variation. This is explained by the fact that stress-related waves in the Earth’s crust are related to the rotation of the Earth and its revolution around the Sun. Diurnal variations depend on the calendar date, the geographical location, and geophysical specifics of the location. Pulsed electromagnetic fields can change due to a change in the soil conditions and due to changing impacts on the field sources. For example, typical diurnal variations can be distorted when rhythmic crustal movements change due to inclusion of separate crustal blocks into a consolidated field during preparations to an earthquake or changes in the stress-strained state of the ground [4,5].
Hence, the passive method of ENPEMF recording can potentially serve as a comprehensive tool for geophysical survey, monitoring of the Earth’s crust geodynamic activity, and Earth science research.

As a further advance of the technology mentioned before, we suggest to calculate the bearing of recorded ENPEMF signals by a solitary recorder, thus allowing one to determine the location of the signal source using a network of such recorders and subsequently outline the focus region of dangerous geodynamic processes.

2. Electromagnetic signal vector analysis and bearing finding method using “MGR-01” recorders

The method for electromagnetic signal vector analysis and bearing detection was first field tested with a network of 12 “MGR-01” recorders incorporated into a stress-strain state control system (SSS-CS). The field test was performed at the Urengoy–Pomary–Uzhgorod pipeline during the frontal passage of a storm in a known direction.

The “MGR-01” stations in the SSS-CS system were located in an area of 600 by 600 meters.

We used two criteria in the geodynamic processes monitoring algorithm based on the ENPEMF parameters. The first one shows the intensity difference in the measurements of the recorders located in the stress-strain state of the rocks control zone and the measurements of the reference recorder located not farther than 25km (VLF band wavelength) from the first group of recorders at the place not prone to the geodynamic processes. The excess of the ENPEMF pulse flow intensity at every control location over the intensity at the reference station is calculated by the formulas

\[ K_{(C-JO)} = \frac{(N_{1T(i)} - N_{1T(r)})}{N_{1T(r)}} , \]

\[ K_{(3-B)} = \frac{(N_{2T(i)} - N_{2T(r)})}{N_{2T(r)}} , \]

- where \( N_{1T(i)} \) is the intensity of the ENPEMF pulse flow in the north-southern direction at the i-th measuring station;
- \( N_{2T(i)} \) is the intensity of the ENPEMF pulse flow in the west-eastern direction at the i-th measuring station;
- \( N_{1T(r)} , N_{2T(r)} \) is the intensity of the ENPEMF pulse flow in the north-southern and west-eastern direction at the reference measuring station.

If the coefficients \( K<0 \), we consider that there are mechanical stress tensions in the respective direction, either north-southern or west-eastern. If \( K>0 \), we consider that there are strain tensions. This parameter serves as one of the main criteria for estimating the ground geodynamic state.

The second parameter of the ground stress-strain state is based on the estimation of the correlation between the i-th control station and the reference station ENPEMF intensity diurnal variation pattern. Calculation of the correlation coefficient for two samples is performed using the Spearman formula:

\[ r = 1 - \frac{6}{n^3 - n} \sum_{i=1}^{n} (x_i - y_i)^2 , \]

where

- \( n \) is the sample size (the number of observations used for the calculation);
- \( x_i \) is the rank of the i-th element of the first sample in that sample (e. g. the sample is \{5, 8, 4, 6\}, then \( x_1 = 2, x_2 = 4, x_3 = 1, x_4 = 3; \)
- \( y_i \) is the rank of the i-th element in the second sample in that sample (Figure 2).
Then we calculate the integrated coefficient for the safety estimation of the ground geodynamic state using the formula

$$ R_{\text{int}} = \frac{K + (1 - r)}{2}, $$

where $R_{\text{int}}$ is the generalized criterion for the remaining stability life of a specific location; the value is determined empirically. A level of integrated coefficient increase of more than 150% for three and more days was found to be dangerous for the further functioning of the industrial site.

3. Thunderstorm discharge bearing finding by the system of monitoring of dangerous geological processes

In May 2017 all SSS-CS stations indicated that the signal intensity exceeded the average diurnal variation more than 10 times that can be observed in Figure 1 over the period of May 1 – May 6.

The left part of the screen shows the average intensity temporal variation in North-South (H1) and West-East (H2) directions measured in pulses per minute. It can be clearly seen that in the afternoon of May 3 the signal intensity over all measurement stations and all directions exceeds 1200 pulses/min, whereas in the previous and following days it never exceeded 100 pulses/min.

![Figure 1. Screenshot of the SSS-CD operator interface.](image)

The top-right corner of the screen shows the result of calculation of the relative signal difference, considering the correlation between each measurement station (Ti) and the reference station (T04) located outside the landslide slope. The upper graph indicates the signal and, hence, the stress-strain direction of North-South, and the lower graph, West-East. The area between the two yellow horizontal lines represents a “green” zone indicating that there are no dangerous geodynamic processes in the region. Between the yellow and red horizontal lines there is a “yellow” zone indicating minor geodynamic effects, and above the red line there is a “red” zone indicating major geodynamic activity. This criterion was determined empirically and is probabilistic in nature.
Figure 1 demonstrates that although on May 3 the intensity exceeded the background values massively, the algorithm has not indicated geodynamic activity, and this may show a possible interference signal. Using thunderstorm activity logbooks, we established that there was a storm in the proximity of the SSS-CS network passing from South-West to North-East on May 3 lasting 4 hours (10:30-14:30 GMT).

Figure 2 shows the ENPEMF signal intensity data recorded by one of the SSS-CS stations over a period from 09 to 15 hours on May 3, 2017.

The graph (Figure 2) shows that the first anomalies in the signal manifested themselves when storm discharges were at a distance of 120-125 km from the SSS-CS and continued to 14:20, when the discharges were at a distance of 90 km after the thunderstorm front passed the closest point to the stations location.

Applying the standard bearing measurement formula for a signal received by two mutually orthogonal ferrite antennas of the “MGR-01” recorder, we can calculate the angle of the incoming signal:

\[ \alpha = \arcsin \left( \frac{N_{h2}}{\sqrt{N_{h1}^2 + N_{h2}^2}} \right) \],

where

- \( N_{h1} \) is the signal intensity over the North-South channel;
- \( N_{h2} \) is the signal intensity over the West-East channel.

Figure 3 shows the result of calculation of the signal bearing during the thunderstorm front passing in the proximity of the SSS-CS. The graph demonstrates that the bearing changed from -70° to +30° while the storm front was passing and when it was passing at a distance of 5km from the SSS-CS station in the northern direction the signal bearing was \( \sim 0^\circ \).

4. Conclusions
The above-described field test of an “MGR-01” recorders application for an ENPEMF parameters vector analysis has proved that with a relevant software and technical adjustment this method can be effective in reliable tracing of atmospheric storm event routes.

At the same time, the primary objective of the SSS-CS was not violated, since the estimation algorithm of dangerous geological processes excluded the interference effect from the ENPEMF stress-strain state analysis over a distributed network of recorders.

References
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