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SEISMOLOGY

Magnetic and Ionospheric Effects of a Series of Strong Earthquakes on April 2–3, 2024 (Taiwan)

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Abstract—The disturbances of the geomagnetic field in the surface atmosphere were considered during a series of strong earthquakes that occurred on April 2–3, 2024, in the vicinity of the island of Taiwan. The data from the Mikhnevo Geophysical Observatory of the Sadovskii Institute of Geosphere Dynamics, Russian Academy of Sciences, and the observatories of the international INTERMAGNET network were analyzed. It was shown that in the absence of sole-related global disturbances of the Earth's magnetic field, earthquakes were accompanied by geomagnetic variations with a maximum amplitude of ~10 nT and a total duration of about four hours. The delay time of the magnetic effect relative to the main shock of the first earthquake was ~60 min. The ionospheric effect of the event considered was established in the form of variations in the critical frequency of the *F*2 layer of the ionosphere on the basis the ionograms of height–frequency sounding obtained at the Okinawa ionospheric monitoring station and freely available on the website of the Japanese National Institute of Information and Communication Technologies.

Keywords: earthquake, instrumental observations, magnetic field, critical frequency of the *F*2 layer of the ionosphere, variation

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Variations in the Earth's physical fields are an important object of research, primarily due to their high sensitivity to external disturbances caused by natural and anthropogenic phenomena and processes [1]. The geomagnetic variations contain important data on the intensity of the exogenous and endogenous sources of disturbances of the environment, as well as data on the origin and mechanisms of geophysical processes in the Earth's interior and its external geospheres. The negative influence of magnetic field variations on the human body and its psycho-emotional state is also well known. These variations influence metabolic processes and, thus, break down the conditions of transmission and perception of control signals in the human body, which leads in some cases to its disbalance and deterioration of the functional state [2–4]. All of these facts stimulate keen interest in the study of magnetic field variations caused by various sources [1, 5].

Along with geomagnetic effects with a significant amplitude, associated with solar activity, effects related to processes and phenomena of different origins and occurring in both the upper and lower geospheres are observed [6–8].

This work reports on the geophysical effects in the form of induced variations of the magnetic field and the critical frequency of the *F*2 layer of the ionosphere during the resonant seismic event that occurred in the period of April 2–3, 2024, in the vicinity of Taiwan. The event was a series of earthquakes, among which 17 earthquakes with a magnitude greater than 5 were the most significant; they occurred within 2.5 h. Meanwhile, the four strongest earthquakes with magnitude 5.7 or greater occurred within 2 h (Table 1). It should be noted that these events followed each other in a short time and the distance between their sources did not exceed 41 km (Table 1).

As initial data, we used the results of instrumental observations made at the Mikhnevo Geophysical Observatory of the Sadovskii Institute of Geosphere Dynamics, Russian Academy of Sciences (MHV, 54.96° N; 37.76° E), and at the observatories of the INTERMAGNET network actively operating during this period of time (Table 2) [7, 9]. The variations of the horizontal component of magnetic induction B_x oriented in the N–S direction, which is most sensitive to external perturbations, were analyzed. The considered period of the event was characterized by a quiet geomagnetic situation (Table 3), which significantly

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Table 1. Characteristics of the strongest earthquakes that occurred in the period April 2–3, 2024, in accordance with data from the USGS catalog as of April 15, 2024

No.	Date	Time (UTC)	Magnitude	Geographical coordinates		Depth, km
				Latitude	Longitude	
1	April 2, 2024	23:58:11	7.4	23.819° N	121.562° W	~35
2	April 3, 2024	00:10:25	6.4	24.064° N	121.672° W	~13
3	April 3, 2024	00:35:36	5.7	24.161° N	121.710° W	~10
4	April 3, 2024	00:46:44	5.7	24.147° N	121.743° W	~10

simplified identification of induced disturbances of the magnetic field.

To analyze the impact of earthquakes on the ionosphere, we used ionograms of height–frequency sounding, plotted during the considered event at the Okinawa Japanese ionosphere monitoring station (GEO: 26.68° N; 128.15° E), which are freely available on the website of the Japanese National Institute of Information and Communication Technologies [10].

Figure 1 demonstrates the magnetic field variations recorded at the MHV observatory during the period of the seismic event considered.

Preliminarily, it should be noted that the seismomagnetic (coseismic) effect, which is manifested in variations of the magnetic field during the period of propagation of seismic waves caused by earthquakes, did not manifest itself (the arrival time of seismic waves in the MHV was at 00:07 UTC April 3, 2024). From the data of Fig. 1, it follows that the period of the earthquakes is characterized by distinct long-period disturbances of the daily variations of the magnetic field induction in MHV (the distance from the origin of the first strongest earthquake is ~7470 km). The beginning of the disturbance was recorded at ~0:58 UTC April 3, 2024, that is, approximately one hour after the first strongest shock. The induced variations of the vertical component B_z represent negative bay with a maximum amplitude of ~8 nT. Moreover, the duration of B_z variation is 3–4 hours.

Table 2. Data from magnetic observatories

Code	GEO		R, km
	Latitude	Longitude	
KNY	31.42° N	130.88° E	~1250
CYG	30.37° S	126.854° E	~1480
PHU	21.03° N	105.96° E	~1630
BMT	40.3° N	116.2° E	~1900
KAK	36.232° N	140.186° E	~2250
KHB	47.61° N	134.69° E	~2890
MMB	43.91° N	144.19° E	~3040
SHU	55.35° N	150.46° W	~7100
CSY	66.283° S	110.533° E	~10060
TAM	22.79° N	5.53° E	~11380
VOS	78.464° S	106.835° E	~11410
GUI	28.321° N	16.441° W	~12750

A more complex response is demonstrated by the main horizontal component B_x: in this case, the magnetic field disturbances are represented by two distinct positive bays with a maximum amplitude of ~10 nT. The beginning of the disturbances was recorded at ~00:58 UTC; the first maximum was observed at ~01:30 UTC April 3, 2024, and the second, at ~04:00 UTC April 3, 2024. It is indicative that similar disturbances of the B_x component were recorded in a number of observatories of the international INTERMAGNET network. For example, Fig. 2 presents records of the magnetic field variations during the Taiwan event obtained in some observatories of the INTERMAGNET network. According to the data in Fig. 2, it should be noted that disturbances of the B_x component, manifested in the form of two positive bays, as observed at the MHV observatory, are recorded at the observatories located at distances greater than about 7000 km from the focus of the main event 1 of Table 1. At distances smaller than about 3000 km, disturbance of the B_x component manifests itself as a single positive bay during the period from ~03:25 to ~04:25 UTC April 3, 2024.

It is necessary to note synchrony of the observed variations of the magnetic field, accompanying the considered seismic event, in a wide range of epicentral distances, and a rather narrow interval of the maximum amplitudes. This indicates the presence of a single global source of disturbances resulting from a series of earthquakes. It was noted earlier that strong earthquakes have a disturbing effect on the main magnetic field of the Earth [11, 12]. Indeed, possible disturbances in the liquid core of the Earth, variations in electrophysical properties of the asthenosphere and the Earth's crust, and, concurrently, disturbance of the long-standing motions of the conductive medium under the seismic impact can cause a hardware-recorded magnetic effect, especially in the case of earthquakes repeated at short intervals, with closely located sources.

In this work, we determined the critical frequency f_0F2 by manual processing of ionograms with URSI interpretation [13]. As a result, a digital series of the data on time variation of the critical frequency of the $F2$-layer f_0F2 with 15-min discretization was formed. Analysis of the data obtained showed that the event considered had a disturbing effect on the ionosphere in the form of f_0F2 variations (Fig. 3). Figure 3 demonstrates that the strongest earthquakes followed each other after a short interval, caused distinct alternating variations of the critical frequency f_0F2 at two time intervals 00:15–00:45 UTC and 01:45–02:45 UTC against the background of the daily variation. The first disturbance was manifested as a positive bay with the maximum amplitude of ~0.7 MHz, while the second was represented in the form of alternating variations with a period of ~30 min and the maximum amplitude of ~0.9 MHz. Analysis of the record using data from [14–16] allows us to conclude that the first disturbance, recorded in the period 00:15–00:45 UTC, is associated with the ionospheric response to the Rayleigh wave, while the second disturbance, recorded in the period 01:45–02:45 UTC, is most likely associated with the propagation of internal gravity waves.

Table 3. Indices of magnetic activity *K* (from MHV data) and *Kr* (from International Service of Geomagnetic Indices (ISGI) data) for April 2–3, 2024

Index	Date, time (UTC)							
	April 2, 2024		April 3, 2024					
	18–21	21–24	0–3	3–6	6–9	9–12	12–15	15–18
K	2	0	2	1	1	2	2	1
Kr	2	1	3	2	1	1	1	2

Thus, it can be stated that a series of strong earthquakes causes the magnetic effect, which is difficult to analyze. The characteristics of the effect depend on the distance to the source of disturbances, and its mechanism should be established with the use of instrumental observations. It is also important to study in more detail the origin, possible sources, and mechanisms of the impact of strong earthquakes on the ionosphere.

We consider that the data presented in this work are significant from the point of view of the accumulation of observational material and quantitative estimates of

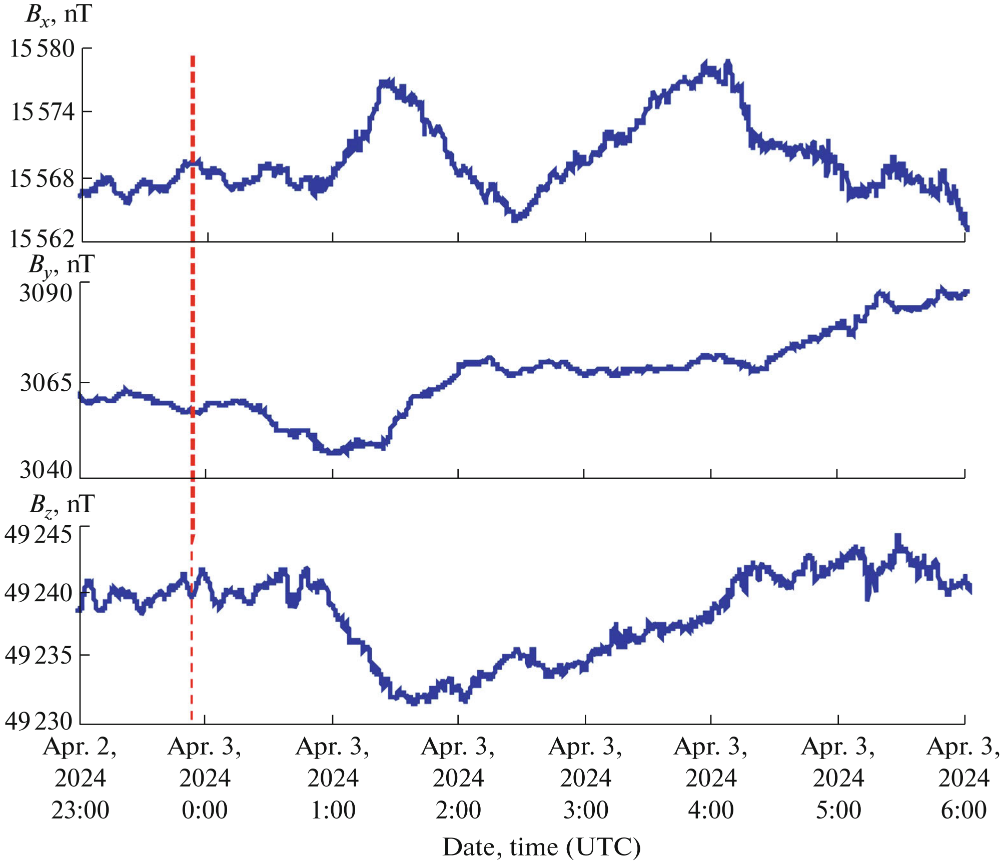

Fig. 1. Variations in the magnetic field components April 2–3, 2024 from MHV data (the dashed line indicates the time of event *1* from Table 1).

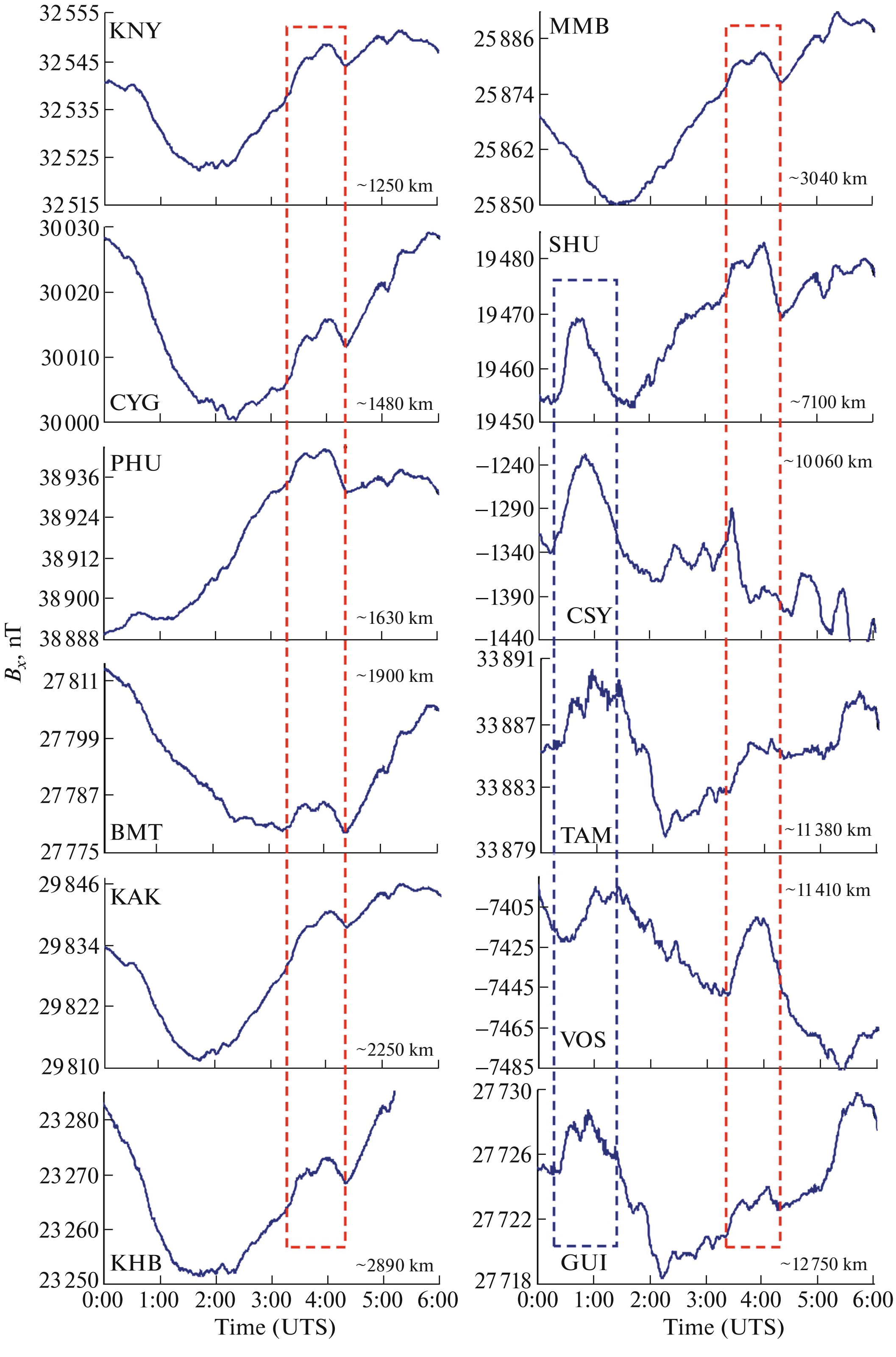

Fig. 2. Variations in the magnetic field components April 2–3, 2024, from INTERMAGNET observatory data (observatory codes are given in the figure field). Blue and red dashed lines indicate the first and second by time disturbances of the magnetic field, respectively.

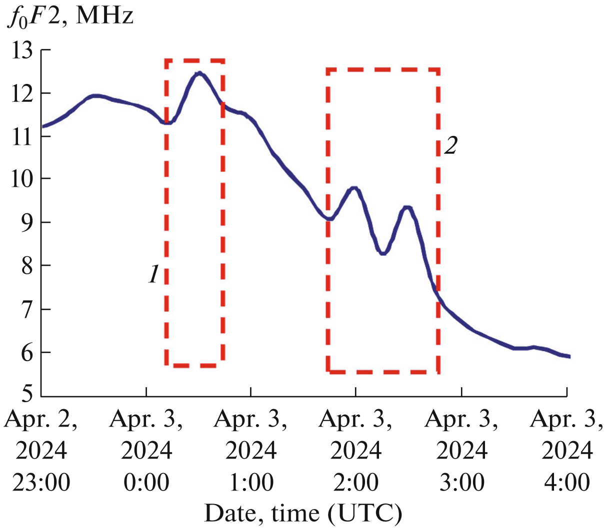

Fig. 3. Variations of the critical frequency of the ionospheric *F*2 layer at the Okinawa ionospheric station April 2–3, 2024 (red dashed line indicates the (*1*) first and (*2*) second periods of f_0F2 disturbances).

geophysical consequences of strong earthquakes. The data may be useful in the development and verification of analytical and numerical models describing their effects on the environment.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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