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Studies of electromagnetic emission of seismotectonic origin in the Kirghiz S.S.R.

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Continuous observations of electromagnetic emission (EME) have been under way at two sites since 1978 in the Issyk-Kul seismic region, Kirghiz S.S.R., to study anomalous effects of seismotectonic origin. EME is recorded by the method of impulse count using two horizontal magnetic aerials with resonant frequency 15 kHz. The 1978–1981 data series has been analysed statistically to study diurnal and seasonal variations in EME background intensity and their relation to various helio-geophysical phenomena (meteorological and geomagnetic ones).

A comparison of EME data and seismicity in the region shows that most of the local earthquakes ($M \geqslant 4.0$, $R \leqslant 400$ km) occurring in the zones of active geological faults are preceded by EME precursors of a few hours to a few days duration. Anomalous effects in EME have also been observed for large and distant earthquakes ($M \geqslant 6.0$, $R \geqslant 400$ km). Mobile measurements have detected increased EME level in active fault zones.

These observations can be accommodated within the model of secondary sources in the atmosphere (lower ionosphere) excited by large-scale processes in the crust, particularly at boundaries of blocks and faults.

1. Introduction

During the last decade considerable progress has been made in the U.S.S.R. in the study of electromagnetic emission (EME) anomalies that precede and accompany large earthquakes (Vorobyev et al., 1976; Gokhberg et al., 1979, 1983a, 1985a, 1986; Mavlyanov et al., 1979; Sadovsky et al., 1979; Sadovsky, 1982; Khussamiddinov, 1983; Larkina et al., 1983; Migunov et al., 1984). Efforts have been made to provide a theoretical substantiation of the possible existence of electromagnetic precursors to earthquakes, leading to the development of a number of models for sources of electromagnetic emissions (Gokhberg et al., 1980, 1985a–c; Sadovsky, 1982; Gershenson et al., 1987). This interest in EME anomalies is because they can be classified as immediate precursors of earthquakes.

It is not yet certain, however, whether these anomalies are caused by active radiation sources in the crust or by regions (in the ionosphere) of increased ionization which only modify the conditions of radiowave propagation. Therefore, it still remains an urgent task to accumulate evidence on EME anomalies in different geological and geophysical conditions to refine models of electromagnetic emission sources.

2. Seismotectonic environment and measurement techniques

Observations of EME have been conducted in the Issyk-Kul seismic region, Kirghiz S.S.R., since 1978. This report presents the results of permanent-station and mobile observations for the period 1978–1981.

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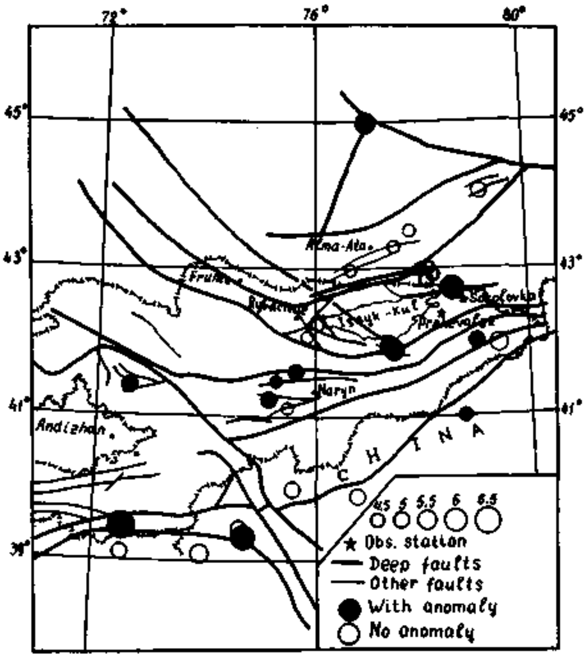

Fig. 1. Map of fault tectonics for the Kirghiz S.S.R. and epicentres of earthquakes with $M \geqslant 4$ for the period 1978–1981 (from Table I).

The Issyk-Kul seismic region lies within northern Tien-Shan. It is characterized by frequent seismic occurrences, up to catastrophic ones, and is classified as a zone of intensity IX in maps of seismic zoning. In recent years a number of destructive earthquakes have occurred there: the Sarykamysh ($K = 16$) 1970 earthquake, the Zhalanash-Tyup ($K = 15$–16) 1978 earthquake, and some others. The tectonic structure of this zone is peculiar in that the principal structural units have block structure. Most large earthquakes are related to a sequence of deep-seated faults (Fig. 1). The hypocentral depths are within 10–20 km.

Observations of EME at permanent stations were conducted at two sites 60 km apart, the town of Przhevalsk and the village of Sokolovka. EME was recorded by impulse counting method using two ferrite aerials oriented north–south and east–west with resonant frequency 15 ± 1 kHz. The sensitivity was 3×10^{-4} nT. The parameter of interest was field intensity measured as the number of impulses per hour.

Mobile observations of EME were conducted in zones of large geological faults using portable impulse counters to study spatial characteristics of EME and their relation to earth dynamics. Profiles were measured as quickly as possible to reduce the time variation of EME to a minimum. The effect of the time variation was checked by examining records of two permanent variation stations.

3. Analysis of variations in EME background intensity

A dependable identification of effects of seismotectonic origin requires knowledge of variations in EME background intensity. With this end in view, the EME time-series for the period 1978–1981 has been subjected to statistical processing on a computer to study patterns in regular EME variations (diurnal and seasonal ones) and their variance.

An analysis of plots of the monthly means of daily behaviour for EME during the 4-year period has shown that daily variations in EME background intensity are recorded in all seasons, but their shape and amplitude are subject to seasonal modifications. In winter they have a daytime minimum and a night-time maximum. During spring and summer an afternoon maximum appears, which is larger than the night-time one during summer. The pattern is reversed in autumn and winter. The amplitude of daily variations is ~ 4000–5000 impulses h^{-1} in summer, whereas the winter value is an order smaller. Changes in shape and amplitude for both components of the field are approximately similar (Fig. 2).

Seasonal variations of EME are characterized by a maximum in mean monthly values of field intensity during summer months and by a minimum during winter months. The magnitude of the maxima and minima and their locations vary somewhat from year to year (Fig. 3).

The fact that the shape and amplitude of EME background variations are identical at the two sites testifies to the observations being fairly representative.

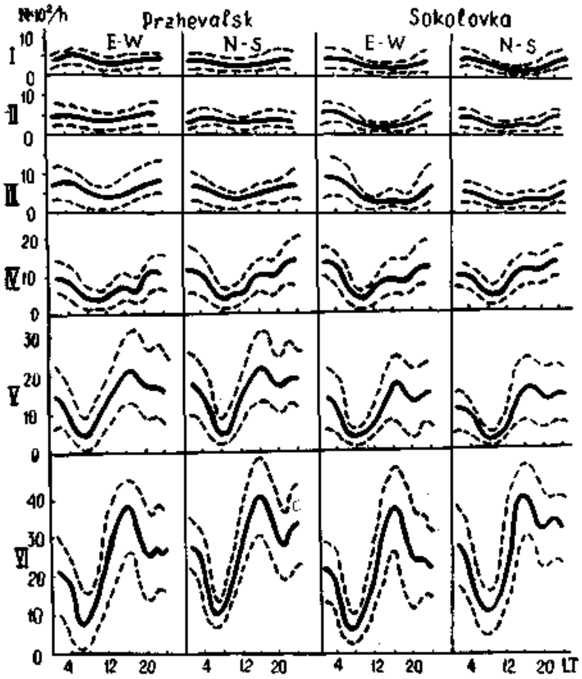

Fig. 2. Mean monthly EME behaviour for two components of the field (days with thunderstorms and earthquakes have been excluded) from January to June 1980 at stations Przhevalsk and Sokolovka. Dotted lines denote the standard deviations ($\pm\sigma$).

The variance (standard deviation) of the monthly means of daily behaviour is ±30% on average. EME anomalies were identified when the departure from the monthly mean of daily behaviour exceeded twice the standard deviation ($\pm 2\sigma$).

In the literature there is some evidence of a possible effect of meteorological factors and geomagnetic variations on the character of EME background variations; accordingly, we have compared the EME time series with observations at meteorological station Przhevalsk and magnetic observatory Alma-Ata.

We have not detected any effects on daily and seasonal behaviour of EME of such meteorological factors as air temperature, cloudiness, humidity, atmospheric pressure, wind velocity and amount of precipitation. The relevant coefficient of correlation was below 50%. An exception was near thunderstorms.

EME intensity shows an anomalous increase during thunderstorms (by a factor of 1.5–8), falling off rapidly after the thunderstorm. These anomalies are of short duration. Their mean duration is ~1 h. In the winter, snowstorms excite noticeable EME anomalies. These intervals of time were eliminated from subsequent analysis, as they might obscure the relation of EME anomalies to seismic activity.

The technique of EME observations used permits comparison only with long-period variations of the geomagnetic field (with periods above 1 h). These include quiet solar-daily variations (S_q), magnetic storms (D_{st}) and bays ($DP1$).

A comparison of daily variations in EME intensity with geomagnetic S_q variations has shown that they behave differently over the year. The daily behaviour of S_q variations remains unchanged, whereas an afternoon maximum appears in the daily behaviour of EME during spring and summer, indicating different origins of these variations.

Fewer than 10% of cases have been recorded in which temporal coincidence with EME disturbances exists, out of 103 magnetic storms and 85 bays (of duration > 1 h and intensity > 15 nT) for the period January 1978–December 1981. Even for these cases, however, the coincidence is not satisfactory (the beginning, duration and intensity are not identical).

To sum up, a comparison of variations in EME background intensity with meteorological factors and geomagnetic variations has not revealed a connection between these geophysical phenomena, except near thunderstorms.

The main patterns of EME background intensity variations can be accounted for by thunderstorm activity over the globe and by conditions of very low frequency wave propagation within the Earth–ionosphere waveguide.

4. Comparison of EME anomalies and seismicity

Relying on the possibility suggested by the models of electromagnetic precursor excitation for earthquakes of magnitude $M \geqslant 4$ that occur in the zone of strain precursors (within a circle of radius

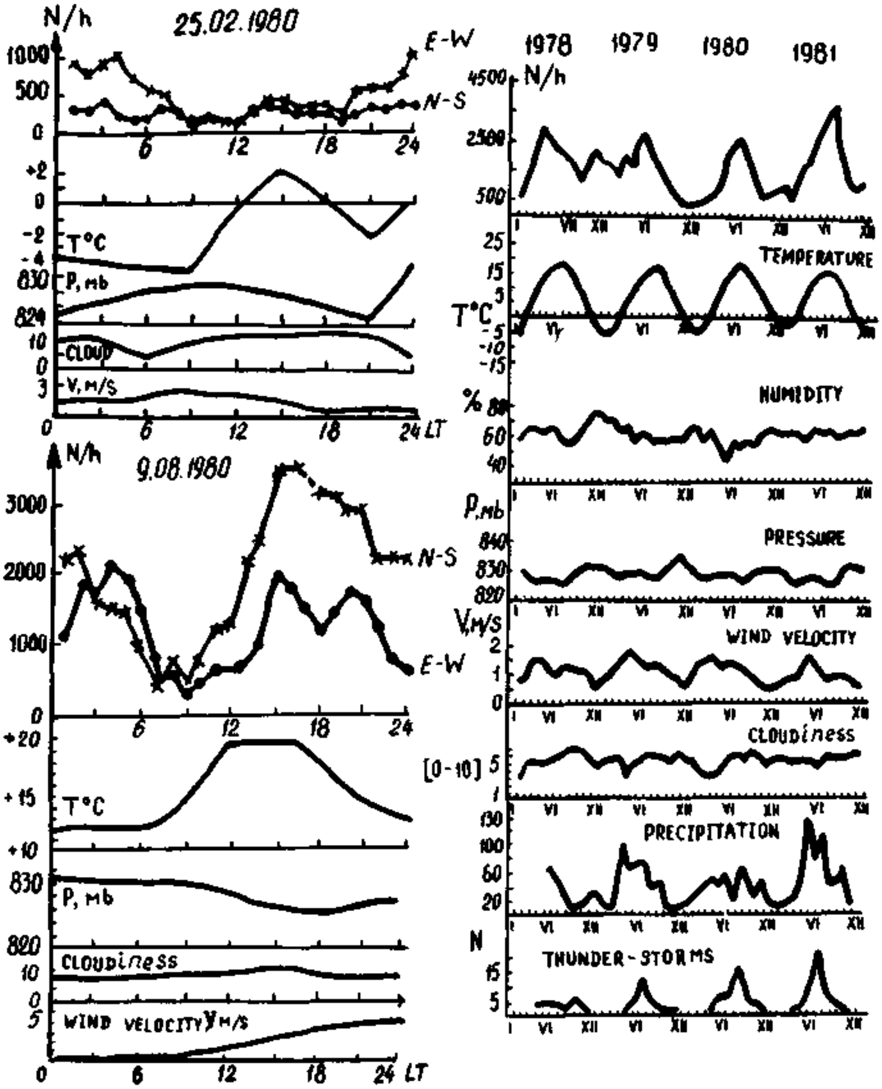

Fig. 3. Comparison of daily and seasonal EME variations with meteorological factors.

$R_d = e^M$, where R_d is in km, M is the magnitude), these events have been selected to analyse the relation of EME anomalies to seismicity. Apart from these, events in adjacent areas were included if they were preceded by clear anomalous EME disturbances. The events selected are listed in Table I. The symbols '+' or '–' mark the presence or absence of EME anomalies preceding earthquakes. The interval for the analysis of EME disturbances was chosen on the basis of data relating to the excitation periods of short-term strain precursors to earthquakes, i.e. 4–5 days.

Anomalies in the regular behaviour of EME have been identified in 15 cases out of a selection of 25 seismic events, in seven cases the observations being conducted in the preparation zone of earthquakes (Fig. 4).

The following features are noted in EME anomalous disturbances before earthquakes with $M \geqslant 4$:

TABLE I

Events selected for comparison of EME anomalies and seismicity

No.	Date	Time (UT)	Lat.	Long.	M	R (km)	R_d (km)	EME effect
1978								
1	17.02	00^{h}35^m	43.10	78.10	4.4	70	78	+
2	12.03	08 29	42.00	79.80	5.6	135	256	−
3	24.03	21 05	42.80	78.60	6.1	55	420	+
4	14.04	06 11	41.20	75.30	4.4	295	78	+
5	25.04	03 33	43.80	76.70	4.4	150	78	−
6	16.09	15 35	33.20	75.50	7.2	2000	1250	+
7	08.10	14 20	39.20	74.40	6.1	700	420	−
8	19.10	16 08	39.90	76.80	4.4	312	78	−
9	01.11	19 18	39.20	72.36	6.7	600	760	+
10	02.11	06 24	39.26	72.30	5.6	600	256	+
1979								
11	06.04	18 30	42.00	77.50	5.0	105	140	+
12	09.05	18 41	42.10	79.10	5.0	75	140	+
13	22.05	14 48	42.10	75.90	4.4	200	78	−
14	07.09	15 39	41.50	75.20	4.4	235	78	+
15	25.09	13 05	45.00	77.00	5.6	320	256	+
16	15.11	01 33	41.40	72.68	4.4	487	78	+
1980								
17	15.02	09 09	41.00	78.80	4.4	160	78	+
18	16.03	01 44	41.60	75.70	4.0	320	60	−
19	19.03	00 42	41.20	75.20	4.4	280	78	+
20	05.07	20 25	41.90	77.50	5.6	118	256	+
21	31.07	19 03	39.30	74.48	5.3	450	140	+
22	04.09	06 47	44.30	79.13	4.4	200	78	−
1981								
23	03.03	05 52	39.19	72.36	6.1	625	420	−
24	23.04	09 47	40.00	75.60	4.6	357	80	−
25	30.08	04 04	42.90	78.45	4.6	75	80	−

[1] R, epicentral distance to Przhevalsk station; $R_d = e^M$, zone of strain precursors.

(1) the regular daily behaviour of EME breaks down;

(2) changes occur in the intensity of regular maxima that exceed the standard deviations of EME daily behaviour by a factor of two or more;

(3) the greatest effects in EME disturbances always precede the earthquake shock;

(4) the disturbances last for periods ranging from a few hours to a few days;

(5) effects of anomalous EME disturbances have been identified for seismic events occurring at deep-seated faults.

The fact that earthquakes preceded by anomalous EME effects are confined to the zones of deep-seated faults indicates the presence of active tectonic movements along them. This is confirmed by mobile measurements of EME in zones of deep faults. In all, seven profiles have been measured traversing zones of deep faults. All zones of geological faults are characterized by increased EME levels. Repeated measurements were made to provide a check on reproducibility of the observations. Detailed surveys of the Dzhergalan and Tasmin faults at intervals of 0.2–0.5 km demonstrate that the greatest EME level occurs at fault axes. The level increased at the axis of the Dzhergalan fault by a factor of 25, and at the axis of the Tasmin fault by a factor of 10 (Fig. 5).

An oscillographic study in the shape and duration of EME signals has been carried out to clarify

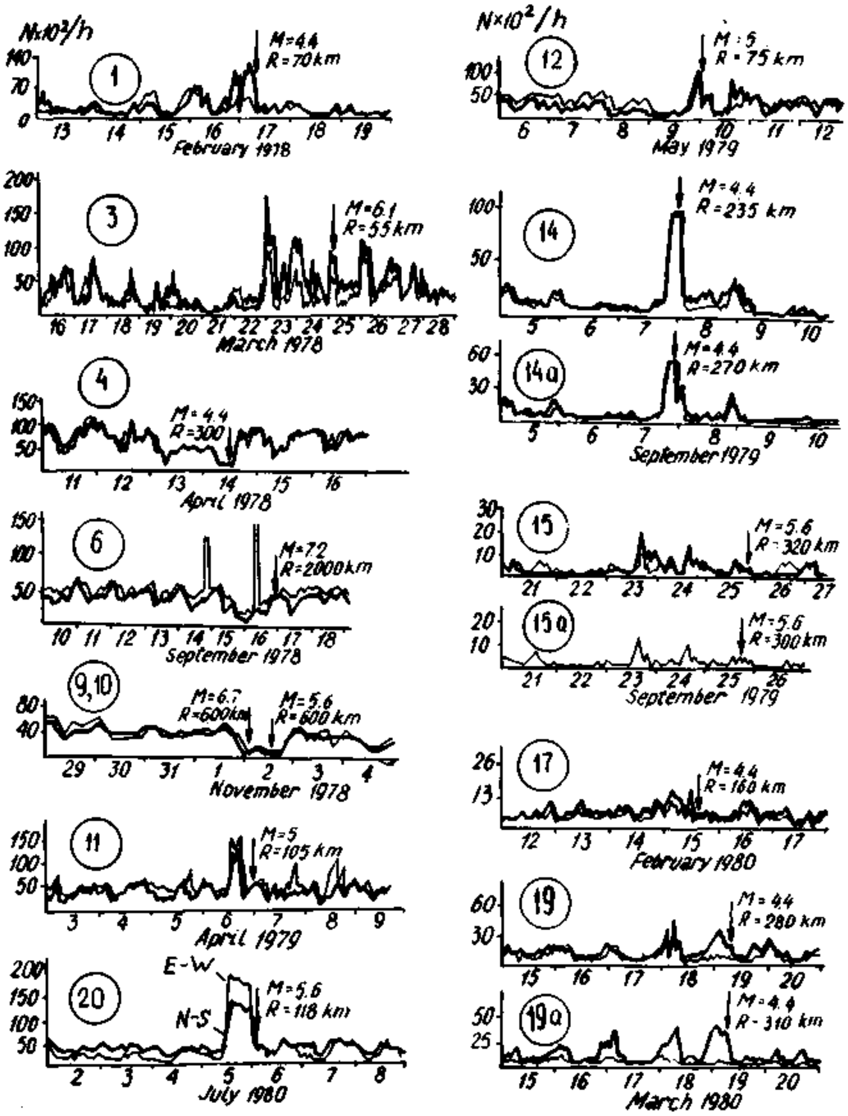

Fig. 4. Anomalous effects of EME before earthquakes at station Przhevalsk. Numerals in circles correspond to numbers of earthquakes in Table I. Index 'a' denotes the same event at station Sokolovka.

the nature of the recorded impulses. This has shown that over 90% of the recorded impulses correspond to typical atmospherics shapes at source-to-receiver distances > 1500–2000 km. Fewer than 4% of the recorded impulses may provisionally be classified as impulses of lithospheric origin, as we have not succeeded in identifying these with industrial and wind noises. Thus, the question of the existence of impulses of lithospheric origin remains open. However, the evidence obtained allows one to regard EME as consisting mainly of atmospherics and to analyse

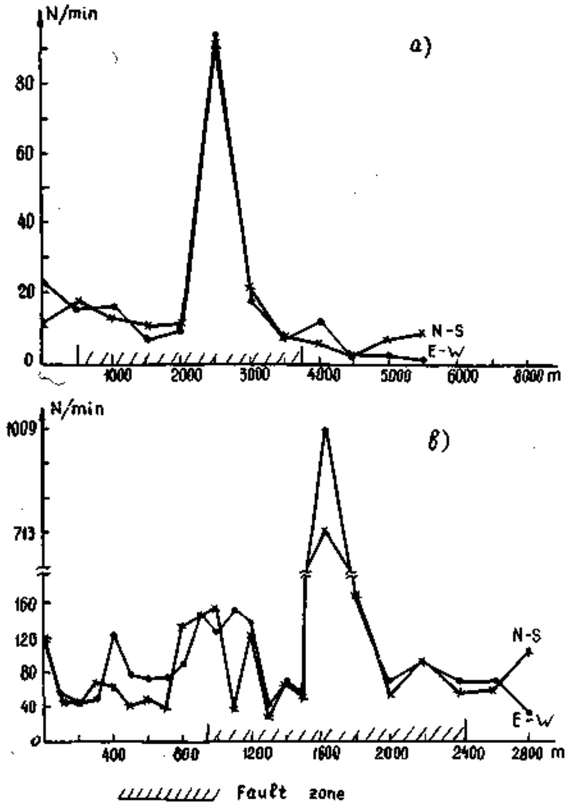

Fig. 5. Anomalous EME level above (a) the Dzhergalan and (b) the Tasmin faults. Abscissa represents the distance between the mobile station and the beginning of a profile across fault zone.

disturbances in their daily behaviour during bursts of seismic activity.

5. Conclusion

The possibility cannot be ruled out that a geological fault itself can generate impulsive electromagnetic emission owing to activation of geodynamical processes, but most probably, the origin of EME anomalies precursory to earthquakes is related to changes in the conditions of propagation of atmospherics above an earthquake preparation zone. It should be noted that such a zone is felt by a measuring system at distances that exceed the dimensions of the strain precursory zone. Also, we emphasize that the radiation of lithosphere sources has not been identified even when receivers were installed in the epicentral zone of the catastrophic Zhalanash-Tyup earthquake of 24 March 1978.

These observations are consistent with the model of secondary sources in the upper atmosphere (lower ionosphere) excited by large-scale crustal processes, particularly at the boundaries of blocks and faults (Gokhberg et al., 1985b).

The results obtained testify to the use of EME observations being promising for the study of crustal dynamics and seismicity in an area.

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