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Seismic and anthropogenic activity effects in the nighttime sporadic E layer of the ionosphere

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Abstract. Data from a network of vertical ionospheric sounding stations are used to study the correlation of the mean nighttime values of the f_bE_s frequency for various pairs of stations. It is shown that one-two days prior to an earthquake, the correlation coefficients decrease by 30–50% compared with the background values. The quasi-permanent ionospheric effects of anthropogenic activity may be of the same order of magnitude as the above preearthquake effects.

1. Data from one vertical sounding (VS) station [*Husamiddinov,* 1987; *Kolokolov et al.,* 1992; *Liperovskiy et al.,* 1993] were the basis for examining variations of sporadic ionospheric E layer parameters several days before an earthquake with magnitude $M > 4.5$. Seismogenic effects in the E_s layer at distances up to 500 km from the earthquake epicenter were registered. However, because of strong variability of the ionospheric background due to solar, meteorological and anthropogenic factors, it is difficult to detect effects of a seismo-tectonic nature in the sporadic E_s layer.

For this reason, it was worth trying to use a network of ionospheric stations to establish, with higher reliability, the background state of the E_s layer during the preparatory stage of an earthquake. It was natural to suggest that the mean night values of f_bE_s for closely situated stations should demonstrate high mutual correlation.

2. This paper compares the effects of earthquakes with magnitude $M > 4.5$ and the effects of anthropogenic activity. To do that, we used hourly values of the f_bE_s frequency from five Central Asia (Ashkhabad, Dushanbe, Alma-Ata, Tashkent and Karaganda) and two Italian (Rome, Gibilmanna) stations of VS. Gibilmanna station is located in southern Sicily. The Central Asian stations are separated from each other by 300–1700 km, and the distance between the Italian stations is 400 km. E_s layer behavior was studied only for nighttime conditions. Night was conventionally accepted as lasting from 2100 to 0500 LT, where LT = UT + 4 for Ashkhabad, UT + 5 for the rest of the Central Asian stations, and UT + 1 for the Italian stations. Data were available for the Central Asian stations (with some gaps) for the periods of May 1 to July 30, 1985, and August 1 to September 30, 1987, and for the Italian stations for the period of August 1 to October 31, 1987. For the earthquakes that took place between 0500 LT and 2100 LT, the previous night was assigned a minus sign ("−1"). For the nighttime earthquakes, the night was assigned a minus sign ("−1") if the event took place after 0100 LT. For the earthquakes occurring before 0100 LT, the current night was given plus sign ("+1").

Variations of the temporal behavior of f_bE_s averaged over one typical night were studied. It is worth remembering that $f_bE_s \sim \sqrt{N}$, where N is the electron concentration in the E_s layer [*Gershman et al.,* 1976]. If there was no E_s track on the ionogram, the value of the minimum operating frequency of the station was accepted as a f_bE_s frequency. Because the minimum operating frequencies are different for different stations (1.5 MHz for Ashkhabad, 0.5 MHz for Dushanbe, and 1.2 MHz for the rest of the stations) their maximum values were used for the comparison, and it was conventionally accepted that there is no layer at lower frequencies.

If the data on f_bE_s were absent due to the complete screening of the $F2$ layer or due to technical reasons in 30% of all the measurements during a night, the missing data were restored by extrapolation. If the loss of information exceeded 30%, the night was excluded from the analysis.

3. *Kolokolov et al.* [1992] and *Liperovskiy et al.* [1993] showed that the effect of the E_s spreading takes place a few hours before an earthquake. However because of strong variability of this layer due to various factors (meteor showers, solar activity, velocity and direction of the winds [*Gershman et al.,* 1976]), it is rather hard to extract the effects of E_s layer spreading and of f_bE_s depletion induced by seismogenic sources. When the above sources were absent, the E_s behavior might be taken as background. In that case, mean night values of

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Table 1. The correlation coefficients r for the averaged night f_bE_s values

The pair of stations	ΔR	Summary		Seismo-Active		Background	
		n	r	n	r	n	r
Dushanbe–Tashkent	310	66	0.70	29	0.50	37	0.80
Tashkent–Alma-Ata	760	84	0.64	37	0.32	47	0.79
Dushanbe–Alma-Ata	870	70	0.73	32	0.57	38	0.84
Ashkhabad–Dushanbe	890	66	0.41	27	0.20	39	0.45
Ashkhabad–Tashkent	930	66	0.35	20	0.37	46	0.55
Ashkhabad–Alma-Ata	1690	81	0.44	36	0.32	45	0.50
Karaganda–Alma-Ata	780	95	0.48	34	0.47	61	0.50
Karaganda–Tashkent	1020	84	0.52	36	0.31	48	0.67
Karaganda–Dushanbe	1300	90	0.44	37	0.20	53	0.63
Karaganda–Ashkhabad	1820	74	0.26	22	0.35	52	0.24

n is number of the nights analyzed.

f_bE_s for the ionospheric stations separated by a distance ΔR of about several hundreds km should be mutually correlated [*Gershman et al.,* 1976]. To reveal the effects of the seismic nature, a correlation study was done of mean night background f_bE_s values during the preparatory phase of an earthquake for the stations Ashkhabad, Dushanbe, Tashkent, Karaganda, and Alma-Ata. The results are shown in Table 1.

It is hypothesized that the processes of earthquake preparation induce ionospheric effects only if the distance to the epicenter at least for one station of the pair is $R < 1000$ km. Earthquakes with magnitude $M > 4.5$ were considered [*ISCB,* 1985; 1986]. The nights designated "-1" and "-2" were taken as seismically active, and all the rest were considered background ones. The results were analyzed for the following pairs: Tashkent–Alma-Ata, Dushanbe–Alma-Ata and Karaganda–Alma-Ata. This analysis leads to the conclusion that earthquake preparatory processes initiate ionospheric effects at distances not less than 1000 km. Let us remember that, based on single-point observations, seismotectonic effects in the E_s layer were detected only at distances not more than 500 km from the epicenter.

It follows also from Table 1 that during periods of earthquake preparations, the correlation coefficient of the mean night values of f_bE_s was about a factor of 1.5–2 less than the background one.

4. It is known that the ionospheric state might be changed also by anthropogenic influence. So one may expect the strongest variability of ionospheric parameters above industrial centers. The population of Rome is 3 million. Let us compare mean night values of f_bE_s above industrial Rome and situated in the country Gibilmanna. Earthquakes in that region are a very rare occurrence, and the several nights in question are excluded from consideration. The correlation coefficient r between the averaged values of f_bE_s for all the data (71 night) is 0.44. It is well known that in many developed countries industrial activity falls off on Saturdays and Sundays, producing the so-called "weekend effect" [*Gulyelmi and Zotov,* 1986; *Fraser-Smith and Coates,* 1978]. Let us consider separately the nights corresponding to the work days of the week and to weekends. In the first case the correlation coefficient for 41 nights is $r = 0.28$, and in the second (for 30 nights) $r = 0.77$. Thus, a quasi-permanent anthropogenic influence, in the same way as the processes of an earthquake preparation, reduce the background correlation coefficient by more than 50%.

The Central Asian stations are situated in the vicinity of large cities with populations of various sizes. The most populated among them is Tashkent. But one may assume that the strongest E_s layer variations of anthropogenic nature should be detected above Karaganda, because this city is a powerful industrial center in Central Asia. Let us compare two pairs of stations Alma-Ata–Karaganda, and Alma-Ata–Dushanbe. The distance between the first pair of stations is only 90 km less than that between the second pair, although the correlation coefficient for the first pair is 1.7 times lower than for the second. It seems reasonable to suggest that the depletion of the correlation coefficient is due to the anthropogenic influence on the ionosphere above Karaganda. It is worth noting that the "weekend effect" is not observed for the Central Asian stations, because all the big manufacturing plants in the former USSR were working every day of the week.

Let us compare now the correlation coefficients for two pairs of stations: Alma-Ata–Dushanbe and Alma-Ata–Tashkent. The distances in each pair are of the

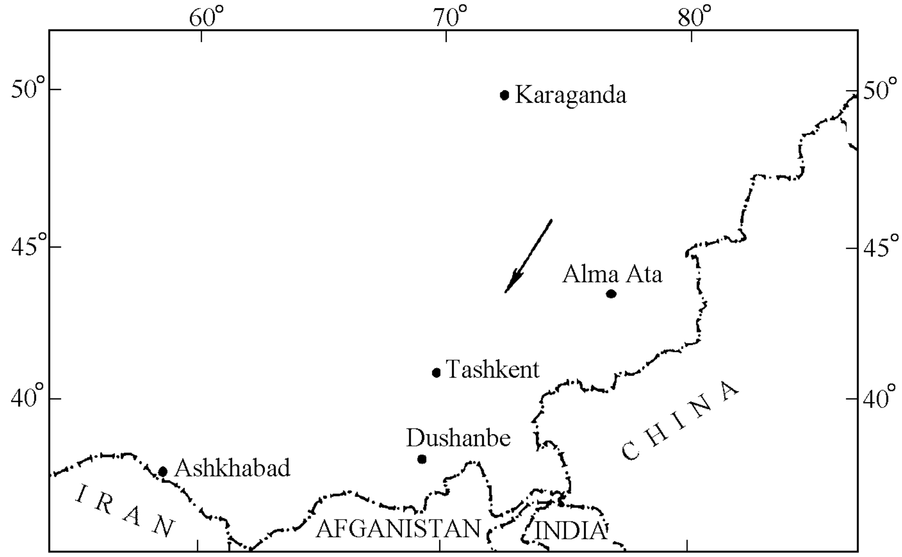

Figure 1. A schematic map of Central Asia: A, Ashkhabad, A-A, Alma-Ata, D, Dushanbe, T, Tashkent, K, Karaganda. The arrow indicates prevailing wind direction.

same order, Tashkent being 100 km closer to Alma-Ata than to Dushanbe, and the background correlation coefficient for the second pair is 1.2 times lower than for the first one. Thus the sporadic ionospheric E layer above Tashkent also is modified, but less than above Rome and Karaganda.

Thus the effects of earthquake preparation and anthropogenic effects in the ionospheric E_s layer are found to be comparable in amplitude. Therefore, isolating the effects of earthquake preparation requires use of stations situated far from industrial centers.

For a comparison of mean night $f_b E_s$ values, the wind direction at ionospheric E region heights must be accounted for. In summer it is a meridional wind from the pole to the equator. The Coriolis force affecting that moving air flux is directed to the west [*Danilov et al.*, 1987]. Figure 1 schematically shows a map of Central Asia. The correlation coefficients of the averaged nighttime values of $f_b E_s$ for the pairs Alma-Ata–Dushanbe and Karaganda–Tashkent are much higher than that for the pair Karaganda–Alma-Ata. As is seen in Figure 1, the line connecting Karaganda and Alma-Ata is almost perpendicular to the wind direction. The distance between these stations is about 780 km, and only slightly exceeds the mean dimensions of the clouds in the E_s layer. In the process of sporadic layer formation, different fluxes of the neutral wind flow above these stations. Obviously that may be a reason for the strong difference in the correlation coefficients.

5. Correlation study of the mean night values of $f_b E_s$ for the sporadic layers for different pairs of ionospheric stations have shown that 1–2 days prior to an earthquake the correlation coefficients decrease by 30–50% relative to the background values.

It is shown that ionospheric quasi-permanent effects of anthropogenic origin might be of the same order of magnitude as the earthquake preparation effects.

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