Natural Hazards and Earth System Sciences (2005) 5: 59–62
SRef-ID: 1684-9981/nhess/2005-5-59
European Geosciences Union

Natural Hazards and Earth System Sciences

On spread-E_s effects in the ionosphere before earthquakes

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Received: 1 July 2004 – Revised: 11 November 2004 – Accepted: 12 November 2004 – Published: 4 January 2005

Part of Special Issue "Precursory phenomena, seismic hazard evaluation and seismo-tectonic electromagnetic effects"

Abstract. The spread-E_s phenomenon which appears as diffusivity of the traces of sporadic E-layers on the ionogrammes of vertical sounding stations and which reflects the turbulization of the sporadic layers E_s is studied in connection with earthquake preparation processes. Spread-E_s data obtained at night every 15 min by the midlatitudinal vertical sounding station of the ionosphere in Dushanbe (ϕ=38.5° N, λ=68.8° E) are analysed. Groups of earthquakes with different magnitudes and different distances between the epicenter and the sounding station are considered. A statistical analysis of the obtained results is performed. It is shown that during the three nights before an earthquake, spread-E_s phenomena are observed more often than during the forth, fifth and sixth nights before the event. This effect is found to depend on both the magnitude of the earthquake and the distance between the epicenter and the sounding station.

1 Introduction

To date hundreds of papers and monographs are devoted to the very important practically problem – the problem of seismo-ionospheric coupling (for example Gokhberg et el., 1995; Liperovsky et al., 1992; Pulinets et al., 1998; Hayakawa, 1999; Liperovsky et al., 2000; Hayakawa and Molchanov, 2002).

One of the seismoionospheric phenomena is the plasma turbulence which is caused by processes of earthquake preparation. Plasma turbulence modification a few days before events was firstly mentioned in Alimov et al. (1989), Parrot and Mogilevsky (1989) and Liperovsky et al. (1992) in works using routine vertical sounding set data. Turbulization reveals itself in different ionospheric regions – i.e. at different heights.

One of the turbulent phenomena in the E-region is spread-E_s. This phenomenon was studied in a number of works (Bowman, 1985; Whitehead, 1989; Barnes, 1992; Mathews, 1998). Spread-E_s is observed as diffusivity of the traces of sporadic E-layers on ionograms of vertical sounding stations. It is supposed that spread-E_s is a consequence of ionospheric turbulent processes in sporadic E-layers at altitudes of 100 km. According to a wealth of observations, the diffusivity takes place during less than 10% of the night, and it is found to less than 3% at day time. Spread-E_s generally occurs more often during the 11 years solar cycle minimum and depends strongly on the season. Spread-E_s is mainly found in the frequency range of $f_b E_s$<2.5 MHz. The hypothesis exists that the spread effect is caused by acoustic pulses propagating in the atmosphere (Bowman, 1985; Whitehead 1989).

During the last 15 years, in a series of works it was tried to find a link between the spread-E_s phenomenon and the processes of earthquake preparation (Alimov et al., 1989; Liperovskaya et al., 2000; Silina et al., 2001). In the work by Liperovskaya et al., basing on experimental data registered during six years, it was found that the probability of the observation of spread-E_s 1–3 days before an earthquake does not change in comparison with the background. Cases were analysed when the magnitude of the earthquakes equals M=4.5–5.0 and the epicenter is localized at a distance not larger than 500 km from the vertical sounding station. On the contrary to this result, in the paper by Silina et al. (2001), an increase of the observation probability of the spread-E_s phenomenon before several earthquakes with $M \geq 5.5$ at distances from the vertical sounding station of $R<600$ km was demonstrated, but the statistical justification of the result of Silina et al. was not sufficient.

The present work continues the search for the dependence of spread-E_s in connection to earthquakes. A few groups of earthquakes are considered which possess different magnitudes and epicenteres located at different distances from the vertical sounding station. A statistical analysis of the obtained results is performed.

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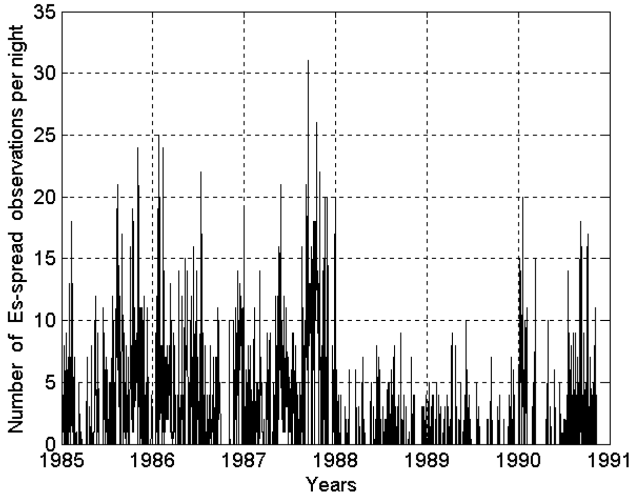

Fig. 1. The time dependence of the number of spread-E_s observations per night on time.

2 Data analysis

Data of spread-E_s registered for the nighttime, mid latitudinal E-region are considered. The data were obtained every 15 min by the vertical sounding station Dushanbe (ϕ=38.5° N, λ=68.8° E) in the years 1985–1990. "Nighttime" was assumed to be from 22:00 LT till 05:00 LT.

Figure 1 shows the dependence of the number of spread-E_s observations per night on time. In the years of Solar maximum (1988 and 1989) the number of spread-E_s observations is considerably smaller than in the other years.

Earthquakes the epicenters of which are situated at a distance smaller than 400 km from the vertical sounding station are taken into account and only such earthquakes were considered for which the 6 days before the event did not belong to the 6-days period before another earthquake. If a few earthquakes occurred within 6 days, only the first earthquake was taken into account. During the analysis, for every earthquake the sum of the spread-E_s occurrence during the nights (−6, −5, −4) and (−3, −2,−1) before the event were calculated. It should be mentioned, that in studies of 6-day intervals of time, the dependence of the spread-E_s occurrence on the season and the Solar activity cycle is negligible.

For every considered earthquake it was determined if the number of spread-E_s events increases or decreases from the nights (−6, −5, −4) to the nights (−3, −2, −1). Only such six-nights intervals are analysed for which at least one spread-E_s event was found in both night-triplets (−6, −5, −4) and (−3, −2, −1). We got that during the nights (−3, −2, −1) spread-E_s is registered more often than during the nights (−6, −5, −4). In Tables 1 and 2, lists of the analysed earthquakes are given. The sign + shows the earthquakes where the number of spread-E_s effects during the nights (−3, −2, −1) was larger than during the nights (−6, −5, −4). In the contrary case, the sign − is put into the tables. For equal numbers of spread-E_s events during the nights (−3, −2, −1) and (−6, −5, −4), the sign 0 is introduced. For 11 earthquakes with magnitude $M \geq 5.5$, which happened at a distance less than 400 km from the sounding station, eight times an increase of the spread effect is obtained. Three times the number of spread-E_s observations does not change (see Table 1).

Further, the nondimensional value *DELTA_spread-*E_s was calculated,

$$DELTA\_spread\text{-}E_s = 2\frac{(W(-3,\,-2,\,-1)-W(-6,\,-5,\,-4))}{(W(-3,\,-2,\,-1)+W(-6,\,-5,\,-4))}.$$

Here $W(i,\ j,\ k)$ designates the number of spread-E_s observations during the nights $i,\ j,\ k$. The mean *DELTA_spread-*E_s value of the 11 earthquakes equals $\bar{D}_{M\geq 5.5,R<400}$=0.44.

Now we need to investigate if this ionospheric effect is casual or not – i.e. to evaluate the probability of the obtained result. To answer this question we studied the variations of the *DELTA_spread-*E_s with a random background process model using 1000 sets of "virtual events". The number of "virtual events" was taken equal to the number of real earthquakes in each set (11) and the day of "virtual" earthquakes were chosen using a random number generator. The virtual events were chosen so that data were available for all 11 earthquakes. The number of real events was not large and the number of seismo-days (−6, −5,..., −1) was equal (66=11×6), what is much less than the total of days used (1192 over 6 years, data were with gaps), so we used total data.

We calculated $\bar{D}_k$ – the mean value of *DELTA_spread-*E_s for each set k of virtual events. The mean $\{\bar{D}_k\}$, k=1,..., 1000 satisfy the normal distribution law, with mean $\{\bar{D}_k\}$=0 and the standard deviation σ=0.23.

Thus, the mean spread value of the real events $\bar{D}_{M\geq 5.5,\ R<400}$ is about two times larger than σ, exactly $\bar{D}_{M\geq 5.5,\ R<400} \approx 1.9\sigma$. Thus the spread-$E_s$ increase is not accidentally with a probability more than 94%.

Further, the possible modification of spread-E_s occurrence was studied for "near" earthquakes with a distance between the epicenter and the sounding station of $R<200$ km. Spread-E_s modifications for 24 earthquakes with magnitude $4.0<M<5.5$ were analysed. The number of the spread-E_s observations increased in (−3, −2, −1) nights for 15 events, decreased for 6 events, and did not change in 3 cases (see Table 2).

For the 24 analysed earthquakes, the mean *DELTA_spread-*E_s value equals $\bar{D}_{M<5.5,\ R<200}$=0.16. As results of the modeling of the background random process of the 24 studied events, it was found that the mean $\{\bar{D}_k\}$=0 and the standard deviation equals σ=0.16. Thus, in case of earthquakes with magnitudes $4.0<M<5.5$, which happen at a distance $R<200$ km from the sounding station, it is possible to speak about a tendency of an increase of the number of spread-E_s observations only. Finally, an analogous investigation was performed for 20 earthquakes with magnitudes $5.0 \leq M \leq 5.5$, which happened at a distance of $200<R<500$ km from the vertical sounding station. The mean increase of the *DELTA_*E_s spread was found to equal

Table 1. Characteristics of the analysed normal earthquakes.

Date	Lat.	Long.	M	R (km)	h (km)	effect
13 Oct. 1985	40.3	69.8	5.8	219	16	+
26 April 1986	36.5	71.1	5.6	302	186	+
07 May 1986	36.4	70.7	5.6	291	222	+
17 Sept. 1986	37.3	71.7	5.5	290	119	+
02 April 1987	36.1	71.2	5.7	338	102	+
05 May 1987	36.5	70.6	5.8	279	202	+
03 Oct. 1987	36.4	71.4	5.9	326	95	+
20 July 1988	37.0	72.9	5.5	397	40	0
24 July 1989	36.1	71.1	5.8	335	95	0
13 July 1990	36.4	70.8	5.6	291	216	0
03 Nov. 1990	39.0	71.4	5.6	235	51	+

Table 2. Characteristics of the analysed "near" earthquakes.

Date	Lat.	Long.	M	R (km)	h (km)	effect
15 Aug. 1985	38.9	71.0	4.6	195	33	+
23 Sept. 1985	37.1	67.6	4.1	185	33	+
27 Nov. 1985	37.8	69.7	4.9	111	20	–
01 Feb. 1986	37.2	69.7	4.5	165	33	+
22 Feb. 1986	38.8	60.0	4.4	109	33	+
07 March 1986	38.4	69.2	4.5	40	5	+
21 March 1986	39.7	69.0	4.8	136	33	0
10 Jan. 1987	39.5	68.0	4.7	134	33	+
06 Feb. 1987	36.9	69.6	4.3	191	33	+
25 April 1987	38.2	67.8	4.2	98	33	+
03 May 1987	37.8	68.4	4.3	85	33	0
17 July 1987	38.7	70.7	4.8	169	33	–
14 Oct. 1987	39.7	70.2	4.3	182	33	–
30 Nov. 1987	37.1	69.8	4.6	173	56	+
21 Dec. 1987	38.7	70.7	4.8	164	14	+
29 Dec. 1987	37.4	70.5	4.6	188	33	+
28 June 1988	38.1	70.0	4.3	112	87	–
11 Aug. 1988	37.4	70.0	5.1	166	76	+
22 Jan. 1989	38.4	68.7	5.3	10	33	–
14 July 1990	38.4	70.2	4.5	125	33	0
28 Aug. 1990	38.9	71.0	4.2	199	33	–
08 Sept. 1990	37.7	69.7	4.5	116	35	+
21 Sept. 1990	37.3	69.0	4.3	140	101	+
30 Sept. 1990	38.8	70.8	5.0	179	33	+

0.08, which is within the limits of the statistical error. Thus, one can conclude that before earthquakes with magnitude $5.0<M<5.5$ and distance $200<R<500$ km, on the average, the number of spread effects was not modified.

3 Discussion and conclusions

In the present paper it was shown an increase of the number of observations of spread-E_s three days before earthquakes in comparison to previous three days. Data of 15 min routine vertical sounding of the ionosphere were used. For strong earthquakes with magnitudes $M\geq5.5$ and epicenters situated not larger than 400 km from the sounding station, this phenomenon happens with a probability of more than 95%. But for weaker earthquakes with $4.0<M<5.5$ at distances $R<200$ km, there exists only a tendency of an increase of the spread-E_s. During the last tens of years the physics of spread-E_s was discussed in a number of works of different authors. Now we list some conclusions made in connection with the interpretation of the results.

Bowman (1985) pointed out that ionospheric structures producing spread-E_s were plasma clouds with sharp boundaries and horizontal dimensions of 10÷50 km. The clouds consist of smaller structures with velocities of $0\div150\,\mathrm{m\cdot s^{-1}}$. These structures were supposed to be caused by the propagation of acoustic-gravity waves.

According to the model of From and Whitehead (1986) spread-E_s arises due to a set of very short-living (2÷3) s small-scale clouds.

In the paper of Miller and Smith (1978) the results of dynamic processes investigations in mid latitude E_s-layers are presented. They noted that turbulence generated by instabilities is typical for E_s-layers. The main conclusion is that the structure of E_s-layers is extremely variable in the minute range.

In the papers Shaftan et al. (1981), Ponomarev and Erushenkov (1977) it is pointed out that seismoionospheric effects can take place above the earthquake preparation region if in the near-ground atmosphere before earthquakes strong infrasound disturbances arise and propagate up to ionospheric heights. These infrasound disturbances can cause the backscattering of radiowaves and these processes can be studied in connection to the earthquake prognosis. The paper Gorbatikov et al. (2002) is devoted to observations of acoustic emission in connection to earthquakes in Japan.

According to Hickey et al. (2001) amplitudes of acoustic waves with periods above a few seconds increase sufficiently by propagation from the Earth up to the ionospheric E-region. Thus in the region of the non-linear evolution of acoustic waves, destruction and dissipation arise.

Notice that flashes of infrasonic waves with periods T=(10÷100) s were observed at heights h=100 km before earthquakes (Najita et al., 1974).

In the paper Tsunoda et al. (1993), it had been pointed out the existence of local electrical fields which were generated by the action of acoustic-gravity waves on sporadic layers E_s. The three-dimensional current system which can arise under the action of acoustic disturbances on inhomogeneous E_s-layers was analysed in Liperovsky et al. (1997). Usually the nighttime sporadic layer is an inhomogeneous cloud with horizontal size of a few tens of kilometers and a vertical size up to a kilometer (see also Barnes, 1992, 1993). The cloud is surrounded with weakly ionized plasma of less density. Under the action of acoustic disturbances with characteristic time scales of (1÷5) min, the sporadic layer polarizes. This leads to the generation of local electric currents, which are closed in the surrounding plasma. Local currents lead to heating and to the increase of the inhomogeneous structure (Liperovsky et al., 1997). Probably this structure can be observed as spread-E_s on ionograms.

Thus spread-E_s is caused by different acoustic and acoustic-gravity disturbances. It should be underlined that an increase of spread-E_s effects was not found for the earthquakes which happened during the time of the Solar activity maximum (1988–1989), not for the strong events (Table 1) and not for the weak earthquakes (Table 2). Thus one may conclude that the dissipation of the acoustic pulses at Solar activity maximum increases so strongly, that before earthquakes essential modification of the turbulization of the sporadic layer E_s is not possible. The range of spread-E_s increase before earthquakes is not large (200÷400 km). Thus the authors suggest that the increase of spread-E_s phenomena before earthquakes with magnitudes $M \geq 4.5$ is caused by an enhanced activity of acoustic pulses, which propagate from the region of earthquake preparation into the atmosphere and ionosphere.

But the other physical mechanism, the quasielectrostatic one (Pulinets et al., 2002; Liperovsky et al., 2000), cannot be excluded interpreting the spread-E_s increase. According to this mechanism electrical fields connected with processes of earthquake preparation reach up the ionosphere and cause a number of disturbances, among them also in E_s-layers.

Acknowledgements. The authors thank M. V. Rodkin for valuable discussions. The work was partly supported by the RFBR Grant-No. 02-05-064493.

Edited by: M. Contadakis
Reviewed by: two referees

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