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Nat. Hazards Earth Syst. Sci., 8, 101–107, 2008
www.nat-hazards-earth-syst-sci.net/8/101/2008/

Natural Hazards and Earth System Sciences

Quasi-static electric fields phenomena in the ionosphere associated with pre- and post earthquake effects

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Received: 17 July 2007 – Revised: 13 November 2007 – Accepted: 18 January 2008 – Published: 21 February 2008

Abstract. To prove a direct relationship between the quasi-static electric field disturbances and seismic activity is a difficult, but actual task of the modern ionosphere physics. This paper presents new results on the processing and analysis of the quasi-static electric field in the upper ionosphere (h=800–900 km) observed from the satellite INTERCOSMOS-BULGARIA-1300 over earthquakes' source regions (seismic data of World Data Center, Denver, Colorado, USA). Present research focuses on three main areas (i) development of methodology of satellite and seismic data selecting, (ii) data processing and observations of the quasi-static electric field (iii) study and accumulation of statistics of possible connection between anomalous vertical electric fields penetrating from the earthquake zone into the ionosphere, and seismic activity. The most appropriate data (for satellite orbits above sources of forthcoming or just happened seismic events) have been selected from more than 250 investigated cases.The increase of about 5-10-15 mV/m in the vertical component of the quasi-static electric field observed by INTERCOSMOS-BULGARIA-1300 during seismic activity over Southern Ocean, Greenland Sea, South-Weat Pacific Ocean, Indian Ocean, Central America, South-East Pacific Ocean, Malay Archipelago regions are presented. These anomalies, as phenomena accompanying the seismogenic process, can be considered eventually as possible pre-, co- (coeval to) and post-earthquake effects in the ionosphere.

1 Introduction

An anomalous increase of 3–7 mV/m in the vertical component of the quasi-static electric field were first observed on board INTERCOSMOS-BULGARIA-1300 satellite in the near-equatorial ionosphere over the earthquake region ∼15 min before an earthquake with M=4.8 by Chmyrev et al. (1989). Possible generation of seismically related electric field in the atmosphere and the mechanisms of penetration of atmospheric field into the ionosphere were studied by Pierce (1976), Rapoport et al. (2004), etc. An electrodynamic model of atmosphere-ionosphere coupling was formulated by Sorokin et al. (2001a). This model provides an explanation of some electromagnetic and plasma phenomena connected to the effects of amplification of the DC electric field in the ionosphere. A theoretical model of the electric field disturbances caused by the conductivity currents in the atmosphere and the ionosphere initiated by external electric current was proposed by Sorokin and Yaschenko (2000) and Sorokin et al. (2001b). According to this model, the external current arises as a result of emanation of charged aerosols transported into the atmosphere by soil gases and the subsequent processes of upward transfer, gravitational sedimentation, and charge relaxation. Further development of this model including a new method for computation of the electric field in the atmosphere and the ionosphere over active faults for arbitrary spatial distribution of external current in oblique magnetic field was reported by Sorokin et al. (2005, 2006). In our previous papers (Gousheva et al., 2005a, b, 2006a, b, 2007) we found observational evidence in the INTERCOSMOS-BULGARIA-1300 satellite data for increases in the horizontal and vertical components of the quasi-static electric field up to 2–15 mV/m in the near equatorial, low, middle and polar latitude ionosphere. In this paper we present new results from observations of the quasi-static electric field on board INTERCOSMOS-BULGARIA-1300 satellite in polar, middle, low and near equatorial latitude ionosphere above sources of moderate earthquakes.

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Table 1. Satellite orbits above sources of forthcoming or just happened seismic events.

No	Orbits	Date
1	213	1981.08.22
2	250	1981.08.25
3	251	1981.08.25
4	546	1981.09.15
5	709	1981.09.26
6	1527	1981.11.23
7	1576	1981.11.27
8	1610	1981.11.29

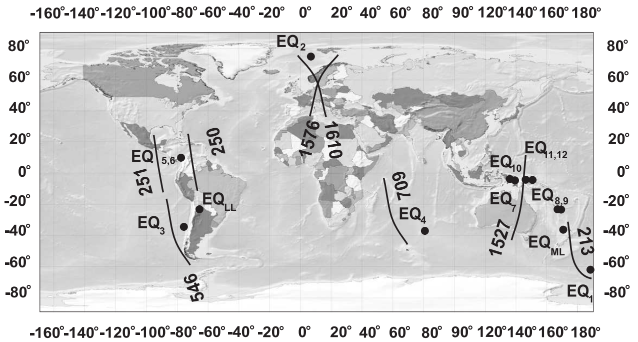

Fig. 1. INTERCOSMOS-BULGARIA-1300 satellite orbits over earthquakes' source in different regions (Southern Ocean, Greenland See, South-West Pacific Ocean, Indian Ocean, Central America, South-East Pacific Ocean, Malay Archipelago).

2 Database and observation methodology

The INTERCOSMOS-BULGARIA-1300 satellite was launched on 7 August 1981. It had a perigee of 825 km, an apogee of 906 km and orbital inclination of 81.2°. The INTERCOSMOS-BULGARIA-1300 satellite operated for two and a half years. Observations of the quasi-static electric field, as in our previous papers, were carried out by the IESP-1 instrument. IESP-1 instrument measured the electric field using the Langmuir double probe's floating potential method, identical to that of a voltmeter: the potential difference between two top-hat probes (Pedersen et al., 1984, 1998).To obtain one component, two sensors are needed. The basis for the X and Y components was 7.5 m (1.8 m for Z component). The dynamical range was ±300 mV/m for the X component, ±600 mV/m for the Y component, and ±90 mV/m for the Z component. The sensitivity was 1 mV/m for each component. E_x is the horizontal component almost parallel to the magnetic field line; E_y is the horizontal component perpendicular to the magnetic field line; E_z is the vertical component – Earth upward. Specialized software has been used for processing the experimental data for the quasi-static electric field. The earthquake data and related details for the same period were obtained from United State Geological Survey (USGS) website. Eight orbits have been chosen above sources of twelve earthquakes in different regions: Southern Ocean, Greenland Sea at polar latitudes; South-West Pacific Ocean, Indian Ocean at middle latitudes; Central America, South Pacific Ocean, Malay Archipelago at low and near equatorial latitudes, complying with the following conditions:

– the observations to be for satellite's orbits over sources of earthquakes at different latitudes;

– the angular distance between the earthquake epicenter and the closest point of the satellite orbit to be $\Delta\lambda < 25°$;

– the seismic events to be on magnetically quiet days (the average geomagnetic activity index K_p up to 5);

– the events not to be in the beginning or in the end of the orbit when there are calibrations, etc., and the data is unreliable;

– intervals with clear instrumental effects not to be considered;

– the orbits not to contain terminator crossing.

The number and date of orbits of INTERCOSMOS-BULGARIA-1300 are given in the Table 1.

3 Observational results

3.1 Southern Ocean and Greenland Sea

Two events (EQ_1, EQ_2) were recorded: on 23 August 1981 and 27 November 1981 with magnitudes 5.0 and 5.1, respectively. The date of events, origin time of seismic events, loccations of epicentre, magnitude and depth are give in the Table 2.The pass of INTERCOSMOS-BULGARIA-1300 for orbits 213, 1576 and 1610 is shown in Fig. 1. The data corresponding to these events are presented in Figs. 2, 3, 4. Here and further, the arrows indicate the moments when the satellite passed at the closest distance $\Delta\lambda$ from the earthquake epicenter.The data are presented as a function of the Universal time (UT), satellite altitude (ALT), the geographic latitude and longitude (LAT, LONG), and the invariate latitude (Inv LAT). On the background of the trend, we observe to the north of the earthquake's epicentre, an increase in the E_z component of about 26 mV/m (Fig. 2), 33 h before this event. It should be noted that these measurements were made on a quiet day (K_p=3), so the observed anomalies were not caused by a solar-terrestrial disturbance. Moreover, EQ_1 was an isolated event – that is, there were no other major seismic or volcanic events on this day. We observe, just after EQ_2, an increase in E_z component of about 15 mV/m (Fig. 3). Figure 4 illustrates the next increase in E_z component of about

Table 2. Parameters of 12 earthquakes selected from USGS website.

No	D, M, Y,	Time, UTC hhmmss.mm	Lat	Long	M	Depth km
EQ_1	1981.08.23	23:45:28	−63.58	−167.21	5.0	10
EQ_5	1981.08.25	16:54:39	6.94	−76.60	5.2	33
EQ_6	1981.08.25	17:29:07	7.01	−76.59	5.1	33
EQ_3	1981.09.19	11:40:57	−39.08	−74.81	5.6	30
EQ_4	1981.09.24	21:09:42	−45.65	79.86	5.5	33
EQ_7	1981.11.21	12:00:46	−4.25	146.82	5.3	24
EQ_8	1981.11.24	23:30:32	−22.50	170.63	6.9	29
EQ_9	1981.11.24	23:49:54	−22.37	170.56	6.2	33
EQ_{10}	1981.11.25	09:36:40	−3.20	142.15	5.6	24
EQ_{11}	1981.11.25	10:40:58	−4.85	153.52	5.4	72
EQ_{12}	1981.11.27	19:38:43	−4.94	153.88	5.4	10
EQ_2	1981.11.27	00:04:57	73.77	8.39	5.1	10

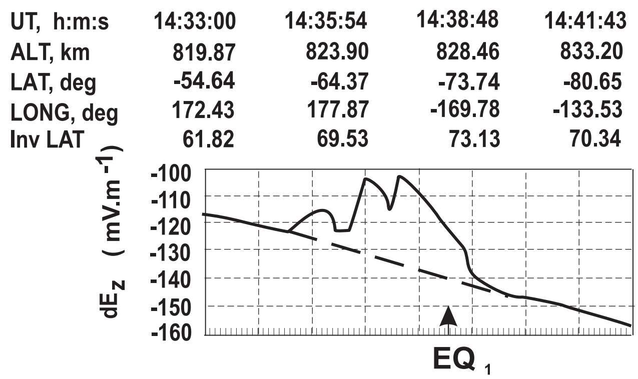

Fig. 2. Disturbances in E_z components of the quasi-static field, orbit 213.

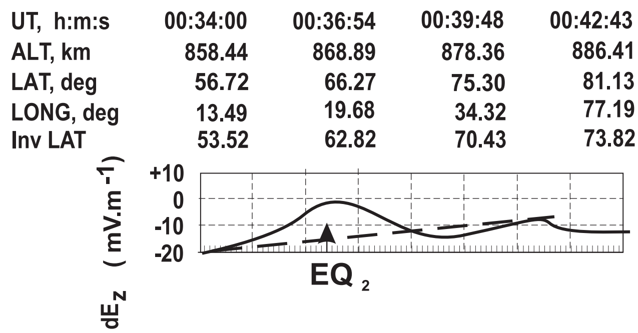

Fig. 3. Disturbances in E_z components of the quasi-static field, orbit 1576.

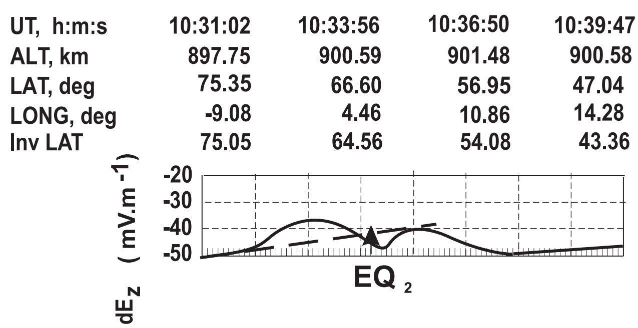

Fig. 4. Disturbances in E_z components of the quasi-static field, orbit 1610.

10 mV/m 58 h after EQ_2. The ionosphere disturbance zones (Figs. 3, 4) are centred around the earthquake's epicentre. It should be noted that the observations were taken on a very quiet day (K_p=1) and the event EQ_2 occurred isolated in the time-space domain.

3.2 South-West Pacific Ocean and Indian Ocean

The first earthquake EQ_3 of magnitude 5.6 occurs on 19 September 1981 in the South-West Pacific Ocean (see Table 2). The pass of INTERCOSMOS-BULGARIA-1300 (orbit 546) 89:37 h before this activity is shown in Fig. 1. Figure 5 shows an increase in E_z component of about 15 mV/m; that is to the north of the earthquake's epicentre (in this case a quiet day K_p=2). It is not impossible, though not likely, that there is also some influence of EQ_{LL} (1981 09 20, 104820.34, −23.080 −66.632 234 5.1), which will occur in 5 days. The second event EQ_4 of magnitude 5.5 occurred on 24 September 1981 in the Indian Ocean (see Table 2). The satellite passed (orbits 709) 43:45 h after the earthquake EQ_4 (Fig. 1). We can also observe an increase (Fig. 6) in E_z component of about 15 mV/m; that is almost centered over the earthquake's epicentre. These observations were taken on a medium quiet day K_p=4, and EQ_4 occurred isolated in time and space.

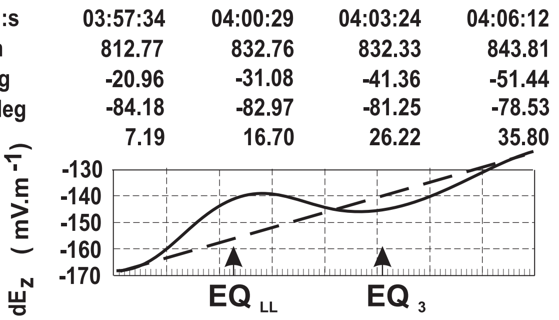

Fig. 5. Disturbances in E_z components of the quasi-static field, orbit 546.

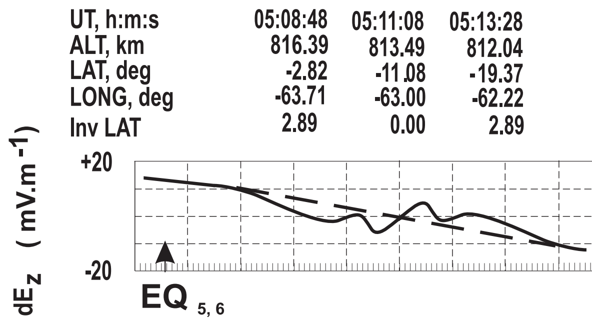

Fig. 7. Disturbances in E_z components of the quasi-static field, orbit 250.

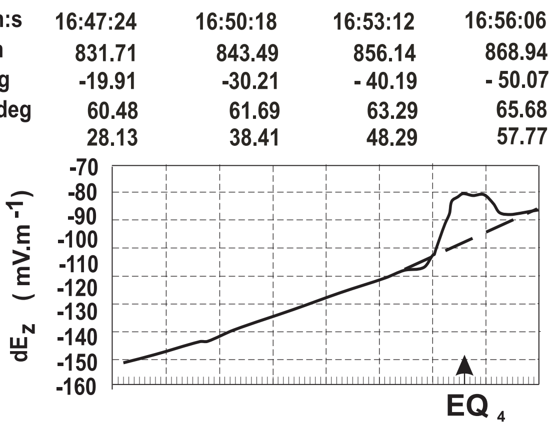

Fig. 6. Disturbances in E_z components of the quasi-static field, orbit 709.

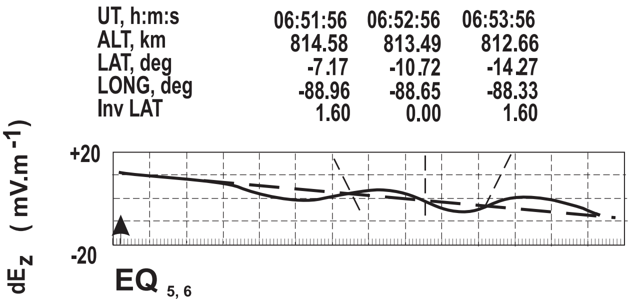

Fig. 8. Disturbances in E_z components of the quasi-static field, orbit 251.

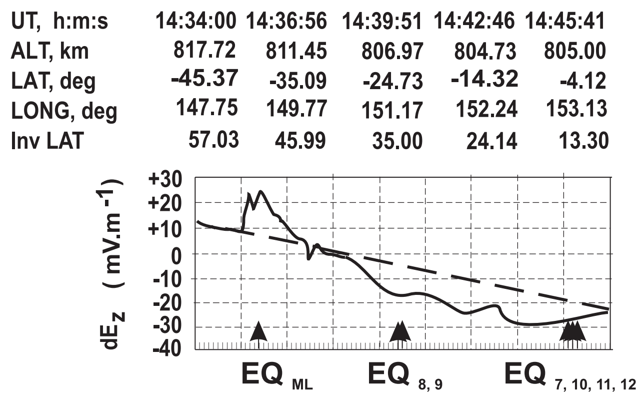

Fig. 9. Disturbances in E_z components of the quasi-static field, orbit 1527.

3.3 Central America

The two earthquakes EQ_5 and EQ_6 occurred on 25 August 1981 in Central America (see Table 2) The pass of INTERCOSMOS-BULGARIA-1300 (orbits 250 and 251) 11–13 h before these earthquakes has been shown in Fig. 1. The disturbances in the E_z component of the quasi-static electric field: the first one to the south of the earthquake epicentres (projection over the equipotential magnetic field lines in the low ionosphere at satellite altitude) and second one – in the magneto conjugate region of about 5–10 mV/m for these events are shown in Figs. 7 and 8. It should be noted that these measurements were made on a quiet day (K_p=3), so the observed anomalies were not caused by a solar-terrestrial disturbance. It is highly probable that the disturbances in the E_z component are due to the cumulative effect of EQ_5 and EQ_6.

3.4 South-East Pacific Ocean and Malay Archipelago

Two strong earthquakes events EQ_8 and EQ_9 and four moderate earthquakes $EQ_{7,10,11,12}$ (Table 2) are taken for the (0°; −50°) latitude range and (135°; 175°) longitude range from these regions in the time period 19.11.1981–27.11.1981. The pass of INTERCOSMOS-BULGARIA-1300 (orbit 1527) 10–100 h before these events. Observations in Fig. 9 indicate that anomalous disturbance zone persisted in a wide latitudinal interval. The increase in E_z component is about 10–15 mV/m. It should be noted that these measurements were made on a medium quiet day (K_p=3). It is highly probable that the disturbances in the E_z component are due to the cumulative effect of $EQ_{8,9}$, $EQ_{7,10,11,12}$ and forthcoming EQ_{ML} (latitude −39.64° S, longitude 174.03° E,

Table 3. Disturbances in the vertical component of the quasi-static electric fields observed by INTERCOSMOS-BULGARIA-1300 during seismic activity.

No	Orbit	Δt, h	Ind. of geo magnetic activity K_p	Disturbances of the quasi-static electric fields mV/m	Distance from satellite to epicentre r, km	Δλ, deg
POLAR LATITUDES						
EQ_1	213	−33:07	3	26	1467	10.20
EQ_2	1576	+00:31	1	15	1809	13.00
EQ_2	1610	+58:29	1	10	1298	07.90
MIDDLE LATITUDES						
EQ_3	546	−89:37	2	15	1280	07.50
EQ_4	709	+43:45	4	15	1959	14.00
LOW AND NEAR – EQUATORIAL LATITUDES						
EQ_5	250	−11:05	3	10	1641	12.00
EQ_5	251	−10:06	3	5	1788	13.00
EQ_6	250	−12:23	3	10	1639	12.00
EQ_6	251	−10:41	3	5	1790	13.50
EQ_7	1527	+49:19	3	15	1007	07.48
EQ_8	1527	−32:49	3	10	2383	19.10
EQ_9	1527	−33:09	3	10	2374	19.02
EQ_{10}	1527	−42:51	3	10	1527	11.02
EQ_{11}	1527	−43:55	3	10	807	00.45
EQ_{12}	1527	−100:50	3	10	811	00.82

06:46:46 UTC and depth 206 km) earthquake (occurrence 40 h later).

4 Summary and conclusions

Data from INTERCOSMOS-BULGARIA-1300 satellite have been employed to present a possible correlation between seismic activity and quasi-static electric field anomalies in the upper ionosphere. The above observations suggest the presence of quasi-static electric field disturbances during seismic activity in different regions: Southern Ocean and Greenland Sea at polar latitudes; South-West Pacific Ocean and Indian Ocean at middle latitudes; Central America, South-East Pacific Ocean and Malay Archipelago at low and near equatorial latitudes. The earthquake data are from the World Data Center-Denver, Colorado, USA. Results of 12 events selected from INTERCOSMOS-BULGARIA-1300 data-base are summarized in the Table 3. The observed anomalies in the quasi-static electric field are:

4.1 Polar latitudes

– increase to the north of the earthquake's epicentre in the vertical component E_z of the quasi- static electric field of about 26 mV/m, 33 h before a moderate earthquake;

– increase centred around the earthquake's epicentre in the vertical component of the quasi- static electric field of about 15 mV/m, 31 min after a moderate earthquake;

– increase centred around the earthquake's epicentre in the vertical component of the quasi- static electric field of about 10 mV/m, 58–59 h after a moderate earthquake.

There are several empirical models. The Heppner (1977), Heppner and Maynard (1987) models are based on OGO 6 (Polar-Orbiting Geophysical Observatory 6) and DE 2 (DynamicsExplorer 2) electric field measurements and provide the electric potential and field poleward of 60 geomagnetic latitude. Electric Convection Field Model was reported by Heelis et al. (1982).Accordingly it would be suitable to investigate and study the anomalous effects of the quasi-static electric field in the polar latitudes for small values of Kp index. We suppose that such type of disturbances in satellte record can be considered eventually as possible pre-, co- and post-seismic effects

4.2 Middle latitudes

– increase to the north of the earthquake's epicentre in the vertical component E_z of the quasi- static electric field of about 15 mV/m, 89 h before a moderate earthquake;

– increase centred around the earthquake's epicentre in the vertical component E_z of the quasi- static electric field of about 15 mV/m, 43 h after a moderate earthquake.

We demonstrate in (4.1 and 4.2) that the disturbances before an earthquake can reach values of (15–26) mV/m. Such electric fields have been reported from satellite observations both over storm and hurricane regions (Sorokin et al., 2005b; Isaev et al., 2006). Our plans for future work include accumulation of statistics from other satellites, with subsequent statistical analysis.

4.3 Low and near – equatorial latitudes

– increase to the soutth of the earthquake's epicentre in the vertical component E_z of the quasi-static electric field of about 5–10 mV/m, 10–12 h before a moderate earthquake (effects are also observed in the magneto conjugate region);

– increase to the north of the earthquake's epicentre in the vertical component E_z of the quasi-static electric field of about 10 mV/m, 32–33 h before a strong earthquake;

We regard these anomalies as earthquake precursors because the seismoionospheric disturbances have a duration of 3–4 h 5 days before the earthquake, and limit our study to the main shocks.

Therefore, we can conclude that at polar, middle and low latitudes, possible ionospheric effects related to seismic activity most probably begin some time before the earthquake, persist during the earthquake itself, and are felt some time after it.

Our observational results on effects in the quasi-static field of the order of 10 mV/m confirm the new method for computation of the electric field in the atmosphere and the ionosphere over active faults proposed by Sorokin (2005a, 2006).

According to the numerical simulation of Sorokin and Yaschenko (2005a), the disturbances in the ionosphere are limited to about 1500 km in both X and Y directions (see their Fig. 3). They do not explicitly specify the altitude in the ionosphere at which this estimation is made. Taking into account that the disturbances propagate along the magnetic field tubes, at the altitude of "Bulgaria-1300" satellite the minimum distance from the epicenter at which the diturbances can be detected is 800 km. The fact that in the majority of cases the distance between observation point and EQ epicenter is over 1500 km implies that the model may underestimate the spatial extend of the disturbances.

Southern hemisphere are shifted to the north of the earthquakes' epicenters. The ionospheric zones of electric field disturbances in cases of earthquakes in the Northern hemisphere are shifted to the south of the earthquakes' epicenters. This is connected with the electric field projection along magnetic field lines into the low ionosphere at satellite altitudes. The effects are also observed in the magneto conjugate region as it has been already noted by Chmirev et al. (1989).

For orbits (250, 251 and 1527), over sources of moderate earthquakes EQ_6, EQ_7 and $EQ_{10,11,12}$, the electric field is perpendicular to the magnetic field line (or to magnetic field). Ions and electrons are moving perpendicular to the plane which is determinated by the electric and magnetic vectors. They cannot immediately compensate the charge that causes the electric field so this field is expanded into a large area.

For the first time we show disturbances of the same size after the earthquake, possibly related to the seismic activity.

We speculate that the disturbances in the quasi-static electric field can be of seismic origin.

These anomalies, as phenomena accompanying the seismogenic process, can be considered eventually as possible pre-, co- (coeval to) and post-earthquake effects. Of course, none of the effects studied so far can't guarantee a 100% probability of a future earthquake. The same pertains to the demonstrated possible post-effects.

We plan to continue collecting statistics from past and operational satellites for the further investigation of seismically related anomalous effects in the ionosphere. This will allow the evaluating of some morphological peculiarities of the quasi-static electric field disturbances, such as the time of their appearance before the main shock, sensitivity to the earthquake's magnitude, amplitude, sign, and time duration.

The obtained results strengthen our earlier studies (Gousheva et al., 2005a, b, 2006a, b, 2007) and are informative about the existence of possible pre-, co- and post-seismic effects in the ionosphere. A number of observations of this type will be necessary to confirm the existence of the relation between the phenomena shown here. If these changes are well defined they could be included in the complex of phenomena used for seismic prognosis and analysis.

Edited by: P. F. Biagi
Reviewed by: O. Molchanov, P. Velinov and two other anonymous referees

Supplement: http://www.nat-hazards-earth-syst-sci.net/8/101/2008/nhess-8-101-2008-supplement.pdf

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