Pergamon

Adv. Space Res. Vol. 22, No. 6, pp. 903–906, 1998
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Printed in Great Britain
0273-1177/98 $19.00 + 0.00

PII: S0273-1177(98)00121-5

SEISMIC ACTIVITY AS A SOURCE OF THE IONOSPHERIC VARIABILITY

S. A. Pulinets

Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation,
Russian Academy of Sciences, (IZMIRAN), Troitsk, Moscow Region, 142092, Russia

ABSTRACT

Ionospheric variations, observed mainly by vertical sounding technique, over the seismically active regions are interpreted in terms of lithosphere-ionosphere coupling. The methods of identification of variations induced by seismic activity within the ionosphere are proposed. It is shown that such variations have their individual features, different from variations induced by magnetic disturbances and other kinds of external activity. The magnitude and occurrence of such variability lead to conclusion that seismic activity is important source of the ionospheric variability.
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INTRODUCTION

Spatial and temporal irregular behavior of the ionosphere was usually interpreted only in terms of solar and geomagnetic influences. All energy input into the ionosphere was explained mainly by the sources from above the ionosphere (particle precipitation, closing of the magnetospheric currents etc.) Thermosphere-ionosphere coupling by tides, winds, gravity waves, travelling ionospheric disturbances etc. is also interpreted in terms of external sources while other influences on the ionosphere were practically neglected. However, global-scale studies made with the help of topside sounding from satellites have demonstrated that electron density distribution has very patchy structure which cannot be explained within the frame of traditional models. Certain irregularities occurring in the ionosphere are apparently caused by seismic activity which could be related with electrodynamic and plasmachemical processes. It is intriguing that the seismo-ionospheric effects appear within the ionosphere in advance of the main event. The seismic activity provoke positive or negative variations in electron density (as at F2-layer peak, so at different altitudes), variations of h_mF2, electron temperature, ion and neutral composition, formation of sporadic E and spread-F layers. A physical explanation of seismo-ionospheric coupling mechanism will be given.

IDENTIFICATION OF SEISMO-IONOSPHERIC VARIATIONS

The first question is how to distinguish the variations stimulated by the seismic activity from other kinds of ionospheric variability. A first technique was elaborated empirically, and now it is developed basing on our understanding of physical mechanisms. The most important is the locality of the effects: they are attached to the region of the future epicenter position. Depending on their magnitude, the effects could be revealed by different techniques. Figure 1 shows strong longitudinal variations of the critical frequency f_0F2 2 and 1 day before a strong earthquake. These were observed by topside sounding (Intercosmos-19 satellite) in the vicinity of the longitude of the future epicenter. In quiet geomagnetic conditions it is difficult to explain so strong variations. Satellite technique allows to do the 3-D mapping of the critical frequency distribution. One can find in Biryukov et al., (1996) such distributions for the case presented in Figure 1. There appears a ring structure of strong negative variation situated close to the future epicenter position, which disappears after the event. In the case of smaller variations ≤ 20 % another technique of ionospheric data visualization was used, first proposed in Pulinets *et al.* (1996). The data from a longitudinal chain of ground-based ionospheric stations in a latitudinal interval ± 5° around the future epicenter were selected and presented in the form of a 3-D distribution (longitude/time) of ΔfoF2. The percentage value of ΔfoF2 is expressed by shadowing. Interpolation between stations was carried out by a Kriging method (Oliver and Webster, 1990). On the Figure 2 such distribution is presented for the case of 3 consecutive earthquakes in Italy and the Balkan in May, 1984. Arrows at the left vertical axis designate the earthquake moments. Earthquakes main parameters are presented in Table 1. As can be seen on the figure the variations occur synchronously in the whole longitude range, i.e. at all longitudes one finds either negative or positive variations. And only in a longitude range near to an epicenter of the future earthquake (~ 14° E) the variations are clearly distinct from the environmental background. Positive variations around noon are particularly well seen in geomagnetically quiet periods. It may be noted that the seismogenic variations occur 5 day prior a seismic shock (cf. May 2). At the end of the chosen time interval the peculiar distribution of Δf_0F2 is displaced to the East synchronously to longitudinal position of the epicenter. Thus, with the help of the given representation of the ionospheric data it is possible to locate position of the seismo-active region. On the other hand, the received result shows that the seismic activity is one of essential sources of day-to-day variability of an ionosphere.

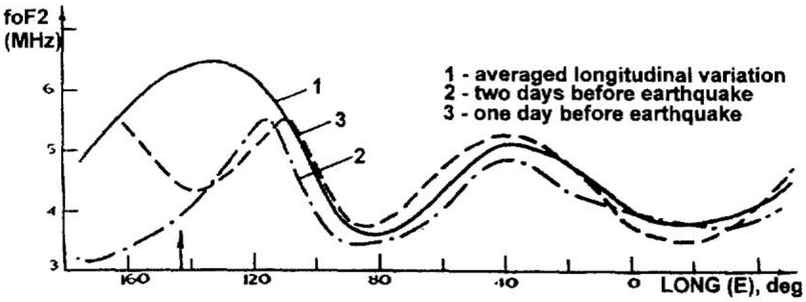

Fig. 1 Longitudinal variations of critical frequency at geomagnetic latitude of the earthquake epicenter obtained by topside sounder for 14.07.80 and 15.07.80 for ~05 h LT. Bold line – averaged distribution obtained for quiet conditions. The reversed direction of Longitude axis is explained by westward shift of the satellite orbit longitude position with UT.

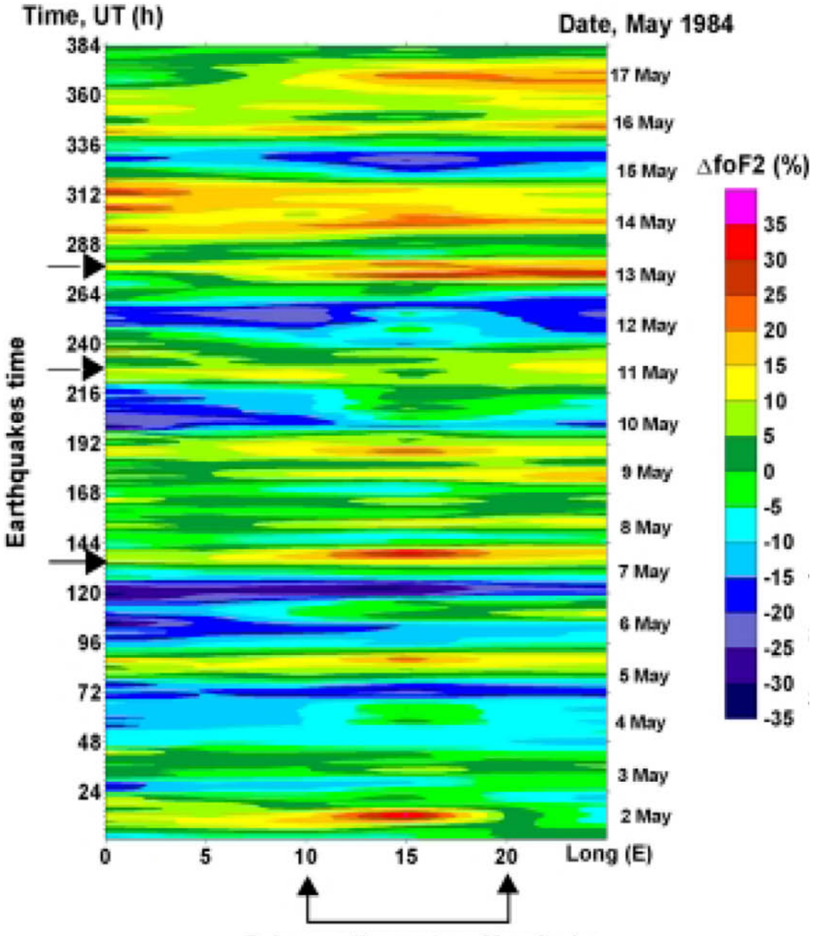

Fig. 2 Deviation of critical frequency foF2 (shadow) in the longitude sector 0° - 25° E at latitudes 35°- 45° N as a function of time for a period of strong seismic activity. Black arrows at the left axis indicate the moments of earthquakes.

Though different kinds of precursors could be described in more detail we shall in the following only resume their principal characteristics:

1. *While storms last 8 to 48 h seismo-ionospheric variations take only 3 to 4 h. They appear every day during a period up to 5 day prior to earthquake at the same local time.*
2. *The seismo-ionospheric variations could be negative or positive; at the given height the sign depends on local time. This dependence for critical frequency was determined in Pulinets et al. (1998 a)*
3. *Seismo-ionospheric variations result in a re-distribution of electron concentration with height. One observes changes of the hmF2, height scale and TEC over the regions of anticipated earthquakes*
4. *The modified region of the ionosphere is "tied" to the position of the anticipated earthquake though the greatest changes not necessarily coincide with the epicenter projection. The size of the modified region is of the order of 20° - 30° in the diameter. Sometimes the modification is observed in magnetically conjugated region also.*
5. *Ion and neutral composition changes accompany the electron concentration variations connected with seismic activity. The O^+, O_2^+, NO^+, concentration changes are in phase and have the same sign. At heights around 2000 km an increase in the concentration of H^+ and He^+ is observed over the regions of anticipated earthquakes.*

Table 1 Parameters of the seismic events presented in Figure 2

Date	Time	Lat	Long	Depth	M	
07.05.84	1750	41.8N	13.9E	16	5.8	ITALY: S CENTRAL: ABRUZZO
11.05.84	1042	41.8N	13.9E	15	5.4	ITALY: S CENTRAL: ABRUZZO
13.05.84	1245	43.0N	17.8E	34	5.1	BALKANS NW:

The main differences from storm-time and other kinds of ionospheric variations are:

1. *The ionospheric variations during a storm have global character, seismo-ionospheric variations are only regional*
2. *An ionospheric storm is a continuous process, developing within 40 to 48 hours*
3. *In middle and low latitudes, the negative phase of a storm always begins in the time between sunset and sunrise and then corotates in a daytime hemisphere. The seismo-ionospheric variations have a completely different dependence on local time*
4. *During a storm the average molecular mass at heights in the F-region **increases** as well as the ratio ([N2]+[O2]) / [O]. Seismo-ionospheric variations lead to **decrease** of the mean mass in the F-region.*
5. *While other kinds of ionospheric disturbances (gravity waves, travelling ionospheric disturbances, etc.) move in space, the position of seismo-ionospheric variations determined by the positions of future epicenter is invariable.*

The physical interpretation of the observed ionospheric variations is still under discussion. Nevertheless we propose the following scheme, which is supported by experimental evidence. One of the main sources of atmosphere-ionosphere modification over the regions where earthquakes later appear is emanation from the earth of different chemical substances. We mention radon, light gases (hydrogen and helium), and submicron aerosols with high metal content (Alekseev and Alekseeva, 1992). This leads to changes of the electrodynamic properties of atmosphere over the region of an originating earthquake and as a result to observed phase variations of VLF signals passing over these regions (Fux and Shubova, 1994). The main effect is a modification of the vertical atmospheric electric filed due to an electrode effect in the near-ground layer of the atmosphere (Hoppel, 1967). Electrode effect in the presence of aerosols in the atmosphere lead to the formation of large-scale electric fields of up to several kV/m (Vershinin et al., 1997, Boyarchuk et al., 1997). These vertical fields reach into the ionosphere where, due to anisotropic conductivity they transform into horizontal fields (Kim and Hegai, 1994). Due to Joule heating the electron temperature increases within the E-layer of the ionosphere, generation of gravity waves and formation of small-scale ionospheric irregularities take place. The same seismogenic electric field provokes formation of large-scale irregularities within the ionosphere observed by topside sounder. The seismogenic electric field within the ionosphere is modulated by daily variations of plasmaspheric electric fields that cause the daily variations of the sign of seismo-ionospheric variations (Pulinets et al.,1998 a).

CONCLUSION

Seismic activity leads to a modification of the plasma at ionospheric heights, as we assume by electromagnetic coupling with the near ground electric field. The ionospheric effects usually are observed for earthquakes with a magnitude higher than 5. This is probably not the threshold of the geophysical mechanism but that of our experimental possibilities limitation. Taking into account that such effects appear at least 5 days before an earthquake (there are observations indicating changes connected with radon emanations in seismo-active regions that might last several months, Pulinets et al., 1998 b), and statistics of earthquakes (near 20 very strong catastrophic earthquakes with magnitude higher than 7, 100-120 potentially dangerous, and 300 000 small earthquakes per year), we conclude that seismic effects on the ionosphere is continuous process and an essential source of global ionospheric variability. There are, of course, also other sources of atmospheric electric field modification: accidents at atomic plants, chemical releases and releases from metallurgic plants, volcano dust, modification of the atmospheric air over large megapolises, etc. Practically, the mechanism of ionosphere modification will be the same. For some cases, especially for Three-mile Island and Chernobyl atomic plants accidents the ionospheric effects were recorded. The degree of ionosphere modification in such cases will be estimated in future publications.

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