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PLASMA DENSITY VARIATIONS OBSERVED ON A SATELLITE POSSIBLY RELATED TO SEISMICITY

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ABTRACT

We discovered a reliable correlation between global distribution of seismic activity and ion density variations in the ionosphere on the basis of the analysis of a rather large data base of plasma density, which was recorded on board a Russian satellite Intercosmos 24 (more than 3000 orbits over the world). The best parameters to find a significant correlation between the two, are normalized standard deviation (NSD) and relative normalized standard deviation (RNSD). Maximal values of density NSD correlated with seismic activity are 10-20 %. However, a clear correlation is found only for daytime (10-16 LT), quiet magnetic conditions and altitude range 500- 700 km, while it disappears in nighttime and during magnetic storms. A mechanism of seismo-ionosphere coupling might be connected with slow gravity waves.

INTRODUCTION

There are quite many papers on satellite recordings of wave/plasma disturbances possibly associated with earthquakes. While appearance of seismic and nonseismic phenomena related to earthquakes on the ground is doubtless, a possibility of observations of seismo-associated effects in the atmosphere and ionosphere is claimed sometimes as questionable. This situation was discussed in several recent papers (e.g. reviews by Parrot et al., 1993, Molchanov, 1993, Hayakawa, 1997) paying attention to different criteria of data selection, frequency range and so on. However, the main problem is that these studies were not statistical in a rigid sense due to multi-parametric dependence of expected events on natural conditions and principal impossibility to separate time and space variations from one-satellite observation. Because we need to have data set either continuous in space at a fixed time or in contrast continuous in time at a fixed place to use the conventional statistical methods. In addition to the ambiguity of observational conclusions, the mechanisms underlying in the seismo-ionospheric or seismo-atmospheric effects are also unclear. On the other hand, study of seismicity and underlying processes could be essentially improved by using the satellite methods as it happened with climate and weather study when proper satellite information became available. Recently, slow tectonic deformations after some great earthquakes have been analyzed by Synthetic Aperture Radar (SAR) installed on the special satellites. Attempts to find a thermal infrared (IR) anomaly on the ground surface before earthquakes were undertaken from satellite observations. These remote-sensing efforts can be combined with other effective satellite recordings, first of all with on-board wave/plasma measurements and radar sounding of density perturbations in a space between satellite and ground. In future, it might be useful to create a global system of earthquake forecast and prevention. However, to do so it is desirable to be sure that atmospheric and ionospheric signature of the earthquakes exists indeed. We have tried to present here a statistically justified evidence of the seismo-ionosphere coupling.

MAIN RESULTS OF STUDY

The main idea of our research is to use an inhomogeneity of seismic activity distribution over the Earth. It is well known that seismic activity in any rather long period of time is concentrated along the so-called great plate boundaries. So, if seismic activity influences the ionosphere indeed, we should find the statistically valuable and similar space inhomogeneity in our data after their averaging over the time. Of course, it is desirable to have rather large data base and to analyze the parameter whose divergence in space scale of a few hundreds kilometers is not fast in comparison with the characteristic time of usual earthquake sequences. The only plasma parameter, which is conserved in this space scale for long time, is the density of cold plasma. Therefore we selected the data of ion density obtained on a Russian satellite Intercosmos-24 (Aktivny) during its operation from October 1989 to December 1991. This satellite had an elliptical orbit, apogee 2497 km, perigee 511 km, angle of inclination 82.6 degree and orbit period 124 minutes.

We selected the following basic parameters of our data:

1. Geographic latitude φ and choose the division $\Delta\varphi = 4$ degree, resulting in $N_\varphi = 45$ divisions.
2. Geographic longitude λ, $\Delta\lambda = 5$ degree, $N_\lambda = 72$.
3. Local time LT; chosen at 4 grades: night, 22-04 LT; morning, 04-10 LT; day 10-16 LT; evening, 16-22 LT, resulting in N (LT)=4.
4. Altitude H, $\Delta H = 100$ km, in a range 500 km - 2500 km, resulting in N (H)=20 divisions.
5. Index of magnetic activity Kp; 3 grades: quiet activity Kp<3, medium activity, strong activity, Kp >5, resulting in N (Kp)=3.

Thus, we organized $N_\Sigma = N_\varphi * N_\lambda * N(H) * N(LT) * N(Kp) = 7.776*10^5$ elementary "cells". The whole volume of our database is about 3200 orbits or about 10^7 points. It means that in each elementary cell we found in average Nc=15-20 points, so that it seems as sufficient for reasonable averaging in the selected configuration. Of course, we could perform a more detailed division, for example, introducing the seasonal subdivisions or taking some atmospheric parameters but it could lead to the failure of statistics. In each elementary cell we calculated the following values: a. an average value $\langle n \rangle = \Sigma n_i / Nc$, b. standard deviation value: $SD = (\Sigma(n_i - \langle n \rangle)^2 / Nc)^{0.5}$ c. normalized standard deviation value: $NSD = SD/\langle n \rangle$, d. relative standard deviation value: $RNSD = NSD/\langle NSD \rangle$, where $\langle NSD \rangle$ is the averaging over a "map" or all the cells with equal LT, H and Kp parameters and with some limitation of latitude in order to exclude geophysical perturbations at high latitudes.

Two types of presentation of the results were chosen: 2-D map presentation and longitudinal dependence. Let us look at a distribution of enhanced RNSD parameter in the situation, H=500-600 km, LT=10-16 (black lines in Figure1). Circles present distribution of seismic activity during the operation of Intercosmos-24 satellite. Each circle shows a place where a rather large earthquake (M >5) occurred. The similarity between seismicity and density fluctuations is rather pronounced. Of course, it is one of the best examples. We have analyzed all the possible maps and we could find out this type of similarity for the following conditions:

a. Altitude H is near the perigee, 500< H< 800 km.
b. Geographic latitudes or geomagnetic latitudes are limited, $|\varphi|$, $|\Phi| < 50$ degree.
c. Only daytime period, LT=10-16 LT.
d. Only geomagnetically quiet periods, Kp <3.

Even after such a selection the correlation envisages from the maps was not so convincing. Furthermore, it was difficult to estimate quantitatively this correlation. So, we finally analyzed only the longitudinal dependence of both ion density RNSD and seismic activity. Such a plot is shown in Figure 2 for altitude range H=600-700 km. The top panel is the number of large earthquakes during all the period of our observation, averaged over latitude. The bottom panel is the density RNSD also averaged over latitude, and a solid line demonstrates it. A thin line for comparison repeats longitudinal dependence of earthquake occurrence. In correspondence with the known criteria we can believe that if RNSD >2 then the probability of random fluctuation is low (It is famous 2σ statistical criteria in our case). It is evident that exceeding the 2σ level happened just in a region above the enhanced seismic activity area, and furthermore, a clear peak to peak correlation can be noted.

Then we have tried to understand whether seismo-ionospheric coupling is controlled geographically or geomagnetically. We found that density variations in the Southern Hemisphere do not correlate with seismic activity in the same hemisphere, but they are rather well correlated with seismic activity in the opposite, Northern Hemisphere. The simplest explanation of the facts presented is that variations in the southern hemisphere are mainly controlled by northern seismic activity, and thus, we need to assume an essential coupling along the magnetic field line or geomagnetic control (see details in the paper by Afonin et al., 1998)

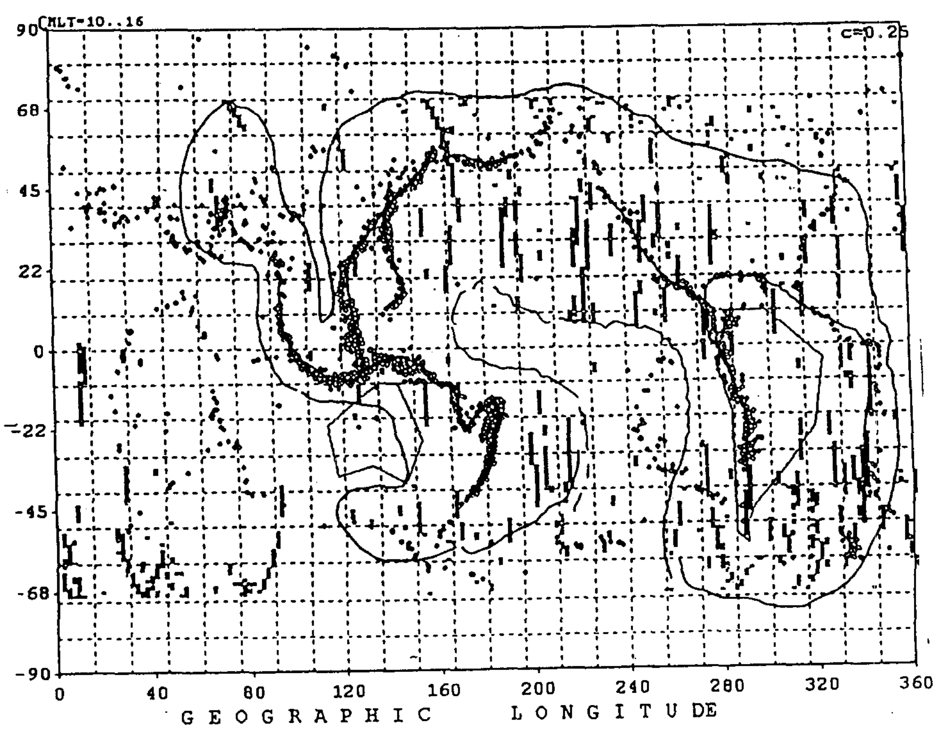

Fig. 1. Global distribution of earthquakes during the interval of analysis (1989-1991, M>5.0, circles) together with the distribution of RNSD of ion density above 2σ level, recorded on Intercosmos-24 satellite (solid lines). H= 500-600 km, MLT=10-16. Area of enhanced coincidental activity of earthquakes and ion density perturbations outlined by a thin line.

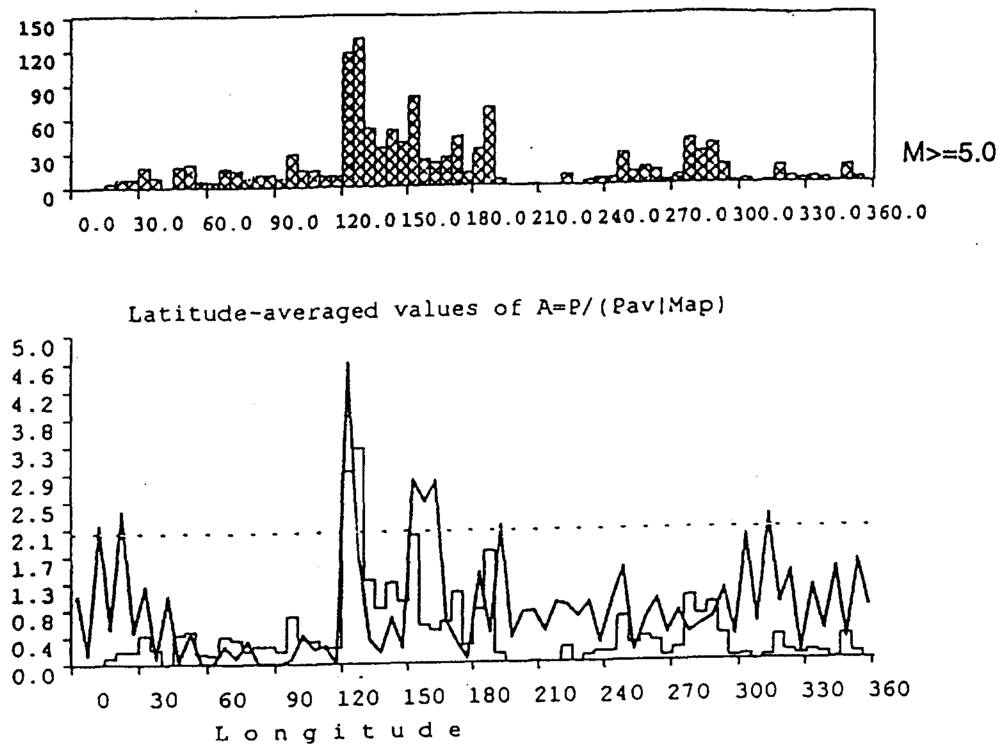

Fig. 2. Dependence on geomagnetic longitude of earthquake occurrence rate (M>5.0, 1989-1991 years), (above) and RNSD of ion density, H= 600-700 km, Kp < 3, MLT= 10-16, $|\Phi|$ <50 degree (solid line, below).

CONCLUSIONS

It seems that our finding has supported an existence of seismic influence onto the ionospheric plasma. Reliability of this proof is justified by using the 2σ statistical criterion and visual peak to peak correlation of seismic occurrence and normalized density variations. It is easy to estimate that correlation coefficient of two plots in these figures in a range λ~ 110-190 degree is better than 0.6. At present we have tried only to prove a feasibility of satellite monitoring for seismic activity. In order to estimate an efficiency of such observations we would like to continue our research using other types of data and different criteria of their discrimination. We are going to do it in the framework of Earthquake Remote Sensing Frontier project, being performed at present in NASDA, Japan.

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