ELECTROMAGNETIC EFFECTS IN ATMOSPHERE, IONOSPHERE AND MAGNETOSPHERE INITIATED BY EARTHQUAKE PREPARATION PROCESS

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1. Introduction

It was established that the final stage of the earthquake preparation cycle is a complex chain of interactions between the geospheres and energy transformations where the electromagnetic processes play an important role [1]. The main and most important one – it is electromagnetic coupling between the ground surface and ionosphere leading to generation of ionospheric anomalies over the earthquake preparation area through the local modification of the Global Electric Circuit [2]. But on the way from the ground up the ionosphere and magnetosphere a lot of electromagnetic interactions of the smaller scale take place including the generation of electromagnetic emissions at different frequency bands and different altitudes, anomalies of the radio waves propagation of different frequencies, wave-particle interactions, aerosol layers electrification and electric discharges, electromagnetic effects in space plasma, etc. [3, 4]. The present paper concentrates on systematization of these lower scale electromagnetic effects leaving the ionospheric anomalies to other author's discussion.

2. Electromagnetic emissions in the lower atmosphere and troposphere

From the very beginning of earthquake precursors' studies probably the most populated was the publication list on the electromagnetic emission registered in the active earthquake areas. But with time it was strongly rarified, so at the moment we will comment only the EM emissions which are registered and reported regularly during recent few years.

2.1 Ground ULF emissions

The most comprehensive information on this kind of emissions is collected in Japan due to regular multi-year observations [5]. Regardless the physical mechanism for this kind of emission was proposed a long time ago [6], it is still not commonly accepted and discussions on the possible mechanism are continuing because the effectiveness of microfracturing electrification proposed in the paper is very low. Recent conception of Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model [7] gives opportunity to put forward the new idea of the emission generation mechanism – it is plasma emission of atmospheric plasma created in the near ground layer of atmosphere due to air ionization by radon emanating from active tectonic faults. This process creates the charged ion clusters with very low recombination rate consisting from positive and negative ions, so called ion-ion plasma [8] immersed in the vertical DC electric field. Taking into account the large mass of the clusters, it will be extremely low frequency emission. Such configuration could be easily electrified facilitating the electric discharges within the plasma volume (similar to thunderstorm clouds) [9]. These discharges can be registered as a pulsed EM emission like it is now reported for the recent earthquakes in Peru [10].

2.2 Electromagnetic emissions in atmosphere

Next altitude level where electromagnetic emissions were detected is emissions from few kilometers over the ground in different frequency bands. The continuous [11] and pulsed [12] emissions are known from the literature. The mechanism of continuous emission from atmosphere in the HF-VHF frequency band was described in [13] where rotational dipole oscillations of the ion clusters are considered as a source of continuous emission. Actually, the ion clusters growing to the aerosol size due to the ion's hydration [7] form the aerosol layers over the earthquake preparation zone. As it happens near ground these layers also to be electrified and emit the pulses due to electrostatic discharges inside the aerosol layer [14].

3. Electromagnetic emissions in ionosphere and magnetosphere

Low frequency emissions were one of the first short-term earthquake precursors detected onboard artificial satellites [15, 16]. Here we mean both ELF and VLF bands. The most comprehensive database on the EM emissions in space plasma before earthquake was collected by DEMETER satellite [17]. But still there no exist

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accordance in the effects understanding and interpretation. If in early publications [15, 16] the increased values of VLF and ELF emissions were reported while satellite passing over earthquake preparation area, recent results from DEMETER satellite statistically show the decrease of intensity of ELF/VLF waves observed in the upper ionosphere close to earthquakes.

Let us divide two types of frequency bands. As it was shown in [13] the changes in intensity of VLF waves registered on satellite before earthquakes are connected with conditions of magnetospheric propagation of VLF waves: passing or trapping in the modified by earthquake magnetospheric tube. The VLF emissions are not generated within the earthquake activated region, but are of natural origin (whistlers, VLF transmitters, power lines, etc.). If within the tube electron density irregularities configuration is favorable for the VLF wave trapping, satellite sees the increased level of VLF noise while passing through the modified tube, in opposite case, it will register the decreased level of noises.

As concerns the ELF emissions, here we have the different story. The morphology of electrostatic ELF noises in the frequency band <500 Hz [18] clearly shows that there nature is not connected with remote propagation, and they are generated directly *in situ*. From our own experience and from the literature analysis, we can state that after the plasma concentration variations over seismically active areas, electrostatic ELF noises are second in the rank of reliability precursors registered onboard the satellites. They frequently appear in association with plasma bubbles developing in ionosphere, and we consider gradient drift instability as a possible mechanism responsible for their generation.

4. Anomalies in radio waves propagation

The first reported anomaly of radio wave propagation before earthquake was the anomaly observed around the time of Alaska earthquake of 28 March 1964 [19] and concerned the HF radio waves propagation. Now these anomalies are registered by ionosondes and GPS receivers. At present time the most exploited and reached the level of practical application in the short-term earthquake forecast is the anomaly of sub-ionospheric VLF radio waves propagation [20]. As concerns the physical mechanism of this anomaly, we consider the changes of boundary layer conductivity which is due to ionization and particle nucleation processes responsible for the variations of amplitude and phase of VLF signals passing over the earthquake preparation areas.

Second kind of anomaly – is the over-horizon propagation of VHF emissions (usually the signals of FM commercial transmitters) [21]. This technique is mainly developed in Japan and used for the short-term earthquakes forecast. It is interesting that this effect is mainly the daytime event what implies the important role of aerosols when the boundary layer turbulence is more developed. In paragraph 2.2 we mentioned formation of aerosol layers over the earthquake preparation areas consisting from the charged ion clusters of aerosol size. Just the fact that these clusters are charged, gives opportunity to reflect the radio waves by the layer. Actually, we can consider effect more as scattering than the reflection. As analogy we can provide the forward scattering of radio wave on meteor trails.

The last very interesting anomaly discovered quite recently – it is the ground VLF transmitters weakening on their way from ground to satellite while satellite passing over the earthquake preparation area [22]. It means that atmosphere over the earthquake preparation area modified by the ionization and aerosol formation scatters the VLF signal leading to its effective weakening on the ground-satellite propagation pass.

5. Conclusion

The variety of electromagnetic effects observed before earthquakes within the area of earthquake preparation is a one more confirmation how complex are the processes of geospheres interactions initiated by the final stage of the earthquake preparation cycle. We mentioned here not all electromagnetic effects which could be found in the literature, but those which are confirmed by studies of not only one group of researchers, and continues to be used in earthquake forecast technologies development. The weakness of this direction of research (contrary to ionospheric and thermal anomalies) is poorly worked physical mechanisms for practically all EM anomalies mentioned in the paper. We need to convert the situation with electromagnetic anomalies before earthquakes to the state we have with seismo-ionospheric anomalies. After the period of hostility of the ionospheric community in relation to the seismo-ionospheric effects, now it is difficult to find the ionospheric group in the world which in larger or smaller extent was involved in the studies of ionospheric effects of earthquakes. This presentation is an appeal to radio physicists to pay more attention to the EM anomalies associated with the earthquake preparation

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