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Prevention project: a complex geophysical observatory in Mexico as a test facility for lithosphere–atmosphere–ionosphere coupling models

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Abstract

During the recent few years different physical models were developed trying to explain the physical mechanisms of electromagnetic and plasma phenomena observed in the area of anticipated earthquake on different levels: near the ground, in the atmosphere and in the ionosphere. All existing models are based on certain hypothesis because of lack of sufficient experimental data. In the best case, the models had to use the data collected at different places, and in different time, for different earthquakes. The project PREVENTION (PREcursors of Volcano Eruptions and Notable Tremors Integral ObservatioN) intends to establish a complex geophysical observatory in one of the most seismically active and potentially dangerous areas of Mexico – the State of Guerrero. The measurements will be done on all levels from the underground to the space to obtain simultaneous multi-parameter data for direct examination of existing physical models of seismo–ionospheric coupling. The second site of experimental survey will be established in the vicinity of Popocatepetl volcano to study the relation between volcanic activity and the ionospheric effects. The concept of the observatory is presented.

1. Introduction

Earthquakes still occupy one of the first places in the list of natural disasters causing fatalities in human life. That is why the earthquake prediction is, in spite of the difficult and entangled history, still on the top of the human task agenda. But the history has shown that empirical approach without understanding of the underlying physical mechanisms is unproductive and dangerous, leading to many faults and speculations. So, the physics of earthquakes precursors is a very urgent task for the modern studies in seismology and in related areas of physical and geochemical precursors of earthquakes. Recent advances in our knowledge of electromagnetic and ionospheric precursors (see references in Hayakawa and Fujinawa, 1994; Gokhberg et al., 1995; Hayakawa, 1999; Hayakawa and Molchanov, 2002) open new perspectives in short-term earthquake prediction. These studies should be firmly supported by adequate physical models giving understanding of the relation between the registered parameters and physical processes in the Earth's crust, atmosphere and ionosphere. The diversity of physical models explaining the same precursory phenomena reflects a poor understanding of the real processes. To progress this situation, existing models should be validated at the same established site or area, where it may be possible to measure a set of key parameters used in the models, especially the temporal and spatial evolution of these parameters in relation to the seismic activity. The PREVENTION project should realize this goal and promote the study of the main physical mechanisms of the seismo–ionospheric coupling. The experimental setup will be deployed on the Pacific coast of Mexico, in the State of Guerrero, one of the most seismically active areas of Mexico. Several instruments will be installed in the vicinity of the Popocatepetl volcano. It is expected to carry out a recording of as many physical and other types of parameters as possible at the same time in the same location, and then to use all this data for the examination of different models of prediction.

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2. Existing models and their problems

The changes in the near ground atmosphere, upper atmosphere, ionosphere and even plasmasphere have been observed within some interval (several weeks/days/hours) before large seismic events, in the areas close around to the future epicenters. Various authors, applying robust techniques of measurements and data analysis, reported noticeable changes of the electromagnetic fields and other parameters of atmosphere and ionosphere. Some examples of these studies are: near ground level measurements of acoustic emissions (Gorbatikov et al., 2002); electromagnetic noise measurements in different frequency bands from DC up to VHF (Hayakawa and Fujinawa, 1994; Parrot, 1995; Uyeda et al., 2002); surface temperature records (Tronin, 1999; Tronin et al., 2002; Tramutoli et al., 2001); estimates of the ground electric potential (Uyeda et al., 2000) and anomalous vertical electric field (Vershinin et al., 1999; Hao et al., 2000; Rulenko, 2000). The results of VLF, LF, HF, and VHF signal propagation anomalies (Gufeld et al., 1992; Molchanov and Hayakawa, 2001; Biagi et al., 2001; Vallianatos and Nomicos, 1998; Kushida and Kushida, 2002) can be interpreted as indirect indication of the changes of parameters of lower ionosphere (D-region). The Earth's ionosphere provides an ample data on the precursory effects: optical emissions were registered in the ionosphere before the earthquakes (Fishkova et al., 1985; Akhmamedov, 1993); the concentration of light ions increases (Bošková et al., 1994) that is equivalent to the decrease of the mean ion mass (Pulinets et al., 2003); electron temperature variations (Afonin et al., 1999); the particle precipitation (Galperin et al., 1992; Galper et al., 1995); formation of the large scale (Pulinets, 1998; Pulinets and Legen'ka, 2003) and small scale (Chmyrev et al., 1997) electron density irregularities, including the anomalous electric field penetration through the plasmasphere into the conjugated hemisphere (Ruzhin and Larkina, 1996; Pulinets and Legen'ka, 1997). Quasi constant ULF and VLF electromagnetic emissions were observed in the space plasma as well (Larkina et al., 1989; Serebryakova et al., 1992).

A lot of work was done to explain the observed anomalies in different fields, their interrelations and connection to the earthquake preparation process. First attempts have been undertaken in the 70s (Pierce, 1976). Then several papers appeared with the discussion of some new ideas (Gokhberg, 1984; Liperovsky et al., 1991; Gokhberg and Shalimov, 1998) but still there were more inferences and speculations than real modeling. These pioneering studies implicitly reveal two main directions in the seismo–ionospheric coupling interpretation: quasi-stationary electric field as a source of the ionospheric perturbations; and the acoustic gravity waves (AGW). Later, several new ideas were developed, such as changes of the atmospheric electricity due to the air ionization produced by the emanating radon (Fuks et al., 1997; Pulinets et al., 1997, 1999a,b) as a cause of the conductivity changes of the near-ground layer of the atmosphere. Summarizing this first period of modeling attempts, we can point out three most promising hypotheses of the seismo–ionospheric coupling: the quasi-stationary electric field penetrating into the ionosphere; acoustic gravity waves affecting the ionosphere; and the atmospheric electricity changes due to changes of the atmosphere conductivity. Of course, a combination or simultaneous action of these processes is also possible.

According to the number of publications, the AGW mechanism seems to be the most popular. We can mention several groups working in this direction (Koshevaya et al., 1997; Blaunstein, 2000; Hayakawa, 2001; Pilipenko et al., 2001; Grimalsky et al., 2003). A new idea that the AGW connection with the ionosphere turbulence is associated with earthquakes was proposed by Molchanov et al. (2002). The influence of the electric field on the ionosphere was considered by Gokhberg et al. (1995), Pulinets et al. (2000, 2002) and Sorokin et al. (2001). The conductivity hypothesis is studied by Fuks et al. (1997), Alperovich and Fedorov (1999) and Bliokh (1999).

All mentioned publications have serious limitations in the experimental verification, or in an accuracy of presented data. For example, the AGW model has very limited experimental support. Most of the observed seismo–ionospheric precursors indicate a large scale and persistent character of the ionospheric irregularities (Pulinets and Legen'ka, 2003), which the AGW theory cannot explain. Another problem in the hypothesis of the seismically induced AGW is how to explain the formation of the electron density irregularities by the AGW action before an earthquake. Seventy percent of the observations indicate (Aushev et al., 2002) that the acoustic gravity waves propagate from the top to bottom, so these waves cannot be associated with the earthquakes. As concerns with the AGW propagating up from the bottom, their intensity related with the meteorological factors is so strong (Boška and Šaul, 2001) that it is very difficult to detect much weaker acoustic gravity waves, possibly associated with seismic activity. There is also an indication of the cutoff limit of the AGW near 130 km altitude, which makes doubtful the seismically induced irregularities in the F-region produced by the AGW (Swenson et al., 1995). In hundreds of experimental papers describing direct observations of the AGW penetration into the ionosphere by radars, Doppler installations and optical techniques, there is no one study reporting the observation of gravity waves associated with the seismic activity. The only experimental result that could be treated as reliable is reported by Miyaki et al. (2002). So, the AGW theories need strong experimental support such as a direct observation of the atmospheric movements, which can be accounted for the AGW generated by preseismic activity. This may be achieved within the frame of aim-directed experiment of the PREVENTION project.

The electric field hypothesis is better supported experimentally, at least the electrodynamic model of seismo–ionospheric coupling (Pulinets et al., 2000, 2002). This model is based on direct experimental observations, it is self-consistent, and coincides, by the order of magnitude, with the observed experimental data. Unfortunately these data were compiled from the publications, in which different parameters were measured at different places by different experimenters for different earthquakes. Within the frame of the PREVENTION project a certain set of parameters can be recorded at the same area for the same earthquakes, this should provide stronger constraints on the models.

As concerns with the theory of Sorokin et al. (2001), there are some problems in the calculations and experimental data used for calculation. For example, the electric field intensity in the ionosphere of 9 mV/m used by the authors is extreme for the middle-latitude ionosphere and have never been observed before. This value is based solely on one observation made near the geomagnetic equator by the Intercosmos-Bulgaria-1300 satellite (Serebryakova et al., 1992), which is insufficient for such serious conclusions made in the paper. The authors try to explain the appearance of ducts within the ionosphere by the acoustic gravity wave instability that creates horizontal irregularities of the electron concentration and conductivity in the E-region of the ionosphere. These conductivity changes cause the field aligned currents and consequently the field aligned irregularities in plasmasphere. Using the formulation of the authors for the electron density irregularity $\Delta N/N$ estimation and applying a realistic value of collisional frequency ν_I at the height of 900 km which is $\sim 10^{-3}$ s^{-1} (Schunk, 1988) but not 1 s^{-1} used by authors, one can assess the $\Delta N/N$ of the order of 0.0005–0.005% which is too small to be detected experimentally.

As concerns with the conductivity theory, we can mention the paper of Bliokh (1999) indicating very small values of the conductivity changes in the ionosphere. Nevertheless, the experimental test of this estimate will be possible within the frame of our aim directed research.

The geoelectric potential variations were also extensively studied (Lighthill, 1996; Uyeda et al., 2000). These variations can be used as an additional information in the set of precursory parameters. The measurements of the geoelectric potential changes will have some lesser weight in the present project because this parameter does not have a direct connection to the considered models.

From the upper review, it is obvious that the experimental examination of the existing theoretical models is now the urgent task. The number of different models is increasing but all them are based on a very limited database, which makes them very vulnerable.

3. Seismic activity in the State of Guerrero and proposed observation site

The Pacific coast of Central Mexico is one of the most seismically active areas on our planet. The boundary between the Cocos and North American plates is the locus of numerous subduction trust earthquakes caused by the convergence of the Cocos plate with the velocity of 5–6 cm/year. Practically all this plate boundary has experienced large seismic ruptures in the last century with the exception of the Guerrero seismic gap (Fig. 1). The Guerrero gap has apparently accumulated more than 5 m of elastic displacement since the last major earthquake in 1911 ($M_s = 7.6$). The Guerrero gap is the nearest to Mexico City (population ~20 million) potentially dangerous seismic zone. Since 1911 only a few $M_s \sim 6$ events have been registered near the edges of the gap. The next anticipated large earthquake in Guerrero could reach a moment magnitude $M_w = 8.1$–8.4 (Suarez et al., 1990; Kostoglodov et al., 1996, 2003) assuming that total area of frictional interplate locking would rupture in a single event. A high probability of the occurrence of large seismic event (Nishenko and Singh, 1987) and an elevated level of the seismic risk are the main reasons to select the Guerrero State as the site for the complex geophysical observatory within the frame of PREVENTION project. Good roads and a relative proximity to Mexico City make this place an ideal range for the planned investigations. The project is supported by the CONACYT (No. 408585) and UNAM's PAPIIT (IN126002) grants.

4. Planned observations

The aim of the observatory creation is twofold:

1. To check the physical mechanism of seismo–ionospheric coupling with the help of a complex set of geophysical measurements.
2. To monitor short-term precursors for possible earthquake prediction.

We intend to make measurements of DC electric and magnetic fields, ELF and VLF electromagnetic fields, optical measurements of atmospheric emissions, HF electromagnetic emissions, the overhorizon propagation of VHF electromagnetic waves, the radon and aerosol monitoring at the surface level, the GPS TEC

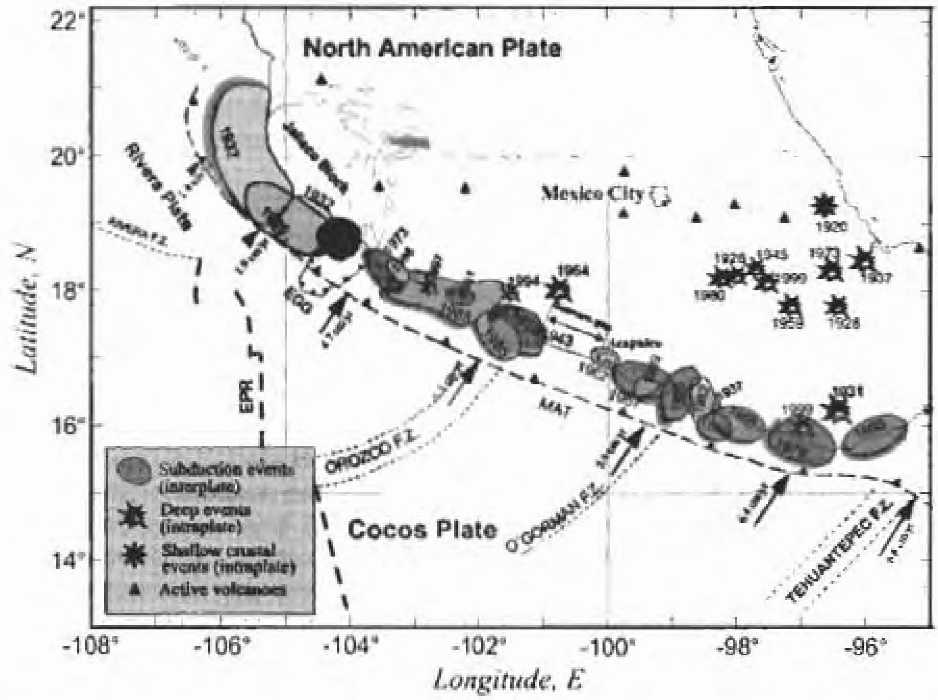

Fig. 1. Seismotectonic setting of the Central Mexico. The Guerrero seismic gap is shown with the two-head arrow.

measurements and ionosphere mapping, the ground based ionospheric sounding at "El Cerrillo" station. The information from dedicated satellites, such as DEMETER, Kompas-2, "Vulkan", and others will be used as well. We also intend to use the satellite data of ionosphere, thermosphere and atmosphere parameters such as DMSP, TIMED, CHAMP and planned COSMIC project. The PREVENTION should have a status of international observatory in order to provide an opportunity to any researcher in the world to check his scientific ideas, installing the instruments in the observatory, or to use the existing equipment for specially designed projects. Any international participation and contribution is welcome.

The information from the network of continuous GPS stations belonging to the Institute of Geophysics of

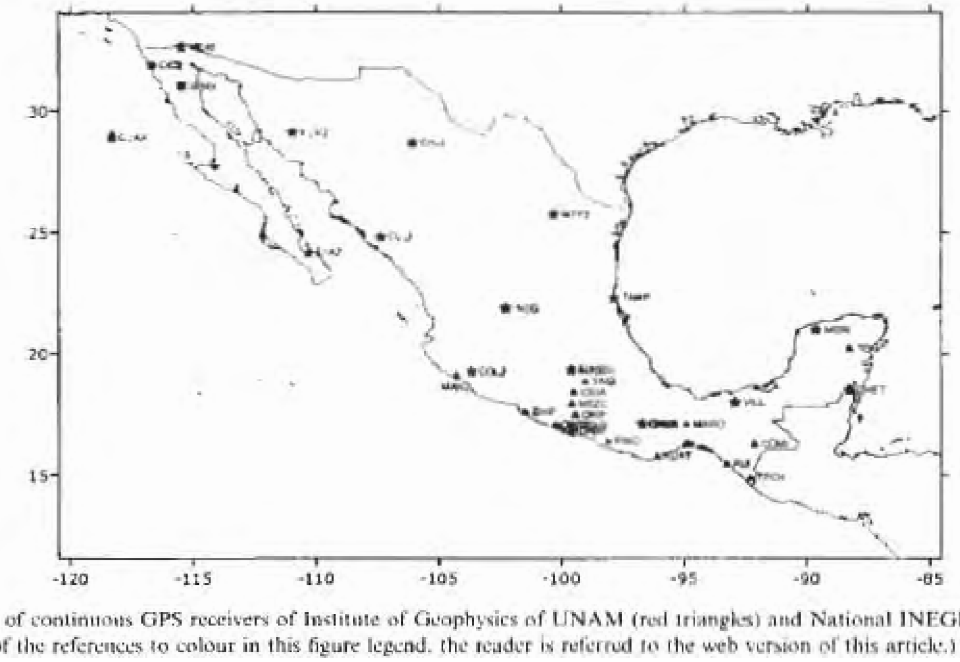

Fig. 2. The network of continuous GPS receivers of Institute of Geophysics of UNAM (red triangles) and National INEGI network (blue stars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the National Autonomous University of Mexico (UNAM) can be used for the ionospheric observations. Most of these GPS receivers are installed in the Guerrero and neighboring state Oaxaca. To have more wide GPS coverage, the data of the National Institute of Statistics, Geography and Informatics (INEGI) GPS network will be used as well. The GPS TEC measurements will supplement the information from the ground based "El Cerrillo" ionosonde (located 60 km from Mexico city). Possibly one or more ionosondes will be installed in the Southern Mexico. The positions of GPS receivers from the UNAM and INEGI networks and ionosondes are shown in the Fig. 2. By the end of 2004, the network of field mills will be installed (preferably at the GPS stations) to measure the atmospheric electric field variations related with the earthquake preparation processes.

5. Conclusion

The creation of the complex geophysical observatory in Mexico is a response to the urgent necessity to check the existing hypotheses and models of the electromagnetic precursors of large earthquakes and seismo–ionospheric coupling. The "PREVENTION" activity will be twofold: the scientific studies planned within the frame of the project and the international scientific cooperation, and continuous monitoring of different precursory parameters for practical purposes of short-term prediction of the catastrophic earthquake expected in the Guerrero region.

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