Available online at www.sciencedirect.com
SCIENCE DIRECT
Radiation Measurements 40 (2005) 670–672
Radiation Measurements
www.elsevier.com/locate/radmeas

Ground radon exhalation, an electrostatic contribution for upper atmospheric layers processes

N. Segovia[a], S.A. Pulinets[a], A. Leyva[a,*], M. Mena[a], M. Monnin[b], M.E. Camacho[c], M.G. Ponciano[d], V. Fernandez[c]

[a] *Instituto de Geofísica, UNAM, Ciudad Universitaria, 04510 México D.F., Mexico*
[b] *Université de Montpellier, France*
[c] *ININ, Ap. Post 18-1027, 11801 México D.F., Mexico*
[d] *Fac. de Medicina, UNAM, Ciudad Universitaria, 04510 Mexico D.F., Mexico*

Received 27 August 2004; received in revised form 14 June 2005; accepted 16 June 2005

Abstract

Radon exhalation from the ground and consequent formation of large ion clusters as a result of ionization and plasma-chemical reactions have been proposed as an agent of seismo-ionospheric coupling mechanisms. Soil radon transfer to the atmosphere was evaluated at fixed stations in Mexico using SSNTD and GPS receivers' data were used to calculate changes in the ionosphere due to the Ms 7.8 earthquake occurred in Mexico in 2003. An anomaly was observed that can be regarded as the earthquake precursor showing its clear spatial connection with the epicentre position.

Keywords: Ground level radon; SSNTD; Seismo–ionospheric coupling; Mexico earthquake

1. Introduction

Near ground atmospheric processes such as earthquakes can influence the upper layers of the thermosphere and ionosphere. Radon exhalation from the ground and consequent formation of large ion clusters as a result of ionization and plasma-chemical reactions have been proposed as an agent of seismo–ionospheric coupling mechanisms (Pulinets and Boyarchuk, 2004). The model describing the generation of anomalous electric field in the zones of earthquake preparation involves the process of formation of mixed (solid–liquid) particles of aerosol i.e. solid hygroscopic particles covered with a layer of condensed water (Timofeev et al., 2003), process essentially connected with the variations of the latent heat in the surface air layer of the zone of the earthquake preparation. During these processes a large amount of heat, of the order of 10^3 cal/g, is released or consumed (Sedunov et al., 1997), and with the seismic activity, the amount and the diameter of the hygroscopic particles increases. In such conditions, in presence of radon, the ionization probability increases and the giant fraction of the aerosol grows with the formation of large ionized particles and clusters. In normal conditions, in case of low seismic activity, when the number of large ions is small, the meteorological processes prevail and the molecular and turbulent diffusion tends to homogenise the surface air layer. When seismic activity increases, according to Pulinets and Boyarchuk (2004), the concentration of hygroscopic particles grows up to 10^5–10^6 cm^{-3}, and a stable cloud of hygroscopic charged particles is formed, with electric charges of opposite sign that distribute in the cloud being the positive ones in the lower bound and the negative ones in the upper

* Corresponding author.
E-mail address: aleycon@yahoo.com (A. Leyva).

1350-4487/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.radmeas.2005.06.024

bound of such cloud. This aerosol provide a contribution to the vertical component of the atmospheric electric field producing variations up to anomalous values which modify the distribution of the free electrons in the ionosphere, making possible its observation and measurement by satellites.

The Pacific coast of Mexico is recognized as one of the most seismically active zones of the World due to the subduction of the Cocos plate under the North American plate. In the last 30 years, earthquakes of magnitudes up to 8.1 have occurred at the zone. Variations in soil radon in zones affected by high magnitude earthquakes have been systematically observed since 1980 and anomalies in the soil radon concentration values have been reported in connection with high magnitude earthquakes of the zone (Segovia et al., 1989; Peña et al., 2001).

In order to determine if the migration of radon, from soil to the surface atmospheric layer, should be representative of the amount of radon in the soil for different types of soils, and to assess, in open air conditions, the possibility of a radon signal from the soil, capable to contribute to some changes in the traditional variation in the latent energy of the atmosphere due to ionization, radon determinations were performed at two different sites in Mexico to obtain the percentage of soil radon arriving 1 m in the atmosphere. An example of ionospheric changes related to the $M = 7.8$ earthquake occurred at Colima, Mexico, in January 2003 is also shown.

2. Experimental

2.1. SSNTD exposure in the field

Field exposures were performed at two sites: Cuernavaca (18.43°N; 99.22°W) and Las Cruces (19.28°N; 99.37°W). Cuernavaca, at 1500 m altitude has an average temperature of 22 °C while Las Cruces, at 3000 m altitude, has an average temperature of 11 °C. The soil composition at the two sites is different: alluvial rocks at Cuernavaca and volcanic cinder at Las Cruces.

At each one of the two sites, LR 115 type II cellulose nitrate detectors (Dosirad Co., France) were exposed at 10 fixed stations, in subsequent periods of 1 month during a total of 6 months. Exposures were performed at 70 cm depth in the soil (−70 cm), at the surface (0 cm) and at 100 cm in open air. Ten fixed stations were distributed in 2000 m^2 area at each site. In the soil the detectors were fixed at the top of 30 cm long PVC tubes inserted in 1 m long buried pipes (Segovia et al., 2001). The detection chambers were protected with membranes, permeable to radon but not to humidity. In the air, the detectors (2.5 cm × 2.5 cm) were fixed at the bottom of a cup (closed also with a transmitting radon membrane), resting at the soil surface (0 cm) and hanging at 100 cm in free air. After exposure the detectors were etched in a 2.5 NaOH solution at 58 °C during 110 min in order to reduce the residual thickness to 6.5 μm. The etched tracks were spark counted. For the specific exposure geometry in the soil, the conversion factor was 8.7 tracks cm^{-2} per kBq day m^{-3}. The cup system was exposed inside a calibrated radon chamber (NPB, England) (Franco-Marina et al., 2001) and the calibration factor for this exposure geometry was 0.027 tracks cm^{-2} per Bq day m^{-3}.

2.2. GPS data

Data related to the $M = 7.8$ earthquake, occurred at Colima, Mexico, at 08:06 (local time) on January 21, 2003, are analyzed considering the earthquake parameters (Pacheco, 2003), the meteorological data from stations close to the epicentre and the ionosphere response obtained through receivers of the Mexican GPS network. Following Pulinets and Boyarchuk (2004), Timofeev et al. (2003) and Sedunov et al. (1997) the temporal fluctuations of the total electron content in the vertical column (1 m^2 cross section) at the observation point (ΔTEC), obtained from GPS observations, were analyzed around the time of the earthquake occurrence considering the monthly median (M) and the percentage deviation of the current time series: $\Delta\mathrm{TEC} = 100\,(\mathrm{TEC} - M)/M$.

3. Results and discussion

In Table 1 the results of 6 months radon monitoring at Cuernavaca and Las Cruces is shown. Average radon values in the soil were different for the two locations and fluctuations were systematically observed due essentially to seasonal effects. However, the radon content reaching the surface (0 cm) at the two locations was 8% and 6.7% from the original soil radon, respectively. When the values in open air at 100 cm in the atmosphere are considered, the original content reduces to 1.3% and 1.1% for Cuernavaca and Las Cruces, respectively. These results indicate that, for the seek of ions present at the low atmosphere due to radon exhalation from the soil, two sites having different altitudes, average temperatures, soil composition and wind patterns, will have a behaviour quite similar as far as the percentage of soil radon is concerned. During the present experiment, no big earthquakes occurred at the two studied locations. It was the aim of these experiments to show that the radon exhalation has a similar behaviour at different sites. When higher exhalation will occur, in the area of preparation of high magnitude earthquakes, within the frame of Pulinets and Boyarchuk (2004) model of seismo–ionospheric coupling, the generation of anomalous near ground vertical profile of the atmospheric electric field by the ionization of the near ground layer of the atmosphere by radon occurs.

An example of the cited model calculations is presented using the database of the earthquake $M = 7.8$ occurred in Mexico, at the State of Colima, on January 21, 2003. The

Table 1
Radon concentration values in Bq m^{-3}: average (Av) and relative standard deviations (RSD) in percentage (Av ± RSD(%)), maximum (Max) and minimum (Min) values obtained at 70 cm under surface (−70 cm), at the surface (0 cm) and at 100 cm height in air

Location	−70 cm			0 cm			100 cm		
	Max	Min	Av ± RSD	Max	Min	Av ± RSD	Max	Min	Av ± RSD
Cuernavaca Bq m^{-3}	4813	873	2249 ± 71	288	86	179 ± 48	37	20	29 ± 6
% original soil radon	100	100%	**100**	6	10	**8**	0.8	2.3	**1.3**
Las Cruces Bq m^{-3}	3197	500	1574 ± 64	159	59	106 ± 33	18	17	18 ± 4
% original soil radon	100	100	**100**	5	12	**6.7**	0.5	3.4	**1.1**

The percent (%) of the original radon content in the soil at 70 cm depth (−70) reaching the surface and flowing up to 100 cm in the atmosphere are also shown.

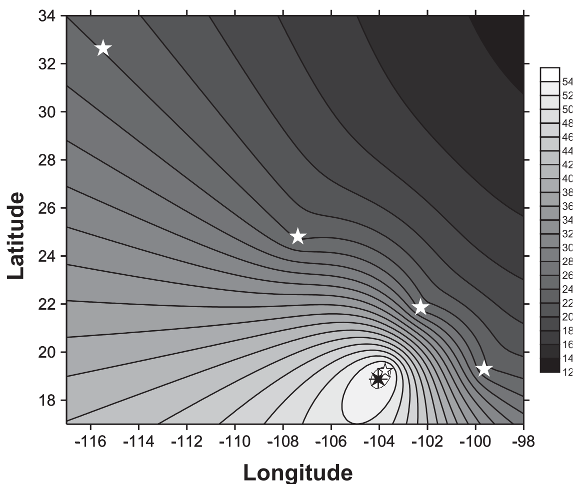

Fig. 1. Spatial distribution of the temporal fluctuations of the total electron content in the vertical column (1 m^2 cross section) at the observation point (ΔTEC), at 10.10 (local time) on January 18, 2003. Stars indicate the positions of GPS receivers, and black asterisk the Colima earthquake epicentre.

data showed a thermal anomaly 1 week before the earthquake, a minimum of humidity of January 15 followed by a sharp humidity increase (Pulinets et al., 2004). The process of humidity increase coincided with a process of anomalous increase in the surface latent heat flux (SLHF) (Dey and Singh, 2003) where the maximum SLHF occurred on January 18, 3 days before the earthquake. The maximum coincided in the time with the formation of the ionospheric anomaly observed by the GPS network receivers shown in Fig. 1. The observed anomaly can be regarded as the earthquake precursor showing its clear spatial connection with the epicentre position.

The preparatory stage of formation of near ground plasma in the form of long living clusters which are the result of ion-molecular reactions (after ionization by radon) in the near ground layer of the atmosphere, with water molecules attachment to the finally formed ions, is proposed as a part of the seismo–ionospheric coupling effect capable to generate anomalies observed through satellites.

Acknowledgements

The authors acknowledge CONACyT project 40858 and Mexican National Institute of Statistics, Geography and Informatics (INEGI) for providing the data of GPS receivers' network.

References

Dey, S., Singh, R.P., 2003. Surface latent heat flux as an earthquake precursor. Nat. Hazards Earth Syst. Sci. 3, 749–755.

Franco-Marina, F., Segovia, N., Ruiz, W., Godinez, L., Tavera, L., Lopez, A., Chavez, A., Peña, P., Ponciano, G., 2001. Short and long term radon survey in Mexico City. Radiat. Meas. 34, 545–548.

Pacheco J.F., 2003. <http://www.ssn.unam.mx/Colima030121/colima03.pdf>.

Peña, P., Segovia, N., Azorin, J., Mena, M., 2001. Soil radon and gamma dose rate at a coastal region in Mexico. J. Radioanal. Nucl. Chem. 247, 39–43.

Pulinets, S.A., Boyarchuk, K.A., 2004. Ionospheric Precursors of Earthquakes. Springer, New York.

Pulinets, S.A., Boyarchuk, K., Karelin, A.V., Ouzounov, D., Singh, R., Leyva, A., Ciraolo, L., Dunajecka, M., 2004. Electromagnetic processes in near ground atmosphere as a source of thermal anomalies before earthquakes. Case study of Colima earthquake M 7.8, January 21(22) 2003. Extended Abstracts from Fourth International Workshop Magnetic Electric and Electro-magnetic Methods in Seismology Volcanology (MEEMSV) Lalonde les Maures, pp. 43–44.

Sedunov, Y.S., Volnovitskii, O.A., Petrov, N.N., Reitenbakh, R.G., Smirnov, V.I., Chernikov, A.A., 1997. Atmosphere Handbook (Reference Data and Models), Leningrad.

Segovia, N., Dela Cruz-Reyna, S., Mena, M., Ramos, E., Monnin, M., Seidel, J.L., 1989. Radon in soil anomaly observed at Los Azufres geothermal field, Michoacan: a possible precursor of the 1985 Mexico earthquake (Ms = 8.1). Nat. Hazards 1, 319–329.

Segovia, N., Valdes, C., Peña, P., Mena, M., Tamez, E., 2001. Soil radon response around an active volcano. Radiat. Meas. 34, 433–436.

Timofeev, V.E., Grigor'ev, V.G., Morozova, E.I., Skryabin, N.G., Samsonov, S.N., 2003. Effect of cosmic rays on the latent energy of the atmosphere. Geomag. Aeron. 43, 636–640.