Nat. Hazards Earth Syst. Sci., 11, 987–991, 2011
www.nat-hazards-earth-syst-sci.net/11/987/2011/
doi:10.5194/nhess-11-987-2011

Natural Hazards and Earth System Sciences

Atmospheric electrical field decrease during the $M = 4.1$ Sousel earthquake (Portugal)

H. G. Silva[1], M. Bezzeghoud[1], A. H. Reis[1], R. N. Rosa[1], M. Tlemçani[1], A. A. Araújo[1], C. Serrano[1], J. F. Borges[1], B. Caldeira[1], and P. F. Biagi[2]

[1]Geophysical Centre of Évora and Physics Department, ECT, University of Évora, Portugal
[2]University of Bari and Inter-Department Centre for the Evaluation and Mitigation of the Volcanic and Seismic Risk, Italy

Received: 8 October 2010 – Revised: 22 February 2011 – Accepted: 2 March 2011 – Published: 28 March 2011

Abstract. In this paper, we report the observation of a significant decrease of the vertical component of the atmospheric electrical field in the Évora region (Portugal) during the $M = 4.1$ Sousel earthquake of 27 March 2010. The epicentre of the earthquake was 52 km from the observation site, which falls within the theoretical earthquake preparation radius. A simple interpretation based on hypothetical radon emissions is presented, and future experiments required to elucidate these observations are outlined. To our knowledge, this is the first reported observation of a decrease of the atmospheric electrical field preceding an earthquake.

1 Introduction

In recent years, various phenomena associated with seismic events have been discussed in the literature. These reported occurrences include unusual ultra-low-frequency electromagnetic emissions (ULF) (Bleier et al., 2009), anomalies in very-low (VLF) and low-frequencies (LF) radio transmissions (Biagi et al., 2009), variation of the ionosphere total electron content (TEC) (Chauhan et al., 2009), atypical emissions of infrared radiation (IR) (Ouzounov et al., 2007), and anomalous levels of various geochemical elements (radon in particular) in the earthquake preparation zone (for a review of this complex topic, see Toutain et al., 1999).

More than 30 yr have passed since the publication of an important article by Pierce (1976) that demonstrated the possibility of a significant ($\sim 30\%$) decrease in the atmospheric electrical field (AE) during earthquakes. This paper stimulated the development of models that relate AE variations with radon released during earthquake preparation stages, (Liperovsky et al., 2008; Omori et al., 2009). In particular, Harrison et al. (2010) related possible atmospheric electrical field anomalies during earthquake preparation with surface air ionisation caused by radon emanations. Moreover, Freund et al. (2009) presented the possibility that enhanced air ionisation (with consequent atmospheric electrical perturbations) results from charge generation in the stressed rock volume followed by positive charge flows that travel kilometre-scale distances to reach the surface and ionise the air within the boundary layer.

It is clear that AE anomalies are candidate electromagnetic seismic precursors for the prediction of earthquakes; however, from our perspective, direct systematic pre-earthquake AE measurements are lacking. Various reports of atmospheric electrical field anomalies can be found in the literature (e.g., Kachakhize et al., 2009; Smirnov, 2008), although no clear conclusions have been drawn at this time. Thus, we believe that in the near future, a deeper inspection of AE variations is required because these studies could be critical for obtaining a better comprehension of seismo-electromagnetic phenomena.

In this work, we present the observation of a significant decrease of the vertical component of the atmospheric electrical field (VAE) that occurred in Évora (Portugal) directly prior to the $M = 4.1$ Sousel earthquake of 27 March 2010. The observation is reported, followed by analysis and interpretation. Preliminary conclusions and plans for future work are also discussed.

Correspondence to: H. G. Silva
(hgsilva@uevora.pt)

Published by Copernicus Publications on behalf of the European Geosciences Union.

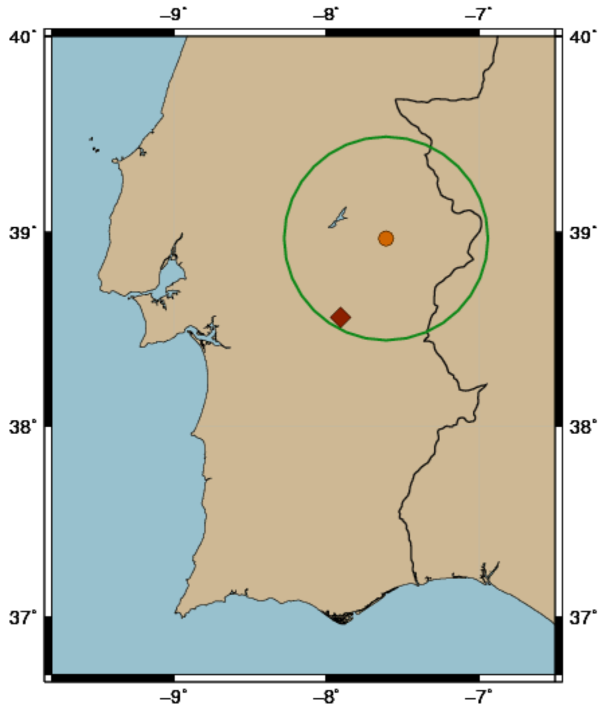

Fig. 1. Map indicating the locations of the sensor (red diamond) and the earthquake epicentre (orange circle). The green circumference represents the earthquake preparation zone (see the text).

2 Observations

The earthquake that occurred on 27 March 2010 in Sousel (Portugal) had an epicentre at 38°58′12″ N and 7°36′36″ W at a depth of 15 km and a magnitude of $M_L = 4.1$ (information was procured from the Instituto de Meteorologia database, Portugal). The VAE sensor was a Keithley model JCI 131 electrometer installed at the University of Évora (38°34′ N, 7°54′ W, 300 m above mean sea level). This equipment has been in operation since February 2005 until the present day (an initial testing period from December 2003 to October 2004 was also recorded). In this study, only the period from January 2007 to December 2010 was considered. The sensor was prepared for continuous monitoring of the VAE and used four scales: 2, 20, 200 and 2000 kV m^{-1} with automatic commutations and corresponding sensitivity thresholds of 0.1, 1, 10 and 100 kV m^{-1}, respectively. A more detailed description of this equipment is presented in Silva et al. (2011). The distance between the VAE sensor and the earthquake epicentre was approximately 52 km. In Fig. 1, we present a map with the locations of the sensor (red diamond) and the earthquake epicentre (orange circle). In addition, the area within the green circle represents the earthquake preparation zone (see below).

Inspection of data for the period from one month before until one month after the seismic occurrence revealed

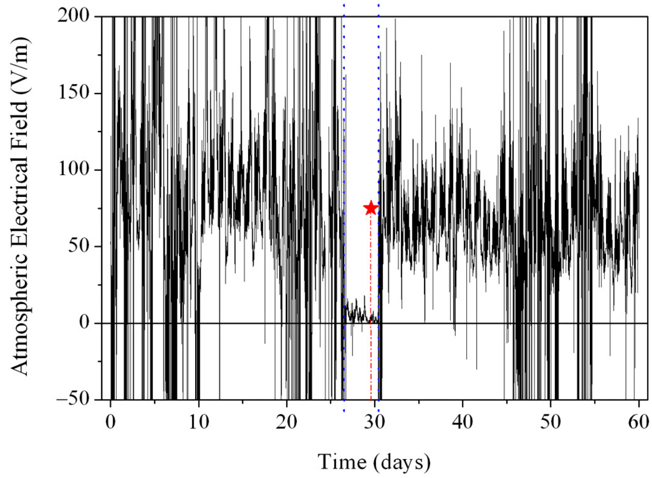

Fig. 2. Atmospheric electrical field data for the Évora region from 27 February 2010 to 27 April 2010. The $M = 4.1$ Sousel Earthquake that occurred on 27 March 2010 (51.8 km from the sensor) is represented by a red star. The dotted blue lines indicate the duration of the VAE decrease.

a significant decrease of the VAE, as shown in Fig. 2. The decrease lasted for nearly 4 days, during which the VAE did not exceed 20 V m^{-1}, a value much smaller than the typical mean daily fair-weather VAE that ranges from 70 V m^{-1} to 110 V m^{-1} (Serrano et al., 2006). Moreover, the Sousel earthquake occurred approximately 3 days after the commencement of the VAE decrease.

Interestingly, the decrease of the VAE shared some common features with the radio transmission decrease reported by Biagi and co-workers in other studies (Biagi et al., 2007), with the difference that radio transmission decrease could last up to 10 days. However, a direct relationship between these observations was not clear because in our case, the VAE measurements were restricted to local low atmosphere electrical fields. In contrast, the observations of Biagi et al. were based on radio wave propagation in the Earth-ionosphere waveguide, and thus, would have been sensitive to perturbations in the ionosphere. It is possible that differences in the duration of decrease events were related to the magnitude of the earthquakes involved (high magnitude earthquakes are expected to produce more noticeable effects), but were also affected by the epicentre distance to the VAE sensor in the present case and the distance to the wave path, in the case of Biagi et al. (2007). It is important to note that the anomalies reported by Biagi et al. were correlated with earthquakes of $M > 5.0$, whereas the magnitude was smaller for the earthquake reported here.

Weather conditions are also a fundamental aspect of AE monitoring because only fair-weather days must be considered (Kachakhize et al., 2009). Weather conditions recorded at the observation site during the Sousel earthquake AE decrease event are plotted in Fig. 3. These weather data show

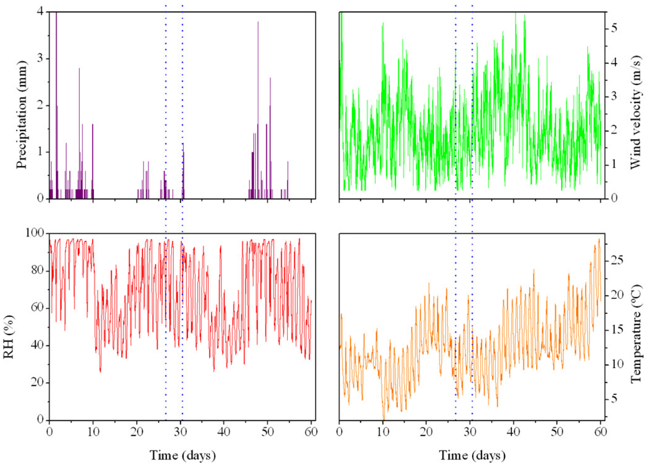

Fig. 3. Weather conditions during the two month period in which the Sousel earthquake occurred. The dotted blue lines indicate the duration of the VAE decrease.

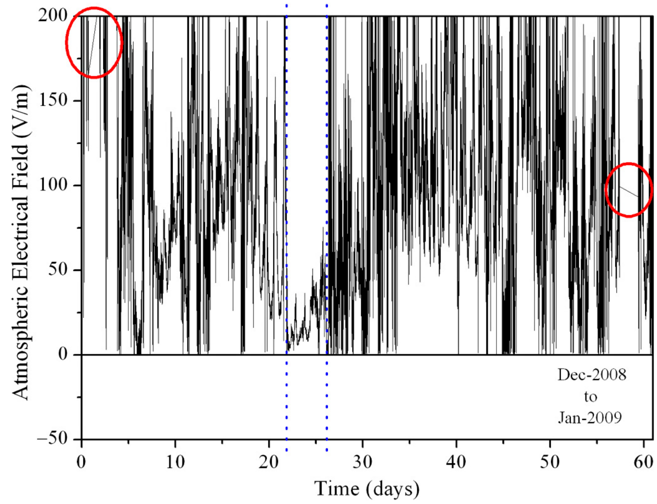

Fig. 4. Atmospheric electrical field data for the Évora region from 1 December 2008 to 31 January 2009. During this time, an AE decrease event occurred. The dotted blue lines mark the VAE decrease, and the red circles show instrument malfunction events where no data were registered.

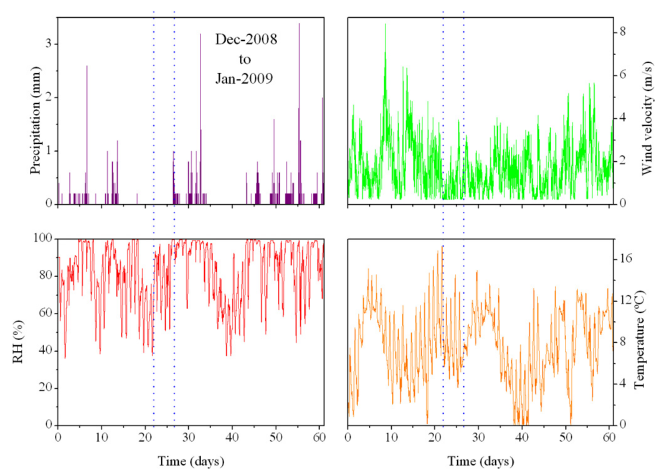

Fig. 5. Weather conditions during the period of 1 December 2008 to 31 January 2009. The dotted blue lines indicate the duration of the VAE decrease.

that temperatures were in the range of 5 °C to 20 °C (typical for that time of year), precipitation values were low, relative humidity varied from 40% to 100%, and wind velocity ranged from nearly 0 to 4.5 m s^{-1}. Such values fit a reasonable description of fair-weather conditions and emphasise that the cause of the VAE decrease was likely not related to weather perturbations. In addition, no anomaly in radiation data (global solar radiation, near-IR radiation, photosynthetic active radiation, ultraviolet radiation, atmospheric radiation and diffuse radiation; not shown) was detected during the decrease event. Finally, no anthropic disturbance or equipment malfunction was found to be associated with this anomaly. In fact, when a sensor malfunction occurs, data are not registered, as shown in Fig. 4 (e.g., the two red circles in where no data were recorded).

It is important to mention that this anomaly was not unique. Three other similar decreases, each less intense and lasting longer than the Sousel earthquake AE decrease, were found in the studied period. Moreover, these other decreases could not be associated with any noticeable earthquake. For example, a VAE decrease occurred during the period of December 2008 to January 2009, as indicated by blue dotted lines in Fig. 4. The weather during this event also fits a reasonable description of fair conditions, as shown in Fig. 5, thus excluding meteorological events as causes of the anomaly. No significant seismic events occurred in this period, and associations with other events were not found. The VAE decrease during December 2008 to January 2009 is discussed below.

3 Discussion

According to the concept of Dobrovolsky et al. (1979), earthquake preparation zones can be approximated as areas of elastic crustal deformation, and therefore it is possible to estimate the radius of such regions as $R = 10^{0.43M}$, where M is the magnitude of the earthquake. The application of this formula to the Sousel earthquake gave a radius of approximately 58 km; this value slightly surpasses the distance of our VAE sensor to the epicentre (52 km), and thus the sensor was within the earthquake preparation zone (see Fig. 1). Consequently, any geological processes that affected this region, such as gas emanations, could also disturb the measured AE. The sensor was located in the Évora region where gneisses, granitoids and migmatites are abundant. These are high-grade metamorphic rocks derived from lithologies similar to granites. Moreover, this lithology is the same as that of the Sousel region (where the earthquake occurred), and no significant fault or any drastic geological feature, which would strongly perturb the tension fields, exists between the Évora and Sousel regions. Thus, this morphology indicates that radon emanations from the lithosphere are likely to occur due to rock microfracturing processes. Radon emanations occur as a sudden release of this gas associated with the local deformation field that promotes a significant increase of the ground permeability. Such emanations would clearly result in an increase in the radon concentration in the atmosphere. High levels of initial deformation (such as those expected during earthquake preparation) should promote a fast and strong release of radon caused by a rapid increase in ground permeability. On the other hand, lower levels of tension accumulation (as expected during seismic movements) should promote a slower and weaker release of radon. The radon released by these mechanisms can then ionise the atmospheric surface layer, causing a VAE decrease that reflects the type of tension accumulation process. Therefore, strong tensions (such as in the Sousel event) would promote a significant decrease of the VAE (compared to typical values) in a smaller time period. In contrast, for cases similar to the example shown in Fig. 4, the VAE would not decrease so dramatically and the anomaly would have a longer duration.

It should be mentioned that radon (^{222}Rn) is a radioactive noble gas that has the ability to ionise tropospheric gases and therefore significantly alter atmospheric electrical fields (Boyarchuk et al., 1998). ^{222}Rn is formed as part of the normal uranium radioactive decay series and has a half-life of 3.8 days. Interestingly, the duration of the observed VAE decrease for the Sousel earthquake was nearly 4 days, which was similar to the radon half-life. This observation further favours the hypothesis of a relevant sporadic release of radon during the earthquake preparation.

Additionally, it is known that atmospheric radon concentrations strongly depend on local meteorological conditions as well as precipitation and temperature in particular (Toutain et al., 1999). Fortunately, the weather conditions during the Sousel earthquake observation were consistent with "fair-weather conditions", as shown in Fig. 3; therefore, any atmospheric effect on the decrease can be disregarded, reinforcing the idea that radon was released from the subsurface. Indeed, previous publications have commonly identified radon emanations as the main cause of seismo-electromagnetic phenomena (Pulinets et al., 2007).

Nevertheless, the model presented here is a hypothesis rather than a definite conclusion. Additional work is required to further verify these arguments. In particular, monitoring the atmospheric radon concentration in the proximity of the VAE sensor must be conducted for future earthquakes that occur in this region. Air conductivity measurements would also be important for future studies.

4 Conclusion and future work

To our knowledge, this report provides the first clear evidence of a decrease of the vertical component of the atmospheric electrical field in the preparatory stage of a seismic event. These observations support the idea that radon emanations are the mechanism behind this VAE decrease. Nevertheless, additional work is required to confirm this hypothesis. In particular, systematic monitoring of radon levels and air conductivity must be performed in the near future.

The scheduled installation of new VAE sensors, radon detectors, and magnetometers in seismic regions to achieve multi-parameter assessment of the preparatory stage of earthquakes, is the next step in addressing VAE decreases as they relate to seismic events. This installation is discussed in more detail in another paper (Silva et al., 2011).

Acknowledgements. The team acknowledges the support of three Portuguese institutions: QREN (Operational Program "Thematic Factors of Competitiveness"), co-funded by the European Regional Development Fund (ERDF), the research program SIRAS, the FCT (Science and Technology Foundation) for grant SFRH/BPD/63880/2009 (HGS), and Fundação Calouste Gulbenkian for the price "Estímulo à Criatividade e à Qualidade na Actividade de Investigação" in the science program of 2010. Finally, we are grateful for crucial support from Samuel Bárias regarding technical issues with the atmospheric electrical field sensor.

Edited by: T. Maggipinto
Reviewed by: two anonymous referees

References

Biagi, P. F., Castellana, L., Maggipinto, T., Maggipinto, G., Minafra, A., Ermini, A., Capozzi, V., Perna, G., Solovieva, M., Rozhnoi, A., Molchanov, O. A., and Hayakawa, M.: Decrease in the electric intensity of VLF/LF radio signals and possible connections, Nat. Hazards Earth Syst. Sci., 7, 423–430, doi:10.5194/nhess-7-423-2007, 2007.

Biagi, P. F., Castellana, L., Maggipinto, T., Loiacono, D., Schiavulli, L., Ligonzo, T., Fiore, M., Suciu, E., and Ermini, A.: A pre seismic radio anomaly revealed in the area where the Abruzzo earthquake ($M = 6.3$) occurred on 6 April 2009, Nat. Hazards Earth Syst. Sci., 9, 1551–1556, doi:10.5194/nhess-9-1551-2009, 2009.

Bleier, T., Dunson, C., Maniscalco, M., Bryant, N., Bambery, R., and Freund, F.: Investigation of ULF magnetic pulsations, air conductivity changes, and infra red signatures associated with the 30 October Alum Rock M5.4 earthquake, Nat. Hazards Earth Syst. Sci., 9, 585–603, doi:10.5194/nhess-9-585-2009, 2009.

Boyarchuk, K. A., Lomonosov, A. M., Pulinets, S. A., and Hegai, V. V.: Variability of the Earth's Atmospheric Electric Field and Ion-Aerosols Kinetics in the Troposphere, Stud. Geophys. Geod., 42(2), 197–210, doi:10.1023/A:1023313222390, 1998.

Chauhan, V., Singh, O. P., Kushwah, V., Singh, V., and Singh, B.: Ultra-low-frequency (ULF) and total electron content (TEC) anomalies observed at Agra and their association with regional earthquakes, J. Geodyn., 48(2), 68–74, doi:10.1016/j.jog.2009.06.002, 2009.

Dobrovolsky, I. P., Zubkov, S. I., and Miachkin, V. I.: Estimation of the size of earthquake preparation zones, Pure Appl. Geophys., 117(5), 1025–1044, doi:10.1007/BF00876083, 1979.

Freund, F. T., Kulahci, I. G., Cyr, G., Ling, J., Winnick, M., Tregloan-Reed, J., and Freund, M. M.: Air ionization at rock surfaces and pre-earthquake signals, J. Atmos. Sol.-Terr. Phys., 71(17–18), 1824–1834, doi:10.1016/j.jastp.2009.07.013, 2009.

Harrison, R. G., Aplin, K. L., and Rycroft, M. J.: Atmospheric electricity coupling between earthquake regions and the ionosphere, J. Atmos. Sol.-Terr. Phys., 72(5–6), 376–381, doi:10.1016/j.jastp.2009.12.004, 2010.

Kachakhidze, N., Kachakhidze, M., Kereselidze, Z., and Ramishvili, G.: Specific variations of the atmospheric electric field potential gradient as a possible precursor of Caucasus earthquakes, Nat. Hazards Earth Syst. Sci., 9, 1221–1226, doi:10.5194/nhess-9-1221-2009, 2009.

Liperovsky, V. A., Meister, C.-V., Liperovskaya, E. V., and Bogdanov, V. V.: On the generation of electric field and infrared radiation in aerosol clouds due to radon emanation in the atmosphere before earthquakes, Nat. Hazards Earth Syst. Sci., 8, 1199–1205, doi:10.5194/nhess-8-1199-2008, 2008.

Omori, Y., Nagahama, H., Kawada, Y., Yasuoka, Y., Ishikawa, T., Tokonami, S., and Shinogi, M.: Preseismic alteration of atmospheric electrical conditions due to anomalous radon emanation, Phys. Chem. Earth, 34, 435–440, doi:10.1016/j.pce.2008.08.001, 2009.

Ouzounov, D., Liu, D., Chunli, K., Cervone, G., Kafatos, M., and Taylor, P.: Outgoing long wave radiation variability from IR satellite data prior to major earthquakes, Tectonophysics, 431(1–4), 211–220, doi:10.1016/j.tecto.2006.05.042, 2007.

Pierce, E. T.: Atmospheric electricity and earthquake prediction, Geophys. Res. Lett., 3(3), 185–188, doi:10.1029/GL003i003p00185, 1976.

Pulinets, S. A., Biagi, P. F., Tramutoli, V., Legen'ka, A. D., and Depuev, V. K.: Irpinia earthquake 23 November 1980 – Lesson from Nature reviled by joint data analysis, Ann. Geophys., 50(1), 61–78, 2007.

Serrano, C., Reis, A. H., Rosa, R., and Lucio, P. S.: Influences of cosmic radiation, artificial radioactivity and aerosol concentration upon the fair-weather atmospheric electric field in Lisbon (1955–1991), Atmos. Res., 81(3), 236–249, doi:10.1016/j.atmosres.2006.01.001, 2006.

Silva, H. G., Bezzeghoud, M., Rocha, J. P., Biagi, P. F., Tlemçani, M., Rosa, R. N., Salgueiro da Silva, M. A., Borges, J. F., Caldeira, B., Reis, A. H., and Manso, M.: Seismo-electromagnetic phenomena in the western part of the Eurasia-Nubia plate boundary, Nat. Hazards Earth Syst. Sci., 11, 241–248, doi:10.5194/nhess-11-241-2011, 2011.

Smirnov, S.: Association of the negative anomalies of the quasistatic electric field in atmosphere with Kamchatka seismicity, Nat. Hazards Earth Syst. Sci., 8, 745–749, doi:10.5194/nhess-8-745-2008, 2008.

Toutain, J. P. and Baubron, J. C.: Gas geochemistry and seismotectonics: a review, Tectonophysics, 304(1–2), 1–27, doi:10.1016/S0040-1951(98)00295-9, 1999.