"TWO DECADES OF EARTH SCIENCE RESEARCH"

CGE
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Celebration of 20 Years

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TWO DECADES OF EARTH SCIENCE RESEARCH

On the occasion of the 20th anniversary of the CGE

Edited by

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Foreword

In 2012, the Évora Geophysics Centre (CGE) celebrates 20 years of activity. In these two decades, the national scientific system underwent a profound transformation, new organizational structures appeared, and participation in structures and international networks, and scientific integration reached very high levels. The national scientific environment is now more qualified and competitive; however the available funding per researcher became scarcer.

Currently the CGE team includes 67 full members, and is organized in two main Lines of Research: (1) *Atmosphere and Hydrosphere*, (ii) *Solid Earth*. The first one comprises the centers of activity: *Meteorology* & *Climate*, *Water, Environment,* & *Surface Processes*, and *Energy* & *Flow Structures*, while the latter is composed of the centers of activity: *Active Tectonics & Risks*, *Lithosphere, Mantle & Geological Resources*, and Heritage & Archeometry.

The time of maturity has come for GCE as a research unit, with a growth trajectory that was not always linear; however it has been progressive with respect to scientific quality, organizational structure, and the scientific and training outputs that were made available to the community.

It is also the time to reflect on the past and to define future strategies. This debate is carried out within the evolving framework in which the CGE develops its activity. Actually, CGE faces new challenges on the times ahead. At the national level new rules of public funding have been announced, which are expected to increase competition for national funding, together with a strong pressure to make networking among the teams for the use of the available facilities. At the international level, CGE is challenged to collaborate with national and international teams to get access to the new European funding program HORIZON 2020.

The workshop "Two Decades of Earth Science Research" was held at the University of Évora, on 23 November 2012, as the closure of the Program of Celebrations, which spanned over the year of 2012. For this workshop we invited national and international key figures as "keynote speakers", and other colleagues, which with us will reflect on the evolution of Earth Sciences, Atmosphere and Hydrosphere, and the national and European science on these two decades. With this initiative we will also make our contribution to the community for the analysis of this framework and define new directions for the scientific activity.

Finally, we wish to thank the keynote speakers, Professors Agustin Udías, Hervé Le Treut, and Maria da Graça Carvalho for their kind collaboration by delivering timely and important speeches, as well all colleagues who contributed to this workshop with their papers, and also all the other people that somehow contributed to the success of the workshop "Two Decades of Earth Science Research".

Évora, 23 November, 2012,

The Organizing Committee,
The Book Editors,

Ana Maria Silva,
António Alexandre Araújo,
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PHYSICS OF SEISMO-ELECTROMAGNETIC PHENOMENA: TWENTY YEARS AFTER

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This paper presents a work that aims to study seismo-electromagnetic phenomena in the Western Part of the Eurasia-Nubia Plate Boundary. This region has a significant tectonic activity combined with relatively low electromagnetic noise levels, rendering high quality seismo-electromagnetic measurements possible. An overview of the topic is made and future perspectives are presented.

1 Introduction

Seismo-electromagnetic phenomena (SEM) constitute a wide research field that studies the conversion of mechanical (seismic) stimulus into electromagnetic emissions. This dynamic and innovative area, in the last years, has revealed rather appealing geophysical observations [1], interesting laboratorial results [2], and attractive theoretical modelling [3].

However, SEM is mostly known by geophysical observations. These comprise peculiar electromagnetic effects in the preparatory stage of impending earthquakes (EQ), normally 1 to 10 days before the hazard, among them we have: abnormal ultra-low-frequency (ULF) electromagnetic emissions [1], very-low-frequency (VLF) and low-frequency (LF) radio anomalies associated with ionospheric perturbations [4], variation of total electron content (TEC) of the ionosphere [1], atypical infrared (IR) emissions [3], and also unusual atmospheric electricity (AE) behaviours [5]. Interestingly, it was shown that SEM occurrences correlate well with anomalous increases of Radon levels prior to seismic events [6]. For that reason, Radon emanations are pointed as a possible mechanism causing SEM. Nevertheless, laboratorial experiments reveal other noticeable SEM occurrences like: unexpected electrical currents streaming out of stressed rocks related with electrical charge creation in the vicinity of fracture [7], and seismo-magnetic conversion linked with electrokinetic coupling [2], among others (see below). Thus, clearly the Physics of SEM is a completely open issue with great possibilities and out-standing applications.

In fact, geophysical observations of SEM are frequently related to short-term EQ prediction (one or two weeks before the EQ) as a consequence of its precursory nature. Indeed, predicting EQ is a long standing challenge of modern science, but the development of a truly pre-quake forecasting system based only in SEM observations is an elusive plan and is not definitely regarded as an objective by the SEM community [8].

Instead, the main effort of this research area is presently directed towards a systematic field observation of SEM effects complemented by laboratorial investigations of the electromagnetic properties of rocks, and theoretical modelling to give new insights into the fundamental Physics of these interesting occurrences. In fact, SEM is a very attractive subject by itself and has interesting applications, like the evaluation of the facture state of a given rock by electrical means, borehole exploration beyond EQ prediction.

2 SEM in the previous twenty years

During the last twenty years researchers all-around the world have provided many proves of the existence of peculiar electromagnetic effects related with mechanical (seismic) stimulus, the so called seismo-electromagnetic phenomena (SEM). In fact, different studies revealed rather appealing geophysical observations [1], interesting laboratorial results [2], and attractive theoretical modelling [3]. Still, SEM is mostly known by geophysical observations. These include unusual electromagnetic effects in the preparatory stage of imminent EQ that can be basically divided into four classes: Ground-based observation of lithospheric anomalous emissions (passive) of ULF electromagnetic fields [1] and unusual atmospheric electricity behaviours [5]; Ground-based observation using radio systems (active) to study seismo-atmospheric and -ionospheric perturbations typically in the VLF/LF bands [4]; Global positioning system (GPS) based TEC measurements [9]; Satellite observation of both anomalous IR emissions [10], and ELF and VLF magnetic-field radiation [11].

First reports of geophysical observations related with SEM recede to the so-called EQ-lights appearing already in ancient manuscripts as was recently reviewed in reference [12]. Nevertheless, no significant attention was given to SEM until the widely known Fraser-Smith et al. work [13] in wish ULF magnetic field measurements near the epicenter of imminent Loma Prieta EQ revealed anomalous electromagnetic activity almost two weeks before the EQ with a remarkable increase three hours before the event. Moreover, since it is easier to detect emissions in LF bands than higher frequency (HF) ones, because LF bands have large skin depth and low attenuation (strongly dependent on the local lithosphere conductivity), the ULF radiation became one of the most reported SEM in literature [9]. Since then SEM became a very dynamic research field and subsequent geophysical studies revealed a wide range of phenomena: Suppression of VLF/LF radio transmission signals connected with ionosphere disturbances [4]; Satellite detection of VLF radio signals escaping from the Earth-ionosphere wave guide due to the same ionosphere perturbations [11]; GPS based TEC that gives a general description of the ionization of the ionosphere [9]. TEC anomalies have been observed in various studies prior to and after M>=5.0 earthquakes [9]; Short-lived anomalies detected by IR satellite monitoring [10], where temperature deviates from typical values with amplitudes of ~4 ºC up to ~20 days prior to the earthquake and disappear few days after it. This effect is sometimes attributed to air ionization due to precursory radon variations in the lithosphere [10]; AE anomalies precursor to 29 out of 41 seismic events studied in the Caucasus region [5].

Furthermore, as exposed previously many laboratorial experiments and theoretical models have been developed concerning seismic to electromagnetic conversion. These opened completely new perspectives ahead SEM geophysical observations, but they also gave interesting insights into the Physics of such observations. Among the most noticeable laboratorial experiments we have: Stick-slip experiments that showed electromagnetic radiations resulting from local charge distributions due to failure of asperities [14]; Pin-on-disk experiments, that mimic the motion of an asperity on a fault plane, and revealed photon emissions by plasma discharge at frictional contacts between natural rock minerals [15]; Stress activated electrical current experiments, in which charge carriers in igneous rocks are activated by applied stresses [16]; Experiments taking place in low seismic and magnetic noises environment showing seismo-magnetic conversion in fluid filled compressed sand caused by ion motion in the pore space, explained by the so called electrokinetic effect [2].

In relation with the theoretical models some significant ones are: Microfracturing electrification where fast fluctuations of charge and electromagnetic fields result from an ensemble of opening microfractures and develops detectable ULF radiation [17]; Ionosphere perturbations caused by redistribution of the atmospheric gravity waves pumping during periods of seismic activity [18]; Seismo-electromagnetic waves radiated by a double couple source in a saturated porous medium in the context of the electrokinetic effect [3]; Radon-induced surface layer air electrical conductivity increase prior to EQ that enhances the vertical fair weather current and lowers the ionosphere [19]. In fact, radon anomalies are among the most referred precursors to earthquakes, for a review see Ref. [20]. Thus its monitoring and correlation is highly desirable and is considered in the present project.

3 SEM in the next twenty years

The roadmap for SEM is now much related with Rock physics. This is crucial to Geosciences especially in important areas like seismology [21] and volcanology [22]. It encompasses the study of rock structural properties (e.g. lithology) under specific environmental conditions (e.g. pressure) as well as the study of relationships between structural and seismic properties (e.g. wave velocity). Rock physics has received attention from petroleum companies and this triggered a huge research effort on the electrical properties of rocks because of its application to borehole logging [23]. Moreover, electrical properties of rocks are now receiving a growing interest mainly because of recent studies on electro-acoustic coupling (EAC) during mechanical action [24]. These effects have been theoretically predicted [25] and have wide experimental validation [2]. The main objective of such studies is to understand the generation mechanisms of SEM. Generically speaking SEM involves the conversion of mechanical actions during the earthquake preparation stage into peculiar electromagnetic emissions. Obviously, this is a very complex subject because it involves a huge number of factors. Earth is highly nonuniform in what is related with geomaterials, and conditions (specially, water content, temperature and pressure). Therefore, understanding of SEM, and consequently EAC, physics must involve the study of many different rocks (with diverse mineral components) at different conditions to establish a robust physical theory to these phenomena. Nevertheless, most studies in literature disregard two important aspects to this end: a proper rock characterization to identify the effect of the above mentioned minerals, and the influence of temperature, because temperature in the seismic source can be very high. In this context, the future works should overcome these limitations by perform a detailed characterization of the rocks, analyse the effect of the temperature treatments to EAC, and most importantly performing a exhaustive analysis of EAC results to elaborate a concise physical theory to explain the results.

4 CGE contribution

The work being developed is supported by the Geophysical Centre of Évora and the University of Évora and is completely focused in the understanding of SEM Physics through two main parts: SEM observation (developing observation networks in Europe), and SEM physical comprehension (performing laboratorial experiments, and theoretical modelling). In this sense it is a board project that is producing intensive results [26-34], and we hope it will reinforce SEM studies in Europe, in particular, in the Iberian Peninsula (IP) where it is certainly an innovative project.

The SEM observation will focus in two aspects: the installation/reinforcement of networks of ULF electromagnetic field sensors, VLF/LF radio receivers, and AE sensors; monitorization and analyzes of the data resulting from these networks. Furthermore, we are already collaborating with INFREP (VLF/LF radio receiver network) and the University of Bari, Italy (UNIBA) leading institution in VLF/LF studies [4], contacts have by now been made to integrate the ULF sensors in SEGMA (a European array of ULF sensors) and collaborations with University of L'Aquila, Italy (UAQ) and the Institut für Weltraumforschung, Graz, Austria (IFW) will be establish in this context, and also the operating vertical component of the atmospheric electrical field (VAE) sensor could in a near future reinforce a collaboration with the University of Reading, UK (UR) top institution on atmospheric electricity that is presently working in the SEM [19]. In addition, the project can profit in the seismological part from solid collaborations with two Spanish intuitions: Geophysics and Meteorology Department of Complutense University of Madrid (UCM), and Real Instituto y Observatorio de la Armada (ROA). Finally, Portuguese institutions that work with us in this field, like the associated laboratory I3N-Aveiro, and the Physics Department of University of Porto (FCUP), will evidently benefit from our integration in such international networks.

In this way, the comprehension of SEM Physics concerns two features: laboratorial studies of the electromagnetic properties of various rocks (with different water contents at diverse temperatures) in the vicinity of facture (simulating seismic ruptures) already underway in collaboration with associate laboratory I3N-Aveiro; theoretical simulations of charging effects in facture processes in common "spring-block" models being developed in association with FCUP; monitoring of Radon concentration levels, and theoretical evaluation of its potential (essentially through ionization) to cause SEM.

The details of wish part of the project will be presented in the following:

4.1 *Geophysical Observations*

As becomes clear from the text above the present proposal is somehow directed towards seismo-electromagnetic multiple-parameters monitoring thus the following observations are receiving or will receive our attention: recognition of anomalous ULF electromagnetic fields; detection of VLF/LF radio broadcasting irregularities; inspection of AE abnormal behaviours; monitorization of Radon levels in the lower atmosphere (surface layer). The first equipments will be installed in the IP and the main focus of the observations will be the Western Part of the Eurasia-Nubia Plate Boundary (WENP). This region encloses the transition from an oceanic boundary (between the Azores and the Gorringe Bank), to a continental boundary where Iberia and Africa meet [35]. WENP has a significant tectonic activity, and relative low electromagnetic noise levels, which constitute a nearly ideal region for these studies. Nevertheless, with the expected integration of these equipments in international networks the project will not be restricted to WENP.

4.1.1 *Observation of ULF magnetic field emissions*

The detection of ULF electromagnetic fields aims to equip seismic stations, in the south of IP with three-component ULF magnetometers of type LEMI-30, produced by the Lviv Centre of Space Research (Ukraine), as commonly used in ULF research [9]. To this end the collaboration with UCM and ROA could be very profitable mainly because of the Western Mediterranean Broad-Band Seismological Network (WMBB), a joint effort among these institutions and the University of Évora, which has various seismic stations candidates to host ULF sensors. The most important point for this part of the project is that the sensors must be installed in specific sites that accomplish significant seismic activity with low electromagnetic noise levels here SEM phenomena have more probability to be visibly detected. Possibly one ULF magnetometer will be installed in the University of Évora for multiple-parameter assessment as will be discussed below. A portable three-component ULF magnetometer, most probably the LEMI-18 model (produced by the same Ukrainian institution), will be used in the search for the proper location to install the equipments through the temporary monitorization of the electromagnetic activity in the elected places. Once a specific site is chosen this magnetometer will be employed in calibration procedures. Moreover, this portable magnetometer could also be used for in-situ aftershock studies, typically M ~ 3 to 5, once the main shock epicentre has been correctly identified.

A special attention will be given to man-made noise sources, such as electricity transmission grids, factories, roads, etc., that must be clearly identified to ensure the reliability of the acquired data, [1]. Our study will be focused in the analyses of low magnitude earthquakes (LME) with $M \leq 4$, these events are frequent in the South of IP, but have been almost completely disregarded in literature. The magnetometers will also integrate the South European GeoMagnetic Array (SEGMA) and could benefit from the planned collaborations with the Institut für Weltraumforschung, Graz (Austria) and University of L'Aquila (Italy).

4.1.2 *Observation of VLF/LF radio signals*

The recognition of VLF/LF radio broadcasting anomalies is already being performed through two antennas (one for each band) connected to a receiver, able to acquire up to 10 signals (distributed in these bands), built by Elettronika (Italy), this equipment is frequently employed in similar experiments [4]. In Fig.4 a photograph of the apparatus installation in the University of Évora (38°34' N, 7°54' W, 300m above the mean sea level) is presented. The system was recently installed in the context of the present project and is in operation since September 1 of this year. It is working perfectly and is already stimulating the scientific production of the project [27]. The receiver integrates the International Network for Frontier Research on Earthquake Precursors (INFREP), and is examining signals emitted from active transmitters of interest to study the seismic activity in the WENP region. It is expected that the receiver could detect anomalies probably related with high magnitude earthquakes (HME), $M \geq 5$, in Europe. The data acquired with this equipment will be available to the INFREP community according to the regulation of the network.

4.1.3 *Observation of the Atmospheric Electrical Field*

Investigation of the AE anomalies related with seismic activity is by now being preformed through a vertical component of the atmospheric electrical field (VAE) sensor, model Keithley Electrometer JCI 131, installed at the University of Évora (in the same coordinates as the VLF/LF system). This equipment has been in operation on the period of December 2003 to October 2004 and from February 2005 until now. It is prepared for continuous monitoring of the VAE and works in four scales: 2, 20, 200 and 2000 kV/m with automatic commutations, respectively with the correspondent sensitivity thresholds of 0.1, 1, 10 and 100 kV/m. Inspection of the data collected until now is revealing interesting results [28] that suggests the existence of a strong ionization of the atmosphere near the ground that could be related with anomalous Radon levels according to recent models [19]. Moreover, this part of the project could in a near future reinforce collaboration with the University of Reading (UK), top institution on atmospheric electricity that is presently working in SEM. In the future it is planned that more VAE sensors could equip the seismic stations that will receive ULF magnetometers, in order, to achieve multiple-parameter monitorization.

4.1.4 *Monitoring of atmospheric Radon levels*

The Radon levels will be monitored, for the moment (the acquisition of new equipments is being considered) by a “Radon Thoron Daughters Meter model 4S” built by Silena (a former Italian company) that uses alpha spectrometry and has a sensitivity of 3.7 Bq/m3 of equilibrium equivalent radon concentration (1 mWL), and an electronically-regulated flow-rate of 3 l/min with 5% precision. The apparatus is now under installation at University of Évora in the same place of the VAE sensor and VLF/LF system to allow multiple parameter assessment of the region. As mentioned before precursor anomalous Radon levels have been reported for various seismic events [20], thus monitoring such levels deserves attention by itself. Even so, direct correlation with SEM could open new insights into the physical mechanisms behind SEM that are the main purpose of this project. Similarly to the VAE sensors, new Radon detectors could, in the future, equip the seismic stations that will host ULF magnetometers. Recent statistical analysis has revealed interesting results [34].

4.2 *Laboratorial Experiments*

In the first stage of this part of the project the electrical properties of different granitic rock types are being studied. Granites are abundant in the lithosphere and should, in principle, play a fundamental rule in SEM. The work is taking place at I3N-Aveiro in a fruitful collaboration with the University of Aveiro. Circular samples with approximately 20 mm diameter are prepared having about 3 mm thickness. The samples are heated from room-temperature (RT) up to ~400 K and after that cooled down to RT again. Aluminium contacts with circular shape of 16 mm diameter are then evaporated on top of each side in high vacuum. Finally, thin cupper wires are glued with conductive silver paint to the aluminium contacts and heated once more. Initially, the dependence of water content and the temperature is been considered in order to properly establish the fundamental mechanism of charge transport in these rocks. This is an important step, disregarded by most authors, in order to afterwards understand appropriately the pressure stimulated current and seismo-electromagnetic conversion experiments. In particular to clarify the different mechanisms that can cause SEM, among others, charge creation [7], and electrokinetic effects [2]. The following measurements are being done: impedance spectroscopy, impedance versus voltage, impedance versus temperature, current versus voltage (I-V), and current versus temperature.

5 New Perspectives and Theoretical Models

New perspectives into the Physics of SEM are expected to rise from original theoretical models. In this way, in this project a novel theoretical 2D model was developed: damage-based fracture with electro-magnetic coupling [32]. This interesting work showed the possibility of generation of electromagnetic emission by fracture of piezo-electric materials. Presently, a generalization to 3D is under construction.

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