“TWO DECADES OF EARTH SCIENCE RESEARCH”

CGE
Centro de Geofísica de Évora
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

Ana Maria Silva, *António Alexandre Araújo*, *António Heitor Reis*, *Manuela Morais*, *Mourad Bezzeghoud*

Centro de Geofísica de Évora (CGE)

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R. Romão Ramalho, 59
7000-671 Évora, Portugal

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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,
António Heitor Reis,
Manuela Morais,
Mourad Bezzeghoud

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We are also grateful to the *University of Évora* for the facilities provided to the workshop "Two Decades of Earth Science Research".

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ORADORES CONVIDADOS

KEYNOTE SPEAKERS

- *KEYNOTE ADDRESS* -
LARGE EARTHQUAKES AND THE DEVELOPMENT OF SEISMOLOGY

AGUSTÍN UDÍAS
Professor Emeritus, Universidad Complutense de Madrid,
Member of the "Accademia Europaea", and fellow of the Royal Astronomical Society
Depto. de Geofísica y Meteorología
Universidad Complutense de Madrid
Madrid, Spain, audiasva@fis.ucm.es

The occurrence of large earthquakes is, in many cases, the occasion for the advancement of seismology. This article examines the influence of six large earthquakes in the development of seismology. The 1755 Lisbon earthquake was the occasion for the establishment of the study of earthquakes as natural phenomena and the introduction of modern ideas about the origin of earthquakes and the propagation of seismic waves. The 1857 Naples earthquake was the object of the first modern field study with a physical mathematical analysis. The 1884 Andalusia earthquake was the first earthquake in Spain subject to a serious and detailed scientific study, which contributed to the development of intensity maps. After the 1906 San Francisco earthquake the elastic rebound theory was proposed. The 1960 Chile earthquake contributed to the theory of Earth's free oscillations. The 2011 Tohoku earthquake led to the revision of seismic risk assessment.

1 The 1755 Lisbon earthquake

On 1st of November 1755, about 9:40 local time, an extraordinarily large earthquake happened, the largest felt in Europe in historical times. Its magnitude has been estimated as between 8 and 9 in the moment-magnitude scale. The source of the earthquake has been located somewhere offshore Cape San Vicente. The tectonic structures of that area responsible for such a large earthquake are not yet fully understood and several proposals have been made. The earthquake caused heavy damage to the city of Lisbon and half an hour after its occurrence waves from the generated tsunami added to the destruction. Estimates of casualties in Lisbon buried under the ruins, affected by the tsunami and by the subsequent fires are between 10,000 and 30,000. Lisbon earthquake was felt over the whole Iberian Peninsula and caused damage in Cadiz, Huelva and Seville. It was felt in Europe as far as Germany and Switzerland.

The Lisbon earthquake was the occasion for the public defense that earthquakes and other natural disasters are natural events and should be studied from a purely natural point of view, staying away from theological considerations. This position was defended by authors holding the new ideas of the Enlightenment. This was an important step in the progress toward a purely natural approach to the study of earthquakes. This debate was part of the general controversy in Europe provoked by the occurrence of the earthquake. The earthquake caused also questions about the generally sensed optimism of the times, which held that the world was a good place in which everything that happens was viewed to be for the best. In Spain this question was not treated and the controversy centered instead on the natural or supernatural character of the earthquake. As an example of those holding that earthquakes are of supernatural nature, Miguel San José, Bishop of Guadix, held that "To deny or doubt that earthquakes are usually the effects of the wrath of God can be considered an error in the faith". In the other position, José de Cevallos, a theologian later Rector of the University of Seville, defended that "the earthquake has been entirely natural, caused by natural and proportioned second causes". Antonio del Barco, a cleric and historian from Huelva, insisted that "he studied, as a philosopher, the causes, duration, extension and effects of the earthquake."

The Aristotelian theory about the origin of earthquakes, caused by trapped winds in cavities of the Earth, was accepted in the West with few modifications through the Middle Ages till the end of the 17th century. With the rise of modern science, this theory was substituted by the theory of explosive sources, proposed in 1684 by Nicolas Lemery (1645-1715) in France and in 1700 by Martin Lister (1669-1712) in England. Isaac Newton (1642-1727) in his *Optics* (1703) and George Louis de Buffon (1707-1788) in *Histoire et théorie de la Terre* (1749) supported this theory. After the Lisbon earthquake this theory became widely accepted.

In 1760, John Michell (1724-1788) proposed for the first time the fundamental idea that earthquake motion propagates through the Earth in the form of waves through the Earth's crust which propagates from the focus. Thus the origin of the earthquake was separated from the waves it generates and which are propagated to large distances (*Essay on the causes of the phenomena of earthquakes*). Together with the explosive nature this consideration separated the focus from the wider area where the earthquake was felt.

A further development, but in a wrong direction, about the origin of earthquakes was the proposal that earthquakes are caused by electrical discharges in the Earth's interior, like lightening and thunders in the atmosphere. This was first proposed a few years before the Lisbon earthquake, in England by William Stuckley (1687-1765 in 1750 and in Italy by Giovanni Battista Beccaria (1716-1781) in 1753. The theory was presented after the Lisbon earthquake in Spain by Benito Jerónimo Feijoo y Montenegro (1674-1764). For him the electrical theory explained well, in the case of the Lisbon earthquake, that it was felt at the same time in so distant places, since electricity propagates at very high velocity. However, he didn't rule out completely the explosive nature, as electricity could also have caused the explosion of the concentration of inflammable materials inside the Earth.

2 Naples earthquake of 1857

On the 16th of December, 1857 at 21:15 local time a large earthquake (estimated magnitude 7) produced very extensive damage in the Italian regions of Basilicata and Campania including the city of Naples. It caused 19000 casualties and destroyed 6300 houses. Greatest damage was produced at the towns Montemurro and Saponara, where half of the population died under the ruins of the houses.

Robert Mallet (1810-1881), an Irish engineer, had become interested before in earthquakes. On 1846 he published, *On the Dynamics of Earthquakes*, which is considered to be one of the first modern texts of seismology, applying the approach of mechanics to earthquakes. He is credited with coining words like seismology, isoseismal map and epicenter. He was the first to measure seismic velocities in the Earth's crust from explosions, a technique widely used afterwards for the study of the velocity structure of the crust.

From February to April 1858, Mallet traveled to Italy to study the effects of the Naples earthquake. His detail study is considered to be the first modern field study of an earthquake and to mark the beginning of seismology as an independent science. In his report, *Great Neapolitan earthquake of 1857. The first principles of observational seismology* (1862), he joined the naturalistic description of phenomena with a rigorous physical–mathematical analysis, integrating geology, physics and mathematics in the study of an earthquake. The report included for the first time 156 photographs. Based on this study, Mallet connected the occurrence of earthquakes with changes in the Earth's crust which result in dislocations and fractures, though maintaining still the volcanic explosive nature of the source.

An important contribution in Mallet's report is his determination of the hypocentral depth of the earthquake. Mallet determined the location of the depth of the focus from the vertical inclinations of cracks in buildings. He was aware of the novelty of his determination and commented that this was "the first approximation to the depth of the focus ever attempted for any earthquake". With his report Mallet went above the mere naturalistic description of the effects of an earthquake to introduce the determination of the location of the focus, its relation to the geology of the region and a measurement of the attenuation of shaking with distance.

3 The Andalusia earthquake of 25 December 1884

On Christmas day of 1884 at 20:45 local time, a large earthquake with estimated magnitude of 6.5 shook the region of Andalusia, southern Spain. More than 100 villages situated between the cities of Granada and Malaga, suffered very heavy damage. Especially, Arenas del Rey, Ventas de Zafarraya and Alhama de Granada were practically destroyed, so that they have to be completely rebuilt. The topography added to the damage with many landslides, ground fractures and cracks. The number of casualties was 745 dead and 1485 seriously wounded. The total number of damaged buildings was about 17000. Shaking was felt as far as Madrid and Valencia, more than 500 km away. Aftershocks continued to be felt during more than a year.

This is probably one of the first earthquakes subject to an international scientific study. Three commissions were established for the study of the earthquake by Spain, France and Italy. The Spanish commission was headed by Manuel Fernandez de Castro, a mining engineer, in charge of the geological map of Spain, and six other members. It distributed 500 questionnaires and based on them published a long report. The French commission was headed by Ferdinand Fouqué (*Académie de Sciences*), one of the most outstanding seismologists of France, with three other members and four assistants. Its report centered on geologic studies of the region and was published in 1890. It was translated into Spanish with commentaries in 1893. The Italian commission was formed by the seismologists Giuseppe Mercalli and Torquato Tarramelli (*Academia dei Lince*). Its report includes a catalogue of earthquakes in southern Spain, the first for this region, and one of the first isoseismal maps.

Mercalli is famous for the development in 1903 of the seismic intensity scale, still used today with some modifications (Modified Mercalli Scale). Mercalli and Tarramelli determined an early intensity map for the Andalusia earthquake with only three degrees of increasing shaking: *disastroso*, *rovinoso*, *fortissimo*. The map also shows the directions of shaking at different locations, which were used for the determination of the location of the epicenter. They also determined the depth of the focus at 12 km and compared the intensity of this earthquake with that of the great Naples earthquake of 1857 (studied by Mallet), finding the latter to be three times larger.

Fouquet and the geologists of the French commission took advantage of this earthquake to propagate the ideas that earthquakes are caused by fracture in faults and tectonic processes. These ideas had been already proposed by Charles Lyell (1797-1875) in his influential book, *Principles of Geology* (1830-33), who began to relate earthquakes to tectonic processes in the Earth's crust and the abandoning of the explosive theory. This idea was also present in the study of the Naples earthquake of 1857 by Mallet. Eduard Suess (1831-1914) in 1875 also proposed that earthquakes occur on lines representing fractures or faults in the Earth's crust. The idea that earthquakes are caused by fracture on Earth's faults was further developed in the late 19th century by Josiah D. Whitney (1819-1896) and Grove K Gilbert (1843-1918) studying California earthquakes and by Bunjiro Koto (1856-1935) studying Japan earthquakes. In Spain these ideas were presented by José Macpherson (1839-1902), one of the founders of modern geology in Spain, who took the opportunity of the Andalusian earthquake to present the tectonic theory of earthquakes (*Los terremotos de Andalucia*, 1885). He began stating that the general causes of all phenomena on the Earth's surface, such as orogenetic and volcanic processes, are derived from the secular cooling and contracting of the Earth. He, then, explained the Andalusia earthquake as caused by the breaks along the system of faults which limits on the north and south the mountains of Sierra Tejeda and Almijara.

4 San Francisco earthquake of 1906

On 18 April 1906, early morning in California, a large earthquake caused catastrophic damage in San Francisco with more than 3000 casualties. About 300000 of the city 400000 inhabitants, that is practically the entire population, lost their houses. The earthquake was followed by a fire, which contributed, to the destruction of the city. Damage was distributed on a narrow band along the coast. The shock broke the San Andreas fault and the ground displacement of the two sides of the fault could be followed along the surface for 430 km, from Cape Mendocino in the north to near Hollister in the south. The horizontal displacements across the two sides of the fault reached 6 meters in Marin County north of San Francisco, with the Pacific west side moving northwest with respect to the east side. According to plate tectonic this represents the motion along the plate boundary between the Pacific and American plates.

After the earthquake in 1910, Francis F. Reid (1859-1944) proposed the elastic rebound theory. Reid had noticed that distant points of opposite sides of the fault had moved 3 meters over the 50 year period previous to 1906, with the western side moving north. This motion had accumulated elastic strain on both sides of the fault which was suddenly released by the earthquake. According to Reid's theory, earthquakes take place by fracture of a fault with the release of the elastic strain accumulated in it by tectonic processes. The process begins with a slow continuous stress accumulation around a fault. This stage in the fault produces a continuous elastic deformation. In terms of plate tectonic theory, as time passes, the slow movement of the plates of the order of a few centimeters per year produces a pre-seismic deformation of the rocks that surround the fault. This deformation causes a generalized increase of the stress level around the fault. When this stress level is larger than the strength of the material of the fault, the two sides will be suddenly displaced producing an earthquake. In consequence, the earthquake process is formed by slow strain accumulation and sudden release by breaking. This theory forms the basis of today understanding of the nature of earthquakes.

5 Chile earthquake of 22 May 1960

Chile is periodically subject to the occurrence of very large earthquakes. Some of them reach magnitudes over Mw = 9.0. These earthquakes take place at the plate boundary between the Nazca and South American plates with underthrusting of the oceanic lithosphere under the continental one. The 1960 earthquake is one of the largest earthquakes ever felt with magnitude Mw = 9.5. In this earthquake the oceanic crust underthrusted the continental one along a length of 800 km with displacements of up to 25 m. Heavy damage was caused to coastal town from Concepcion to Valdivia with up to 3000 dead. In the city of Valdivia 40% of the houses were destroyed. The earthquake produced a large tsunami which contributed to the destruction in the cities and towns along the coast.

A very large earthquake produces that the Earth vibrates as a whole the same way as does a bell when it is hit. The problem of the free oscillations of a homogeneous elastic sphere was already treated in 1882 by Horace Lamb (1849-1934) . In 1911 Augustus E. H. Love (1863-1940) applied the theory to the vibrations of the Earth and calculated the fundamental period for an homogeneous elastic Earth with a value of near to one hour. Free oscillations of an elastic sphere are divided into spheroidal and toroidal modes. In the first the shape of the sphere changes in radial form (in the lowest mode the shape changes from a sphere to an ellipsoid oblate and prolate) and in the second the sphere changes in torsional form (in the lowest mode the upper hemisphere rotates in one direction and the lower in the opposite).

Although free oscillations of the Earth were first observed in the seismograms of the large earthquakes of Kamchatka 1954 and Mongolia 1957, the best observations came from the Chile 1960 earthquake. Observations of the free oscillations of the earth generated by the Chile earthquake recorded by long period instruments were studied by seismologists like L. E. Alsop, Maurice Ewing, Hugo Benioff and Frank Press and began to be published in 1961. They observed both modes, spheroidal and toroidal. The frequency analysis of the displacements produced by the earthquake showed the presence of the different modes. The longest period corresponds to the spheroidal mode $_0S^2$, with 53.9 minutes. This confirmed the early value found by Love. The longest toroidal mode is $_0T^2$ with 44 minutes. The rotation of the Earth produces splitting of the eigenfrequencies, which were also observed. Other effects present in the observations are due to the Earth's ellipticity and deviations of elastic properties and density from radial symmetry. Comparison of observed values of eigenperiods of free oscillations and those calculated from theoretical models is used to obtain global models of the structure of the Earth's interior. Modern models of the Earth's interior integrate observations from the propagation of body and surface waves with those of free oscillations, covering a wide range of frequencies.

6 Tohoku, Japan, earthquake of 2011

On the 11th of March 2011 a large earthquake of magnitude Mw = 9 stroke off-shore northern Japan and produced a large tsunami. The magnitude of shaking and the size of the tsunami were beyond any expectations and caused enormous damage. Shaking produced ground accelerations at 75 km distance of up to three times the value of gravity. The tsunami produced waves up to 30 meters high. This was a high that was above anything that the coastal towns were prepared to. The existing barriers were toppled and the waves flooded extensive areas causing large destruction. Casualties are estimated at about 1600 dead and 3000 missing and damage costs above 10000 million dollar. The maximum earthquake magnitude for the area had been estimated at Mw = 8.5, that is, a level lower than that of the earthquake. The occurrence of this earthquake has caused a growing concern about the need of a revision of seismic risk assessment ideas. In seismic areas were very large earthquakes have happened in the past its recurrence must be taken into account, though they may be separated by very long time intervals. Some have even questioned the probabilistic methods themselves commonly used to determine seismic hazard.

Among the damage produced by the earthquake stands out that produced to the Fukushima nuclear power plant. Though the plant resisted the shaking, it was flooded by the tsunami, whose waves went over the existing barriers. Four of the six reactors were damaged, three of them with full meltdown. This is considered the largest nuclear disaster since Chernobyl. The situation has caused the questioning of nuclear plants security measures. Even there are serious doubts about continuing with nuclear plants at all and a growing concern has been created about the future itself of nuclear energy.

7 Conclusions

New developments in the science of seismology are sometimes produced after the occurrence of large earthquakes. We have presented six examples and shown how certain important developments in seismology were motivated by the occurrence of the large earthquakes of Lisbon, 1755, Naples, 1857, Andalusia, 1884, San Francisco, 1906, Chile, 1960 and Tohoku, 2011. The seismological developments can be summarized as: the consideration of earthquakes as natural events, their explosive source and the propagation of elastic waves; the establishment of quantitative field studies and the macroseismic hypocentral determination; the development of intensity maps and the nature of earthquakes caused by fracture in faults; the elastic rebound theory; the observation of free oscillations of the Earth and the need for a revision of seismic risk assessment.

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- *KEYNOTE ADDRESS* -
FUTURE CLIMATE CHANGES: FROM THE GLOBAL ALERT TO THE DEVELOPMENT OF CLIMATE SERVICES AND ASSOCIATED SCIENTIFIC UNCERTAINTIES

HERVÉ LE TREUT

Laboratoire de Météorologie Dynamique / Institut Pierre Simon Laplace
Université Pierre et Marie Curie, 4 place Jussieu, 75252 Paris Cedex 05.
letreut@ipsl.jussieu.fr

There is now a wide scientific consensus about the existence of a global warming in response to increasing greenhouse gases. But the precise amplitude that this warming may take in the future is subject to uncertainties that have not declined over the years. Other irreducible uncertainties affect the assessment of the regional consequences of these changes. The ability of the scientific community to reduce these uncertainties is a major challenge, as the continuing greenhouse gas emissions call for adaptation strategies to climate change.

1 A new context for climate change studies: an increased certainty of upcoming changes

The anthropogenic increase of greenhouse gases has been identified as a potential threat to our climate since more than fifty years. The first report on the climate change that might arise in response to CO2 increase was presented to the US Academy of Sciences more than 30 years ago by Charney et al (1979).. This early report provided elements of diagnostics which have retained their validity over the years: a global surface temperature increase in response to a CO2 doubling ranging from 1.5°C to 4.5°C; a stronger warming in the polar regions and over the continents; a change of the precipitation distribution often accentuating present trends (decrease in semi-arid regions, increase in moist regions). Three decades of improved models, recent observed changes of the actual climate system, have only confirmed those results, which are also consistent with the current melting of the Greenland ice cap, the decrease of Arctic sea-ice extend at the end of the summer, or the changes in the growing period of different vegetation species.

But in spite of this very stable scientific diagnostics, the context of climate research has been strongly modified over the last two or three decades. This is mainly the result of ever increasing greenhouse gases emissions. To take the only example of CO2 emissions due to fossil fuel burning, their amplitude was between 1 and 2 Gigatons per year (Gt) in the fifties, they reached about 7 Gt at the turn of the century and 9 Gt in 2010, in spite of all international efforts to curve them down. The level to which emissions should go back to maintain stable climate conditions is estimated to be 3 or 4 Gt, and emissions went over it in the seventies.

These simple figures indicate first that the anthropogenic greenhouse increase is a new feature, a few decades old. It is affected by two main types of inertias: one representing the rate at which greenhouse gases accumulates in the atmosphere (the average atmospheric life time of the CO_2 is about 100 years) and the thermal inertia of the surface oceans (a few decades). It is therefore not surprising that the first discernible signs of a global warming have appeared quite recently, after 1990 (Le Treut et al, 2007). These same figures also indicate that this warming is just starting, and that it should increase quickly in the future. Models indicate that the current increase of greenhouse gases emissions might bring us by the middle of the century above a 2°C warming (IPCC, 2007). This is the warming level that the different countries gathered at the Copenhagen conference had promised to avoid, and this objective is becoming increasingly difficult to meet.

2 New expectations from climate sciences, and associated uncertainties

This perspective of rapid climate change is also causing a change in what policymakers may expect from climate science. For many years, the goal of research studies in the field of climate and climate change has mostly been to determine and assess the reality of a danger associated with the emissions of greenhouse gases. But the quick development of greenhouse gases emissions, the early signs of global warming are now creating a new demand, that science may help the planning of mitigation and adaptation measures. This demand has prompted the establishment of "Climate Services" under the auspices of the World Meteorological Organization, e.g a large and organized dissemination of the climate projections realized in international projects such as CMIP5 (Coupled Model Intercomparison Project 5) from the WCRP (World Climate Research Programme), or the CORDEX project (also from WCRP) dedicated to regional simulations.

But our scientific community is facing a strong problem. Whereas the diagnostic of an upcoming climate change is unequivocal, as stated by IPCC (2007), it has been almost impossible to reduce significantly the range of uncertainties attached to its quantification and its localization.

Climate sensitivity is often defined as the equilibrium warming caused by a doubling of CO_2 concentration, compared to its preindustrial value. It is a simple measure of how strongly climate may react to the increase of long-lived greenhouse gases. As stated above, Charney et al (1979) had established a range of uncertainty from 1.5°C to 4.5°C. The different model intercomparison projects summarized in the last IPCC reports (IPCC, 2007, Le Treut et al, 2007) show that it has been impossible during the last decades of research to reduce this uncertainty range. We know that this uncertainty is largely the consequence of the complex feedbacks associated with water vapour and cloud processes and a very active research has been developed to tackle this problem (Le Treut, 2012) . This issue is especially difficult because the recent climate changes are the result of two main processes: the increase of short-live aerosols, whose negative radiative forcing is still very difficult to assess, and that of long-lived greenhouse gases, both of which are affected by complex feedback effects. The magnitude of recent climate changes is therefore not a reliable indicator of its future changes, and dedicated process studies are necessary to establish climate sensitivity. There is a very active research in this area (see for example the CFMIP project), facilitated by an ambitious programme of satellite measurements (the A-train constellation of satellites), but it may require a decade or decades to reduce uncertainties affecting climate sensitivity.

Another source of uncertainty concerns the capacity of models to establish a reliable geographical estimate of climate change consequences. Originally the average horizontal resolution of climate models was about 500 km, and it was gradual decreased to about 100 km. Dedicated regional approaches may bring results at scales of 10 to 50 km, or lower. A French specificity, for example has been to develop (at IPSL and Méteo-France) "zoomed" approaches where global models have a refined mesh in the regions of major interest. The results of the two "zoomed" French models were presented in a report prepared for the National Adaptation Program (Peings et al, 2011).

But this increase in model resolutions may not be enough to improve model results at the regional level. Comparison of current climate models show that, whereas models agree in predicting a widespread warming in the coming century, the regional structure of precipitation changes is not a subject of agreement between models. The IPCC (2007) assessment showed that even the sign of expected average precipitation changes was a matter of discrepancy between models over about half of the Earth surface. Indeed it is still not well known how the mechanisms that determine natural variability (monsoons, ENSO, NAO, blocking patterns at mid-latitudes...) may be affected by climate change, and there are even theoretical reasons to believe that this evolution may not be fully predictable. Also in many cases, climate change is expected to alter the statistics of different climate regimes, an effect which can be assessed in a statistical manner only, with a perspective of dual future climate evolution: the Mediterranean area, for example, may be subject to increased drought conditions, as well as more violent flood events.

Moreover, in the longer term, as soon as new partners such as the deep ocean, the large glaciers, or large forests will come into play, the behaviour of the climate system may become even more chaotic, with possibilities of brutal transitions that are currently difficult to assess. This is also an area where models are less constrained by fundamental physical laws, and include more empirical representation of very complex systems: how to introduce life in the models (biology or ecology, not to mention all social and political constraints) is still a widely open problem, probably one of the major challenges for the years to come.

3 Conclusions

Bringing the expertise of climate research to stakeholders, policymakers, and citizens, therefore represents a very difficult challenge. Climate changes are not the only environmental and development problems to be faced in the future, and taking decisions also involve non-scientific issues such as equity. Therefore climate scientists have to make sure that their message to society involves all aspects of their current knowledge, with their certainties and uncertainties, which are both necessary for adequate decision making.

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- KEYNOTE ADDRESS -
INSERÇÃO DO SISTEMA CIENTÍFICO NACIONAL NO ESPAÇO EUROPEU
INTEGRATION OF THE NATIONAL SCIENTIFIC SYSTEM IN THE EUROPEAN AREA

MARIA DA GRAÇA CARVALHO

Full Professor at IST, Lisbon, Member of the European Parliament, Rapporteur of the implementation of Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020), Principal Advisor of the Bureau of European Policy Advisers of the European Commission.
e-mail address: mariadagraca.carvalho@europarl.europa.eu

The main objective of this presentation is to describe the opportunities that Horizon 2020 - the next European Framework Programme for Research and Innovation - will bring to Portuguese entities and universities in particular. The presentation will start with a general overview of H2020 and its main principles, its structure and priorities. Some attention will also be devoted to the institutional negotiation process and to the particular contribution made by the speaker, Maria de Graça Carvalho as *rapporteur* for the Specific Programme Implementing H2020. The funding that will be devoted to science and innovation in the forthcoming EU budget will also be discussed.

POLÍTICA CIENTÍFICA

SCIENTIFIC POLICY

CREATION AND DEVELOPMENT, FROM THE INDIVIDUAL RESEARCHER TO RESEARCH EMPIRES

A. HEITOR REIS
University of Évora, Geophysics Center of Évora, and Department of Physics, Colégio Luis Verney, R. Romão Ramalho, 59, 7000-671, Évora, Portugal, ahr@uevora.pt

This paper is dated: it was written at the time of the celebration of the 20 years of activity of the Évora Geophysics Centre (CGE). It comprises a brief appraisal of the evolution of scientific research in Europe and in the United States of America, together with a special reference to the development of the Portuguese scientific system. The size distribution of scientific teams in the whole system is addressed, and it is shown that at a state of optimal performance there is room for all team sizes ranging from the individual investigator to research empires. Similarly, we note that research dynamics evolve in time with periods of strong creation intensity that alternate with periods of extension and quiescence. We also note that the new perspectives for the European Research Area, with policies that push strongly to the development side, may be risky in the long term as they might lessen creation, which is the base for sustainability and development. Finally, we briefly address the challenges ahead both for the Portuguese scientific system and the CGE.

1 Introduction

Scientific research, seen as the creation of new ideas that are spread within a community for public use, began with the individual investigator. The celebrated philosophers of Antiquity, Pythagoras of Samos, Euclid and Ptolemy of Alexandria, Archimedes of Syracuse, are examples of people that collected, created and disseminated new ideas in the Ancient World. The new ideas that help us to understand Nature and that might anticipate the knowledge of natural processes are called *scientific knowledge*. From Antiquity to the present time the History of Science comprises many examples of individuals that contributed to creation of the body of scientific knowledge that shapes our current vision of Nature.

The successful ideas last long and shape the context for opinions, judgments, beliefs and actions, namely they become paradigms of knowledge, some of which last for centuries. In our world they provide the ground to develop technologies, decision making, and even to social behavior. Though a new step forward often springs from the individual researcher, the subsequent exploration of the new field of knowledge together with its associated technologic development is a task of a large number people. However, in some rare special cases, namely when huge data collection is needed, the breakthrough comes from a large group of people. This raises the questions of how to balance the role of the individual researchers or the small groups of research in an optimal performing scientific system, and also that of the role of those groups that put more effort on the pursue of new breakthroughs with respect to those whose main work is to regularly extend the knowledge of the working field.

The purpose of this paper is to discuss these two questions in the current Nacional and European frameworks.

2 A quick look on the evolution of the Portuguese scientific system

In Europe, public funding of research activities existed indirectly in the sense that it was carried out in universities and academies that received state funding. This is particularly true for the major European states namely Germany, France and the United Kingdom. From the beginning of the 20th century, foundations have appeared that also contributed to research funding. As Sverker Sörlin [1] notes:"*Some of the largest foundations were started in the US, typically by industrial families and corporations. In Europe foundations were typically smaller, with Wellcome (UK), Gulbenkian (Portugal), and the Wallenberg (Sweden) Foundations as notable exceptions. However, in some European countries the foundations grew quite numerous (Anheier 2001) to make them cater for a substantial proportion of research funding (they never played a major role in the funding of higher education). The foundations were innovative and developed new forms of research funding – projects, programs, centers of excellence, schools of advanced study, specialized institutes – that were later copied and scaled up by public funding agencies."*

In the United States of America, the determinant role of science and technology for the victory of the Allies in World War II was recognized in the Report *"Science The Endless Frontier"* presented to President Roosevelt by Vannevar Bush, Director of the Office of Scientific Research and Development (July 1945) that established the basis for the development of a public funding program of research through the *National Science Foundation.*

In Portugal the governmental body "Board for National Education" (JEN) was created in 1929, which developed in 1936 its specialized office "Institute for High Culture" with the purpose of providing grants to Portuguese scientists to study abroad, and also some support to the few embryonic scientific research groups. In 1950 it became an autonomous office with the name of "Institute of High Culture" (IAC), which was restructured in 1976 to give birth to the "National Institute for Scientific Research" (INIC), which lasted until 1992 when it was extinct. On the other hand, in 1967 the "National Board of Scientific and Technological Research" (JNICT) was created, which accrued the administration of the financing of institutions of higher education and post-graduate fellowships, upon the extinction of the INIC in 1992. The "Foundation for Science and Technology" (FCT) began in August 1997, inheriting functions of JNICT, after its extinction in 1995.

The first Portuguese research teams started either within the university context or were promoted by private entities (e.g. the Gulbenkian Foundation) or else by governmental bodies (e.g., "the Board for Nuclear Power").

In the beginning of the last decade of the XX century, the European programs STRIDE (Science and Technology for Regional Innovation and Development) together with the inter-governmental initiative EUREKA — that had the purpose of creating cooperation and synergy research among activities in the European Union, namely the "Framework Programs for Research and Technological Development", and the "European Research Area" — provided the support for the national programs aiming at boosting the Portuguese science and technology system, namely: the "Mobilization

Program on Science and Technology", the "Basic Program of Scientific and Technological Research", the "European European Southern Observatory", the "CERN Fellowship Program", and the "Program Science, Technology and Society". Many new research units appeared at the time (e.g. the Évora Geophysics Centre, CGE, 1992) covering all fields of Science, Technology, Social Sciences, the Humanities, and the Arts.

FCT started up programs of regular funding together with evaluation of these research units. The funding was provided on an annual basis and accounted both for the rate at evaluation and the number of PhDs of the research unit. In 2012, FCT announced a new funding policy that is aimed to focus on the best rated strategic projects and the objectives accomplished by research units. Networking and reshaping of the actual research units is expected to occur as the right strategy for best positioning for competitive funding.

3 Size distribution of research units and performance of a scientific system

The output of research that is valued socially is the production of new ideas of nature and society, new processes that are reproducible, new technologies and machines that make everyday life easier and safer. Societal valuation is payed back to researchers in the form of social recognition, better salaries, and funding to research. In order to maximize their output researchers collaborate and organize themselves in teams of research.

Two questions arise: (i) Is there an optimal size for a team that seeks to maximize its output? (ii) Will the performance of a national scientific system grow with the size of its research teams?

3.1. *Is there an optimal size for a team that seeks to maximize its output?*

Optimization makes sense only if constraints are present. In the case of research teams the main constraints are the available number of researchers per area of expertise, the funding available on a regular basis, and the facilities made accessible to the team. If some of these constraints is relaxed it can became a variable for optimization to reach maximal research output. For instance, the research team might be in position of optimizing its size in some particular context of funding and facility availability. This objective is achievable because it is possible to find the optimal number of researchers that maximizes the performance of the team in that context.

However, in general, the size of the team evolves in time driven by a multiplicity of factors other than search of optimal performance, the same happening with the team territory (the ensemble of facilities). In this way, any research team may be viewed as an open and lively (out of equilibrium) subsystem with a proper territory (facilities) that exchanges ideas and researchers with the global scientific system.

3.2. *Will the performance of a national scientific system grow with the size of its research teams?*

A scientific system is composed of a constellation of research units of very different sizes that are regularly reshaped due to the main driver that makes the system alive: the social recognition of the research output. In such a system, the individual investigator and the large group coexist in such a way that none of them can get rid of the other, rather they appear entangled and complementary. One might ask if some trend emerges from the internal dynamics that drives the system in a preferential direction, for instance if the large teams are so successful that they tend to be few and larger such that the smaller ones (and the individual investigator as well) will become less and less numerous?

Historically, the national scientific systems have evolved and have been reshaped in time, yet never the smaller research groups neither the individual investigator have disappeared. In fact, those that disappeared were somehow balanced by new emerging research teams. The same move is observed with the larger groups, though at a smaller pace.

Successful models of scientific systems must account both for the cohesion and disaggregation forces that determinate its internal dynamics. A. Bejan [2] provided a beautiful Constructal model of the dynamics of a scientific system that explains in simple form many features of self-organization in contemporary research, namely:

1. *The coexistence of research empires with individual investigators.*
2. *The scaling of the size of the large group with the size of the entire institution.*
3. *The strong relationship between the size and the visibility of the institution.*
4. *The emergence of the first large groups in the largest research institutions of the era.*
5. *In time, as incentives become stronger, small institutions also organize into combinations of large groups and individuals.*
6. *Complete coalescence into large groups is not happenin*g.

As a corollary, he points out: "*the apparent conflict between research empires and individuals is not a conflict: it is a balance that serves the institution as a whole*" [2].

The above conclusions are rather comfortable to small groups and the individual investigator as well, because they indicate that every team regardless its size might find its place in a scientific system with optimal performance.

4 The trade-off between creation and development

Historically, creation has been assigned to the individual investigator, while development has been a task of research teams. Actually, we can never find creation without development, and vice-versa. Reality is far most complex and science progresses in a permanent trade-off between creation and development.

The great breakthroughs in science and technology usually spring from the individual investigator, while the group is the better arena for the flow of ideas and for synergetic thinking. Indeed, the group is short-lived, works discontinuously as compared to the individual. This one carries for long (years, decades) a continuous and unique internal process of elaborate thinking that enables him to makes inferences, testing and re-elaboration of hypothesis, synthesis, and finally theory. This confers the individual a great advantage over the group, and this is why individuals have generally more success on the creation side.

Usually, the group starts forming around a senior independent thinker that attracts other thinkers/researchers, i.e. investigators to carry out a program of research. Every team member contributes to the common goal, yet each one develops different tasks. As the group gets larger, its preeminence grows because it is able to encompass the study of larger and complex systems, yet this is balanced by the progressive weakness due to every team member is progressively less able to think the system as a whole. This is why creation is less likely to occur, and creation intensity gets smaller as the group becomes larger and larger. Large groups develop research programs, which due to their magnitude cannot be carried out by small teams or individuals, yet creative intensity resides in the smaller groups and asymptotically in the individual investigator.

Hence, the research output results from a trade-off between creation and development (extension). Creative individuals (teams) break the existing frontiers, and inspire others to explore every corner of the new field of research. They drive the whole scientific system in a move to map the new territory by accumulating huge amounts of data, install new settlements (facilities, groups, institutes, etc.) making new knowledge globally available (see fig. 1).

By breaking frontiers, creative teams (individuals) are the real drivers of progress in science and technology. However, the exploration of the new territory is not a task at the

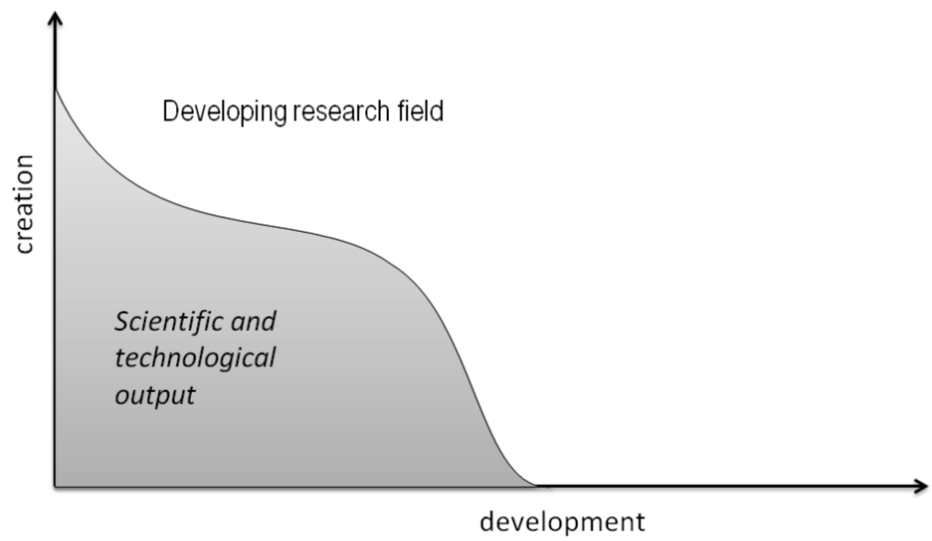

Figure 1. Creation versus development in a developing research field

reach of individuals, and even of most small teams, rather it is a mission that must be undertaken by as many people as those necessary to make a successful journey. It requires organization, a rather long preparation, and funding on a regular basis. Funding is provided to teams at a rate that depends on the economic and social value of their work, and that lasts as long as the research output keeps getting social recognition. In general, exploration of a new field of research initiates at an accelerated pace during some period, peaks at some moment in time, and then decelerates for a longer period, which corresponds to its quiescent state (See fig. 2.)

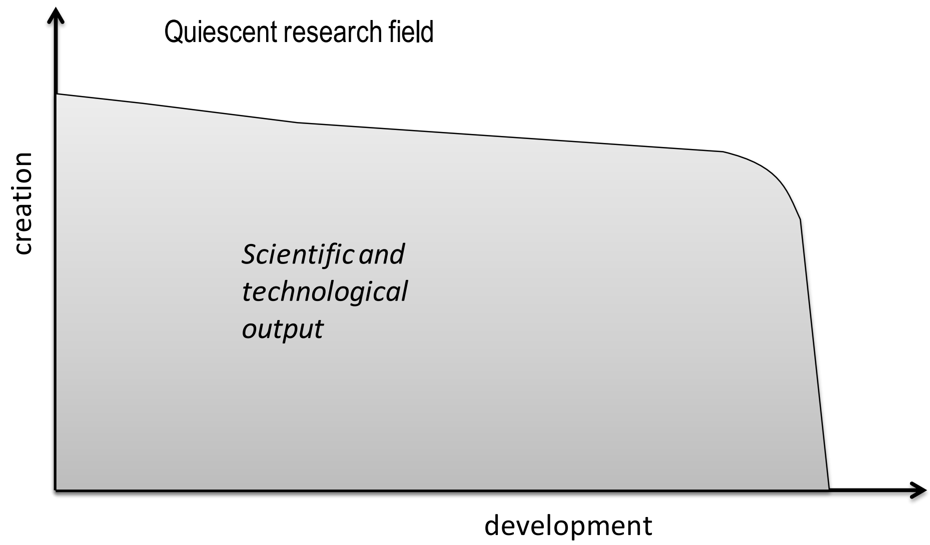

Figure 2. Creation versus development in a quiescent research field

In view of the model outlined above, research teams must periodically appraise their positioning in the research field and the whole scientific system as well. Adaptation at the individual and team levels is required to progress in social recognition, and to keep research teams alive.

5 The challenges ahead

The European Union (EU) is about to launch the new research program HORIZON 2020, for the period 2014-2020. EU programs are important because they usually become referentials for all the European Research Area (ERA). It is recognized that "*Science and innovation are key factors that will help Europe to move towards smart, sustainable, inclusive growth, and along the way to tackle its pressing societal challenges"* [3].

Accordingly, HORIZON 2020 conveys a clear economic purpose: *"The key driver of the problems is Europe's structural innovation gap: compared to its competitors, Europe's patenting performance is weak and it lags behind in developing new products,* *new processes and new services. To boost productivity and growth, it is critically important to generate breakthrough technologies and translate them into new products, processes and services"*[3].

In this way, a marked shift of the current research priorities is expected to occur until the end of this decade that will redirect research preferentially to sectors of strong market value. This goal is expressed clearly by the promoters of this new program, by stating: *"The current separation between research and innovation activities is eliminated. Horizon 2020 sets out three strategic policy objectives: raising and spreading the levels of excellence in the research base; tackling major societal challenges; and maximizing competitiveness impacts of research and innovation. Horizon 2020 is structured around three priorities which link directly to these aims. The selection of actions and instruments is driven by policy objectives and not by instruments"*[3].

In what respects to the CGE main fields of research, only "climate action, resource efficiency and raw materials" deserve some mention (ref. [4], Ch. 5), along with the "Broad lines of the activities": *(a) Fighting and adapting to climate change; (b) Sustainably managing natural resources and ecosystems; (c) Ensuring the sustainable supply of non-energy and non-agricultural raw materials; (d) Enabling the transition towards a green economy through eco-innovation; and (e) Developing comprehensive and sustained global environmental observation and information systems.*

Nevertheless, a small CGE research field might find an opportunity with this program due to the relevance given to the specific area of "Secure, Clean and Efficient Energy" (Ch. 3 in Ref. [4]).

This new policy deserves scrutiny at least from the historical perspective. The prospective new alignment of the EU research policy is going to shift towards the development axis (see figs. 1 and 2) turning out the global scientific system more quiescent. Gains are expected from the side of "innovation", new products, and new practices, and so on. In the short term, positive impacts might be expected in the economy, yet in the long term there is the strong risk of deceleration in the axis of creation, which is the basis for a long-standing and sustainable growth of economies and societies. History shows that the most impressive periods of growth both from the economical and the social side were driven by strong creation intensity (scientific and technological) that opened new frontiers to development. As A. Bejan [2] concluded for the case of the apparent conflict between the individual investigator and the research empires, optimality of the system is always achieved trough balancing contributions of both. We extend that conclusion to the case of the scientific policy by stating that optimality must be achieved through a continuous balancing between creation and technological development.

Thought the Portuguese Scientific and Technologic policy is not yet known in detail, a strong alignment with the European guidelines is expected to occur. FCT has already announced policy goals similar to those of HORIZON 2020, namely, that the selection of actions and instruments will be driven by strategic objectives, quality, and not under the current framework of funding of research units. In this way, the existing research units will be compelled to reshape, redefine objectives, and make networking for pursuing competitive funding. CGE faces such a challenge in the next future.

6 Conclusions

The history of scientific systems in Europe and the United States of America shows similar growth patterns, namely in the fact that both were driven by public and private funding. It was noted that both systems are composed of a constellation of teams and research units, yet in both systems neither the individual investigator has disappeared not most of the research teams have coalesced into huge teams (the research empires), rather one observes a team size distribution that ranges from the individual investigator to the research empire.

We noted that the model of a scientific system put forward by A. Bejan (2008) is able to describe the main features of current scientific systems. One major result that springs from Bejan's model is: "*the apparent conflict between research empires and individuals is not a conflict: it is a balance that serves the institution as a whole*".

Having analyzed the internal dynamics of scientific systems in terms of the creation and development axes we noted that actual systems evolve in time under dominance either of creation or of development (extension), thus defining periods of strong creation that alternate with periods of quasi-quiescence. We also noted that the foundations of the new European program HORIZON 2020 will tend to push the European Research Area towards the development axis, thus rising up the risk of stagnation (quiescence) of the whole system in the long term.

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LABORATÓRIO DE CIÊNCIAS E TECNOLOGIAS DA TERRA ATMOSFERA E ENERGIA: UMA CANDIDATURA AO SISTEMA DE APOIO A INFRAESTRUTURAS CIENTÍFICAS E TECNOLÓGICAS (QREN)

ANTÓNIO ALEXANDRE ARAÚJO

Centro de Geofísica de Évora, Departamento de Geociências, Escola de Ciências e Tecnologia da Universidade de Évora, aaraujo@uevora.pt

Em Outubro de 2008 o Centro de Geofísica de Évora envolveu-se num projecto institucional da Universidade de Évora, da iniciativa do então Vice-Reitor António Heitor Reis, designado por Rede Regional de Ciência e Tecnologia.

O objectivo principal desta rede era o de gerar sinergias entre grupos de investigação, criar equipas com capacidade competitiva, com credibilidade e dimensão suficiente para aproveitar correctamente fundos europeus destinados ao desenvolvimento da região Alentejo.

Em 29 de Outubro de 2008 nasceu a Rede Regional de Ciência e Tecnologia do Alentejo – RRCTA, através da assinatura de um memorando de entendimento por parte de 23 instituições de I&DT do Alentejo.

O grande objectivo que dominou desde o início as actividades da RRCTA foi a preparação de uma candidatura conjunta aos programas Sistema de Apoio a Infra-estruturas Científicas e Tecnológicas e Sistema de Apoio a Parques de Ciência e Tecnologia (QREN regional). Ao longo de 2009 foi-se estruturando uma proposta de plano estratégico que reuniu em torno do mesmo objectivo a maioria das unidades de investigação e centros tecnológicos do Alentejo. Este plano visava a criação de um Parque de Ciência e Tecnologia do Alentejo (PCTA) descentralizado, multipolar, com a sede em Évora e com pólos em Beja, Portalegre, Santarém, Sines e Elvas. A solução encontrada procurou evitar a duplicação de valências entre os vários pólos, criando-se nalguns domínios, laboratórios centrais de uso comum, em Évora, disponíveis a todas a equipas da Rede. A estrutura final, acordada para este Parque descentralizado, não era perfeita mas foi o compromisso possível que permitiu reunir em torno de um mesmo projecto, 21 instituições que assinaram o Contrato de Consórcio para a criação e desenvolvimento do Parque de Ciência e Tecnologia do Alentejo e, no final de Setembro, foi submetida na plataforma electrónica do Inalentejo uma primeira candidatura, liderada pela Agência de Desenvolvimento Regional do Alentejo (ADRAL).

Seguiu-se um período de alguma indefinição relacionado com alterações na equipa do Inalentejo e com a mudança da equipa reitoral na Universidade de Évora. Em Abril de 2010 o Inalentejo informa que o modelo de Parque apresentado na candidatura de Setembro do ano anterior foi considerado demasiado descentralizado e que a proposta tinha que ser reformulada no sentido de centralizar mais em Évora as suas principais infra-estruturas.

Nos meses seguintes o projecto foi reformulado e em Setembro de 2010 foi submetido novo documento ao Inalentejo. Em Dezembro desse ano é aprovado o Sistema Regional de Transferência de Tecnologia – SRTT (anteriormente RRCTA).

No âmbito deste vasto projecto, o CGE propôs a criação de um Laboratório de Ciências e Tecnologias da Terra Atmosfera e Energia (LCTTAE) integrado no conjunto das propostas da Universidade de Évora. O CGE liderava 3 unidades dessa proposta a instalar nos espaços do PCTA mas o LCTTAE englobava ainda outras duas unidades, a Unidade de Ciências do Mar (CIEMAR) e a Unidade de Água e Biogeoquímica Ambiental, que se candidataram autonomamente tendo em vista a requalificação de espaços laboratoriais já existentes.

No seu conjunto o projecto LCTTAE pretende constituir-se como um laboratório em rede dedicado ao desenvolvimento de investigação fundamental e aplicada nos vários domínios das Ciências da Terra (Terra Sólida, Atmosfera, Hidrosfera e suas interacções com a Biosfera), garantindo uma abordagem integrada de problemas relacionados com a extracção e aproveitamento de recursos, com o uso dos solos e da água, com os recursos energéticos e com outros problemas ambientais.

As unidades directamente lideradas pelo CGE eram nesta fase de candidatura designadas por:

- Unidade de Detecção Remota, Imageologia, Informação Geográfica e Modelação Numérica;
- Unidade de Desenvolvimento e de Calibração de Instrumentação Ambiental;
- Unidade Observatório e Laboratório de Geofísica Interna.

Com a aprovação do SRTT o Inalentejo cativou um orçamento FEDER de 1.892.000 euros destinado a estas três unidades (correspondente a 70% do investimento total, de acordo com a regulamentação em vigor a essa data).

A fase seguinte, inicialmente prevista até 31 de Dezembro de 2011, consistia na submissão ao Inalentejo dos projectos de detalhe de cada uma das operações previstas no Plano do SRTT e na assinatura da escritura da Sociedade Parque de Ciência e Tecnologia do Alentejo.

Nesta nova fase o projecto LCTTAE passou a integrar uma nova valência na área da energia solar, incorporando uma iniciativa da Cátedra BES – Energias Renováveis. Esta nova valência, além do seu interesse científico, representava uma garantia de associação a um importante conjunto de empresas, através do Instituto Português de Energia Solar (IPES). O LCTTAE iria instalar-se num edifício próprio no terreno do PCTA e as três unidades lideradas pelo CGE passaram a designar-se:

- Unidade de Avaliação de Recursos Ambientais e Energéticos;
- Unidade de Desenvolvimento e Calibração de Instrumentação Ambiental e de Energia;
- Unidade de Geofísica Interna e Geotecnologia.

Com o trabalho quase concluído, em 30 de Novembro de 2011 a Reitoria convocou os responsáveis pelas operações da Universidade de Évora destinadas a instalarem-se no PCTA para uma reunião com o objectivo de reordenar a utilização dos espaços previstos no Parque. Por limitações orçamentais relacionadas com a construção dos espaços laboratoriais, o projecto arquitectónico iria ser alterado e reduzido. A área prevista para construção foi reduzida e todas as equipas tinham agora que se adaptar a espaços mais modestos, passando os laboratórios destinados às candidaturas da Universidade a ocupar um único edifício. Em simultâneo, o SRTT estava a negociar com o Inalentejo um alargamento do prazo para a entrega das candidaturas, agora até 30 de Junho de 2012.

Seguiu-se um período em que as várias equipas da UÉ trabalharam na organização e ocupação de um único edifício onde seriam albergados todos os laboratórios. As áreas inicialmente previstas foram reduzidas e identificaram-se espaços de uso comum a vários projectos. No final de Abril surge um primeiro esboço do projecto arquitectónico desse edifício.

Em Maio o financiamento global a que cada equipa se podia candidatar fica definido de forma aparentemente definitiva, a candidatura LCTTAE é ultimada com base nesses últimos valores de referência mas, a meio de Junho, a Universidade é informada que o governo procedeu a uma reprogramação do QREN, a qual atingiu os programas operacionais para o Alentejo, implicando uma redução substancial das verbas disponíveis.

Em face da nova situação, a Universidade foi obrigada a adiar para o próximo quadro comunitário de apoio, a construção do complexo laboratorial do PCTA. Algumas das operações foram mesmo integralmente adiadas para 2014. No que se refere ao projecto LCTTAE, foi decidido avançar-se com uma proposta para aquisição da maioria dos equipamentos anteriormente previstos, os quais serão instalados provisoriamente em espaços da Universidade de Évora.

A operação LCTTAE foi finalmente lacrada no dia 28 de Junho de 2012, envolvendo um financiamento global de 2.214.980,21 €, sendo a parcela FEDER de 1.761.313,36 € (aproximadamente menos 7% que o financiamento previsto em 2010).

Passados mais de quatro anos sobre a primeira reunião que levou à criação da RRCTA, na página Web do Inalentejo pode ler-se:

A Sessão de Assinatura dos contratos de financiamento que assinala positivamente a implementação dos projectos integrados no SRTT – Sistema Regional de Transferência de Tecnologia, contou com a presença do Senhor Secretário de Estado Adjunto da Economia e do Desenvolvimento Regional, Dr. António Almeida Henriques, e teve lugar no dia 12 de Novembro, pelas 11,00 horas, no Colégio do Espírito Santo da Universidade de Évora.

Passados estes quatro anos há finalmente "fumo branco", o financiamento solicitado para a operação LCTTAE foi aprovado na íntegra. Esperamos que não surjam novos percalços, novas dificuldades que voltem a retardar ou prejudicar a concretização deste importante projecto que terá certamente repercussões muito positivas para o desenvolvimento económico regional e com inegável interesse científico e tecnológico a nível nacional e mesmo internacional. Esperamos que no âmbito do próximo quadro comunitário de apoio, a partir de 2014, seja possível completar o financiamento inicialmente previsto, para que o LCTTAE não venha a ser mais um exemplo de um projecto que se torna "provisoriamente definitivo", como infelizmente há tantos exemplos em Portugal. A solução agora encontrada passa pelo recurso a instalações já existentes na Universidade de Évora, tornando possível a realização dos objectivos previstos para a actividade do LCTTAE, mas a concretização desta segunda fase de candidatura permitirá optimizar a utilização destes equipamentos e recursos, potenciando os seus resultados operacionais.

TERRA SÓLIDA

SOLID EARTH

VIAGEM AO INTERIOR DA TERRA

MOURAD BEZZEGHOUD
Departamento de Física e Centro de Geofísica de Évora, Universidade de Évora
Évora, Portugal, mourad@uevora.pt

Mais de 200.000 terramotos são registados e localizados à escala mundial cada ano. A monitorização sísmica à escala global, regional e local fornece informação que permite compreender a ocorrência dos sismos e, portanto, permite cartografar as regiões de alto e baixo risco sísmico. Densificação de redes sísmicas e técnicas avançadas da análise sísmica facilitaram a descoberta do até então desconhecidos fenómenos sísmicos (sismos lentos, ruptura sísmicas múltiplas e, velocidade de ruptura supersónica), que vieram iluminar a física dos terramotos. A monitorização sísmica permanente, portanto, fornece informações fundamentais para um melhor conhecimento do interior da Terra e para a avaliação do risco sísmico e a engenharia sísmica.

1 Introdução

A *Sismologia* trata do estudo da atividade das forças físicas responsáveis pela origem dos sismos (ou terramotos) e da propagação das vibrações (ondas sísmicas) geradas por eles. Baseia-se na análise do sinal sísmico e nas características das ondas sísmicas. Todas as estruturas localizadas desde o centro da Terra, até a sua superfície são objecto de estudo desta disciplina. Pode pois considerar-se que a *Sismologia* estuda os terramotos e a estrutura interna da Terra utilizando as ondas sísmicas.

A Terra é o nosso habitat natural. O ser humano e o desenvolvimento económico e social dependem dos recursos do planeta. De facto, a gestão que deles se fizer neste inicio de século XXI será determinante dado que os recursos do planeta não são inesgotáveis; só a sua exploração moderada e racional permitirá que a Terra seja capaz de albergar e sustentar os 10 mil milhões de seres humanos que, calcula-se, será a população no final do século XXI. Em consequência, o conhecimento e a compreensão do funcionamento do nosso planeta são prioritários para que a vida, e a nossa sociedade, se desenvolva de maneira harmoniosa e duradoura. Resta-nos como última escolha e única alternativa o ensinar à nova geração o que é a Terra.

Depois de dominar os conhecimentos físicos como a gravidade (Issac Newton, 1687), o electro-magnetismo (James Clerk Maxwell, 1865) e a propagação das ondas sísmicas (John William Strutt[1], 1887) mas também de ser capaz de realizar observações precisas de diversas grandezas físicas à superfície da Terra, desenvolveu-se uma nova ciência: a Geofísica ou Física da Terra[2]. No século XX, a aquisição de uma quantidade impressionante de observações e de informações foram possíveis devido ao progresso da electrónica e da informática.

Embora a Terra gire à volta do Sol há 4.6 mil milhões de anos, o nosso conhecimento do seu interior era ainda rudimentar no início do século XX. Este atraso

[1] Mais conhecido como Lord Rayleigh
[2] Termo introduzido pela primeira vez por Franz Ernst Neumann (1798 - 1895): “Physik der Erde” (Física da Terra). Mineralogista, Físico e Matemático Alemão.

era significativo quando comparado com o conhecimento sobre o infinitamente pequeno (descoberta da radioatividade por Antoine Henri Bequerel em 1896; identificação do electrão por Joseph John Thomson em 1897; formulação da teoria dos quanta por Max Planck e Niels Bohr em 1900) e infinitamente grande (teoria da gravitação por Isaac Newton em 1687; fundamentos da mecânica celeste por Pierre Simon Laplace em 1799; formulação da teoria da relatividade geral por Einstein em 1916). O conhecimento do interior da Terra é uma obra do século XX: em 1987 John Milne (1850-1913) identificou a crusta, Lord Rayleigh, Lord Rutherford e Emil Wiechert[3] o manto; o limite entre a crusta e o manto foi definido por Andrya Mohorovicic em 1909 (descontinuidade de Mohorovicic ou o *Moho*); em 1906, o notável trabalho de Oldham determinou a dimensão do núcleo externo terrestre (trabalho a que a comunidade científica não prestou qualquer atenção); Beno Gutenberg (1889-1960), em 1912 na sua tese de doutoramento [1, 2, 3], delimitou de forma ainda mais precisa o limite entre o núcleo externo e o manto. Esta interface entre a astenosfera e a endosfera é chamada *Descontinuidade de Gutenberg*; em 1926, Sir Harold Jeffreys (1891-1989) [4, 5], descobriu que o núcleo externo é líquido; em 1936 Inge Lehman (1888-1993) [6], com o célebre PKP forneceu a chave para a identificação do núcleo interno terrestre; núcleo interno que, em 1946, é identificado como sólido por Keith Edward Bullen (1906–1976) [7]. Em 1935, H. Jeffreys e K. E. Bullen publicaram as famosas tabelas de tempo de percurso das ondas sísmicas que levam os seus nomes (tabelas de Jeffreys-Bullen, JB) e que serviram de referência para os sismólogos e geofísicos durante meio século [8]. Todas as descobertas sobre a estrutura da Terra, antes enunciadas (de John Milde à K. E. Bullen), basearam-se no estudo dos terramotos e da propagação das ondas sísmicas. Há também que sublinhar um dos grandes passos dados para o conhecimento da geodinâmica interna deve-se ao irlandês Robert Mallet (1810-1881) [9] e aos franceses, Alexis Perrey (1807-1882) [10] e o conde Fernand Jean Batiste Marie de Montessus de Ballore (1851-1923) [11, 12] que dedicaram parte significativa dos seus trabalhos à recolha de informações referentes a sismos ocorridos em todo o Planeta. A descoberta revolucionaria da expansão dos fundos oceânicos por Drummond Hoyle Matthews e o seu estudante Fred J. Vine no inicio da década de 1960 [13] confirmou a teoria de Alfred Wegener (1880-1930) publicada e comunicada em 1912 [14], altamente controversa para a época.

A Terra é um sistema complexo e de observação difícil, só as respostas obtidas pela Física da Terra Sólida permitem um bom conhecimento do interior do nosso planeta. Recentemente, no ano de 1968, foi proposto e aceite um modelo dinâmico e unificador que no essencial se ajustava às observações até então realizadas. É o modelo da tectónica das placas[4], cuja génese demorou mais de trinta anos. Foram as interrogações de Wegener, colocadas em 1915, que o conduziram a uma reflexão sobre a mobilidade dos

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[3] Físico alemão, co-fundador e director do primeiro Instituto Geofísico.

[4] Teoria da tectónica das placas: teoria da extensão do fundo oceânico (*sea floor* spreading), resultado dos trabalhos de geologia marina de H. Hess e seus colegas publicado em 1962. O nome sea floor spreading foi proposto, em realidade, pelo geólogo R.S Dietz, que estudo com os seus colegas H. Menar, M. Ewing e B. Heezen o fundo dos oceanos nos anos 50.

continentes, na época os opositores mais duros foram os físicos ao demonstrarem que era impossível deslocar fisicamente tais massas continentais. Embora o motor, associado à rotação da Terra, proposto por Wegener fosse pouco credível, quarenta anos mais tarde, observações irrefutáveis, tal como a inversão da magnetização da crusta oceânica antes referida, conduziram à emergência da noção de placas litosféricas e ao seu movimento efetivo determinado por processos geodésicos.

2 Fundamentos

Os tópicos fundamentais abordados pela *Sismologia* podem ser resumidas do seguinte modo:
a) **Estudo da fonte sísmica**. A partir dos registos sísmicos gerados pelas ondas, são obtidas informações sobre a fonte sísmica, incluindo a sua magnitude, localização, duração, profundidade, sua orientação e o seu processo de ruptura ao longo da falha. Uma análise mais detalhada fornece informações sobre as tensões distribuídas ao longo das falhas e as deformações associadas à superfície.
b) **Estudo da estrutura interna da Terra ou tomografia sísmica**. As ondas telesísmicas (ondas provenientes de sismos distantes) fornecem informações sobre a estrutura interna da Terra (crosta, manto e núcleo). Os terramotos profundos fornecem informações sobre a estrutura do manto superior, enquanto os sismos superficiais fornecem informações detalhadas sobre as falhas ativas e a estrutura da crosta.
c) **Sismologia experimental**. As ondas sísmicas induzidas (geradas) por explosões controladas são utilizadas para cartografar a estrutura da crosta terrestre.
d) **Movimentos fortes e risco sísmico**. A *sismologia* relacionada com os movimentos fortes usa as ondas geradas por sismos de forte magnitude para um estudo detalhado da fonte sísmica, prever a aceleração do próximo movimento, estabelecer códigos para uma construção segura e melhorar o design da engenharia sísmica.

3 Sismologia, Ciência dos terramotos

A palavra *sismologia* tem como origem duas palavras gregas *seismos*, agitação ou movimentos rápidos ou tremores, e *logos, ciência: sismologia = ciência dos sismos ou terramotos.* A palavra terramoto resulta, também de duas palavras mas de origem latinos *terrae*, terra, e *motus*, agitado: *terrae motus = agitação da terra.* O termo *sismologia* começou a ser utilizado em metades do século XIX. Para os gregos, a palavra meteoros incluía os estudos dos cometas e de todos os fenómenos de superfície, que hoje em dia constituem a meteorologia, como a chuva, os ventos, os trovões, etc., mas curiosamente incluía também os terramoto s e as erupções vulcânicas, cujo estudo pertence atualmente a outras ciências.

A causa dos terramotos foi explicada pela primeira vez pelos filósofos gregos. Um deles, Aristóteles propôs que a causa dos terramotos consiste na agitação da terra, devido aos vapores ou ventos subterrâneos presos no seu interior, que tentam de sair para a superfície. Evidentemente, nesta explicação relacionam-se os terramotos s e os vulcões.

Esta primeira teoria foi aceite pelos romanos e foi mantida no ocidente, com ligeiras mudanças, até o século XVII. Uma segunda teoria (M. Lister e N. Lesmery), descrevendo que os terramotos são devidos às explosões produzidas por acumulação de material inflamável no interior da terra, surgiu entre finais do século XVII e inicio do século XVIII. Esta teoria foi aceite por Newton e Buffon.

Em 1 de Novembro de 1755, pelas nove e quarenta e cinco da manhã, os habitantes de Lisboa começaram a sentir, com espanto e angústia, que o chão lhes tremia por debaixo dos pés. O terramoto de Lisboa causou a destruição desta cidade e produziu um maremoto (ou tsunami) e foi sentido a grandes distâncias. Para além do seu valor político e estatístico, o inquérito do Marques de Pombal de 1756 (Informações Paroquiais) tem um relevante alcance científico, marcando, na opinião abalizada de Fernand Montessus de Ballore, um passo decisivo no nascimento da *Sismologia* moderna.

A primeira associação entre terramoto e propagação de ondas elásticas no interior da terra foi feita em 1760 por J. Mitchell e a seguir a mesma ideia foi desenvolvida por T. Young e J. Milne, respectivamente em 1807 e 1841.

Em 1696 foi realizado, por J. Zahn, o primeiro catálogo sísmico mundial, muito antes do terramoto de Lisboa (1755). Mas os catálogos modernos começaram a serem publicados só a partir de 1850 com os trabalhos de R. Mallet e A. Ferrey, o que constituiu a base da *Sismologia* moderna. R Mallet desenvolveu a teoria da fonte sísmica e da propagação das ondas sísmicas no interior da terra e em todas as direções e relacionou a ocorrência do terramoto com a do processo de ruptura dentro da crosta terrestre. No inicio do século XX, F. Montessus de Ballore e A. Sieberg atribuíram a causa dos terramotos aos processos tectónicos, tendo contribuído para o desenvolvimento da *Sismologia*. Na primeira metade do século XIX, foram utilizados os primeiros sismómetros com registos contínuos baseados num sistema pendular desenvolvidos por J. Milne, F. Omori (1868-1923), E. Wiechert, B.B. Galitzine e H. Benioff. Os primeiros modelos do interior da Terra, baseados em dados sísmicos, foram propostos entre 1914 e 1939, por B. Gutenberg, H. Jeffreys, K. Bullen, e J. Macelwane.

A partir de 1950 até os dias de hoje, houve um grande desenvolvimento tecnológico da *Sismologia* que será descrito no inicio de cada capítulo. Serão detalhados todos os capítulos da disciplina de uma maneira orientada e sucinta.

A subdivisão da *Sismologia* nas suas três vertentes essenciais se apresenta como segue: 1) sismologia fundamental (teórica e de observação), 2) prospecção sísmica ou sismologia experimental e 3) engenharia sísmica. A sismologia teórica, que é uma aplicação da mecânica dos meios contínuos, em particular, da teoria de elasticidade ao fenómenos relacionados com a ocorrência dos terramotos. Considera-se também o estudo do mecanismo focal responsável pela geração dos sismos e o da propagação das ondas sísmicas no interior da terra.

O estudo dos terramotos e da estrutura da Terra exigem a cooperação entre investigadores a nível nacional e internacional. A constituição de redes de observação, de grupos de trabalhos nacionais e internacionais, de organizações nacionais e internacionais e de consórcios foram, e continuam a ser, fundamentais para o avanço da *Sismologia*. Há que recordar a primeira organização, de âmbito nacional (*Sociedade Sismológica do Japão*), que foi criada depois do sismo de 1880. A seguir foram criada várias organizações nacionais (ex: Itália, 1895; USA, 1906) e a primeira organização internacional foi criada em 1904 (*Associação Internacional de Sismologia*) que deixou de existir em 1916 para se transformar em *União Internacional de Geodesia e Geofísica* (IUGG) em 1919. Mais tarde em 1951 foi criada a *Associação Internacional de Sismologia e Física do Interior da Terra* (IASPEI). Em Portugal, só nos anos 30-40 do século XX temos conhecimento da efémera existência, em Coimbra, da *Sociedade de Meteorologia e Geofísica de Portugal* (SMGP) cujo rasto se perdeu após a criação do Serviço Meteorológico Nacional (SMN), em 1946. Em 1995, perante a sua inexistência e necessidade, um grupo de meteorologistas desencadeou o projeto de recriar uma associação científica e técnica de meteorologia e de geofísica, atendendo à tradicional "proximidade" destas duas áreas e as correspondentes atividades no país. Em 25 de Novembro de 1996 foi celebrada a escritura notarial de constituição da APMG - *Associação Portuguesa de Meteorologia e Geofísica* que iniciou as suas atividades, após a eleição dos primeiros órgãos sociais, em 2 de Abril de 1997. No âmbito das reuniões científicas a APMG organizou alguns colóquios e levou a efeito, até à data, com assinalável êxito e muitos participantes dos dois países ibéricos, 7 encontros científicos (1998, 2001, 2003, 2005, 2007,2009, 2011)[5]. Mas, há de salientar que Raúl Miranda, Professor de Geologia da Universidade de Coimbra e Diretor da revista (irregular) A "terra"[6] publicou, entre 1930 e 1960, vários textos interessantes relacionados com a Sismologia[7] e que podem ser consultados na Biblioteca da Universidade de Coimbra[8].

4 Propagação das ondas sísmicas

Os fundamentos da *Propagação das ondas sísmicas* baseiam-se na Mecânica dos Meios Contínuos e, particularmente, na teoria da elasticidade.

A *Sismologia* estuda os tremores de Terra e a propagação das vibrações (ondas sísmicas) geradas por eles, baseia-se na análise do sinal sísmico e nas características das

[5] O próximo encontro é previsto para Março de 2013

[6] A terra : Revista de Sismologia e Geofísica, 1932 / Diretor e Editor Raúl de ". (ver também o artigo de Ferreira e Fitas, neste mesmo volume)

[7] - Miranda, Raúl de, Carácter sísmico de Portugal Continental no decénio de 1923-1932. Coimbra : [s.n.], 1933. 32p. Comunicação apresentada à V.a Assembleia geral da União Internacional Geodésica e Geofísica, realizada em Lisboa, em Setembro de 1933.
- Miranda, Raúl de, A cortiça, como material orgânico e elástico a aplicar nas construções anti-sísmicas. Coimbra : [s.n.], 1959. 10 p.
- Miranda, Raúl de, Introdução à sismologia. Lisboa : Cosmos, imp.1942. 124, [1] p. (Biblioteca Cosmos ; Nº 30. 1ª Secção, Ciências e Técnicas ; Nº 13 : Ciências da Natureza).
- Miranda, Raúl de, A origem dos sismos de Angola, em face das novas teorias geológicas e geofísicas de Dingemans. Coimbra : [s.n.], 1957. 9 p. Publicações do XXIII Congresso Luso-Espanhol, tomo 3.
- Miranda, Raúl de, Tremores de terra em Portugal : 1923-1930. Coimbra : Instituto Geofísico da Universidade de Coimbra, 1930. 60 p.
- Miranda, Raúl de, Tremores de terra : estudo macrosísmico. Coimbra : Silva Raposo & CaL.da, 1931. 175p.
- Miranda, Raúl de, Tremores de terra : I-estudo macrosismico. Coimbra : [s.n.], 1931. 175 p.
- Miranda, Raúl de, A vida da terra. Coimbra : Ed. da revista "Minerva", 1930. 41 p.

[8] http://webopac.sib.uc.pt/

ondas sísmicas internas (ou volúmicas) e superficiais. Quando se considerar a Terra como um meio elástico deduz-se a equação de equilíbrio de um material elástico sujeito a deformações infinitesimais, obtendo-se a *equação das ondas elásticas*.

Já, no século XVIII, R. Hook relacionou tensões e deformações e J. Bernoulli, D. Bernoulli, L. Euler e J. L. Lagrange estudaram as equações das vibrações, tendo T. Young (séc. XVIII-XIX), introduzido o coeficiente de elasticidade que tem o seu nome. No fim do século XVIII e ao longo do século XIX, o desenvolvimento dos domínios da física e matemática, permitiram avanços fundamentais na teoria de elasticidade, designadamente as que se ficaram a dever os trabalhos desenvolvidos por de C. L. Navier, A. L. Gauchy, S. D. Poisson, G. Lamé, G. Green, G. G. Stokes e Rayleigh. É em 1889 que, pela primeira vez, foi relacionado um sismo ocorrido no Japão e o movimento do solo registado a milhares de quilómetros de distância, em Potsdam: demonstrou-se a propagação das ondas sísmicas à escala global e nascia assim a *Sismologia* moderna. Para estas grandes distâncias, o deslocamento do solo não é perceptível diretamente pelos sentidos, ao contrário, do que acontece na zona epicentral, onde ocorre o sismo, cuja destruição pode atingir algumas centenas de quilómetros. A ruptura, responsável pelas ondas e pela destruição associada, é produzida quando a tensão acumulada na crusta terrestre ultrapassa o nível crítico da resistência do material, tal como um elástico que lentamente é esticado e inexoravelmente acaba por romper num momento dificilmente previsível. No princípio do século XX, o grupo de E. Wiechert, constituído por K. Zoppritz, B. Guntenberg e L. Geiger, aplicou, pela primeira vez, a teoria de elasticidade às ondas geradas pelos terramotos. Há de referir que os métodos de reflexão e refracção, desenvolvidos pela *Sismologia*, são muito utilizados em prospecção e geotecnia para o conhecimento da estrutura do subsolo.

5 Anatomia do interior da Terra

A estrutura interna da Terra é caracterizada por descontinuidades evidenciadas, claramente, pela variação das ondas internas em função da profundidade. Há que referir que um aumento brusco da velocidade V_P (de 6.9 kms/s a 8.2 kms/s) na base da crusta, situada a 10 kms (crusta oceânica) ou a 30 kms (crusta continental) de profundidade, caracteriza a chamada *descontinuidade de Mohorovičić*[9]; uma queda brusca da velocidade V_P (de 13.6 a 8.1 kms/s), caracteriza o limite inferior do manto situado entre 2890 e 2870 kms de profundidade; um forte aumento da velocidade V_P (de 9.5 kms/s à 11.2 kms/s) evidencia o núcleo externo à profundidade de 5100 kms. Estas descontinuidades, mais importantes, são as que limitam a *crusta*, o *manto*, o *núcleo externo e* o *núcleo interno*.

[9] S. A Mohorovičić (1857-1936) realizou em 1909 os primeiros estudos sismológicos sobre a crosta terrestre e observou que os tempos de chegada das ondas geradas pelos sismos locais em Europa Central mostravam uma variação a partir dos 150 km de distância e assim foi evidenciada uma descontinuidade de velocidade a 30 km de profundidade, correspondendo a base da crosta.

A crusta continental é posta em evidência através da análise da propagação das ondas geradas pelos sismos próximos, pela prospecção sísmica ou pela sismologia experimental (sismologia baseada sobre tiros experimentais). Muitos pormenores sobre a constituição da crusta foram alcançados a partir de perfis sísmicos localizados e informações resultando de furos que atingem até 9 kms de profundidade. O conhecimento sobre a crusta está hoje em dia bem avançado. A crusta continental constituída principalmente de granito, tem uma velocidade das ondas *P* aproximadamente de 6.2 kms/s. Esta velocidade é atribuída às ondas refractadas *Pg* (ou cónicas) que se propagam debaixo do limite superior da crusta granítica. A sua espessura média é de 30 kms mas atinge os 40 ou 50 kms debaixo das montanhas; em particular no Himalaia (Hindukuch) onde a espessura da crusta continental atinge os 70 kms. Em Portugal continental a crusta tem uma espessura cerca de 30 kms.

A crusta oceânica é constituída por uma camada de sedimento por baixo da qual existe outra camada basáltica onde a velocidade das ondas *P* varia entre os 6.4 e 6.9 kms/s. A espessura da crusta é de 10 kms abaixo da superfície do oceano e em alguns caso pode atingir cerca de 5 kms de espessura.

As ondas cónicas *Pn* que viajam no limite superior do manto com uma velocidade de 8.2 kms/s. Algumas anomalias de velocidades foram detectadas, no manto superior, a partir de explosões nucleares subterrâneas (Ilhas Aleucianas, Nevada nos Estados Unidos, Sahara em Argélia). Uma dessas anomalias foi determinada a 100 kms de profundidade onde foi observada uma fraca diminuição da velocidade das ondas *P* e *S*. Outra foi observada a uma profundidade 700 kms através de um aumento rápido da velocidade.

O núcleo externo é evidenciado, claramente, com o desaparecimento das ondas *S* na zona de sombra (entre 105^o e 143^o). No Limite Manto-Núcleo a velocidade das ondas *P* baixa subitamente de 13.6 kms/s para 8.0 kms/s enquanto a das ondas S baixa de 7.3 kms/s para 0 kms/s; i.e as ondas S não atravessam o núcleo externo. As ondas refractadas que atravessam uma vez o núcleo externo são chamadas PKP. Mas existe percurso mais longo como por exemplo a onda chamada PKIKP. Foi a partir da PKIKP que o núcleo interno[10] foi posto em evidência. A profundidade do núcleo interno foi medida através da onda reflectida no LNENI chamada PKiKP. Através da identificação das fases dos sismogramas de um conjunto de distâncias fonte-estação, os sismólogos constroem tabelas e curvas de tempos de propagação para a maior parte das fases e delas inferir as velocidades de propagação das ondas sísmicas nas diversas estruturas que compõem o modelo terrestre. Esse trabalho foi desenvolvido na primeira parte do século XX e completado por Jefferys e Bullen (1958) que elaboraram as conhecidas tabelas JB, a origem das tabelas ainda hoje usadas, com as quais se podem construir diagramas de tempos de percurso.

A *Sismologia* é uma ciência apenas centenária mas modificou profundamente o nosso conhecimento do interior da Terra. Os perfis radiais de velocidades sísmicas e da densidade no interior da Terra são conhecidos agora com precisões superiores a 1%. As

[10] O núcleo interno foi descoberto em 1936 pela sismóloga dinamarquesa Inge Lehmann.

imagens obtidas, hoje em dia, do interior da Terra são espetaculares. Tais resultados são o fruto da "tomografia sísmica", ferramenta poderosa da *Sismologia* desenvolvida desde os anos 1980, o que constitui uma espécie de raios X do interior da Terra.

6 Conceitos físicos

A origem dos sismos está associada à libertação de energia acumulada durante anos, ou milhares de anos, na forma de energia gravítica, química e elástica. Esta energia é libertada subitamente (segundos) e provoca o tremor de Terra. O fenómeno conhecido por terramoto é, porventura, o evento natural mais violento com que o homem se confronta desde sempre e consequentemente o que maior curiosidade lhe suscita. O testemunho desse interesse está na profusão de alusões ao fenómeno, manifestações de culto e interpretações que nos chegaram através de documentos históricos, alguns verdadeiramente bizarros no contexto atual. Por curiosidade e por estar diretamente relacionado com o terramoto de Lisboa de 1755, hoje considerado o marco na história da sismologia científica [15], Voltaire caricaturou a posição oficial da ciência ao descrever, no seu livro *Cândido*, a chegada de dois ilustres viajantes a Lisboa no dia da catástrofe[11].

Foram R. Mallet e R. D. Oldham que, pela primeira vez, propuseram que os sismos são produzidos num foco pontual (o primeiro depois de estudar o sismo de Nápoles (Itália) de 1857 e o segundo o de Assan (Índia)). Contribuíram assim para mostrar a sua relação com as falhas. Em 1875, E. Suess propôs que os sismos são gerados pelo movimento relativo e oposto dos dois blocos de uma falha. Mas com o desenvolvimento do conhecimento científico dos últimos séculos estas crenças mudaram profundamente e atualmente, tanto os terramotos como as suas propriedades mais comuns são completamente explicados através de modelos procedentes dos últimos desenvolvimentos da física e da matemática com o apoio da tecnologia. O confronto de algumas propriedades dos sismos ocorridos numa zona sismogénica bem monitorizada, região da Califórnia nas proximidades da falha de Santo André, com os resultados decorrentes da utilização da máquina revela-nos analogias de tal maneira próximas donde podemos inferir a eficácia do modelo. Os primeiros passos dados no sentido do estabelecimento de uma teoria física explicativa das causas imediatas do fenómeno sísmico foram dados por H. Reid [16]. As suas conclusões basearam-se em observações de carácter geodésico,

[11] (…) Apenas puseram os pés na cidade, chorando a morte do seu benfeitor, sentem a terra tremer debaixo dos pés, o mar agitou-se mesmo dentro do porto a despedaçar os barcos ancorados; turbilhões de chamas e cinzas cobrem as ruas e as praças públicas; as casas desmoronam-se, os tectos esboroam-se (…) – Este tremor de terra não é novidade nenhuma respondeu Pangloss. – A cidade de Lima aguentou as mesmas sacudidelas, na América, o ano passado: mesmas causas mesmos efeitos. Há certamente um rastro de enxofre subterrâneo desde Lima até Lisboa (…) Sustento que o facto está demonstrado! (…)
Após o tremor de terra que destruíra a três quartos de Lisboa, os sábios do país cogitaram em que o meio mais eficaz de prevenir a ruína total da cidade consistia em dar ao povo um rico auto de fé. Fora decidido pela Universidade de Coimbra que o espetáculo de várias pessoas queimadas a fogo lento, com grande cerimonial, era um segredo infalível para impedir a terra de tremer. (…) Nesse dia a terra voltou a tremer com fragor espantoso.

geológico e geofísico, realizadas antes e depois do sismo da Califórnia de 1906 e conduziram à formulação da teoria do *Ressalto Elástico*, às vezes também chamada por modelo do ressalto elástico.

Dez anos após a apresentação da teoria de H. Reid, sismólogos japoneses observaram uma regularidade na distribuição do sentido do primeiro movimento (polaridade da onda P) nas estações que rodeiam o sismo: esta regularidade consiste numa distribuição de polaridades por quatro quadrantes, alternadamente positivos e negativos (compressões e dilatações); a separação dessas polaridades é feita por dois planos ortogonais entre si: surge assim o conceito de plano nodal, introduzido por Nakano [17].

O *modelo de forças equivalentes* constituído por dois pares de forças orientados em direções ortogonais (*double couple model:* e.g. [18, 19]) mostre que o efeito do conjunto das forças reais que atuam numa fonte pontual é equivalente ao de um par de forças aplicado na fonte. As equações de onda decorrentes deste modelo são lineares e ajustam-se razoavelmente ao padrão da radiação verificado para as ondas P representado, e.g. [20, 21].

A dificuldade que enfrenta a mecânica dos sismos deve-se à profundidade a que a fractura se produz. Por isso o fenómeno de ruptura nunca foi, e não pode ser, diretamente observado. Esta inacessibilidade se por um lado constitui um obstáculo à compreensão da mecânica dos sismos, por outro lado deixa livre o caminho da imaginação e daí a diversidade de modelos propostos. Existe outra dificuldade que se relaciona com a dualidade temporal do fenómeno: primeiro tempo – uma falha (pré-existente) sossegada durante milhares ou dezenas de milhar de anos acumula tensão; segundo tempo – de repente e inesperadamente rompe acompanhado de uma queda de tensão) libertando em escassos segundos, grande parte de energia acumulada. É este último tempo que é considerado nos modelos de ruptura.

Os modelos de *fonte sísmica* são representados por dois tipos de modelos mecânicos que descrevem o fenómeno físico da fractura: cinemáticos e dinâmicos. Nos modelos cinemáticos o campo de *deslocamento* obtém-se diretamente do vector de deslizamento da fractura em função das coordenadas da fractura e do tempo, sem considerar o estado das tensões. Nos modelos dinâmicos calcula-se o deslocamento da ruptura a partir do estado das tensões atuando na região focal. Apresenta-se também a descrição dos modelos de *fontes finitas* (ou pontual) e *extensos* necessários à modelação das zonas sismogénicas. Essas modelações podem ser conseguidas a partir de diferentes modelos de ruptura. Dois desses modelos cinemáticos são aqui destacados e descritos, por serem fundamentais: modelo de falha rectangular de [22] e o de falha circular de [23]. É sabido que estes modelos simples não explicam da melhor forma os sismos complexos, isto é, aqueles que devido a sua grandeza não cabem na categoria dos modelos acima referidos.

Para situações de rupturas marcadamente unilaterais, e de acordo com o previsto pelo efeito Doppler, a análise sistemática das mesmas fases num conjunto de registos sísmicos de estações distribuídas azimutalmente em relação ao epicentro revela variações que dependem da posição da estação é chamado efeito de diretividade [24].

Os grandes sismos alteram a topografia da Terra e por consequência provocam graves estragos nas construções humanas: edifícios, pontes, barragens...e às vezes cidades são totalmente destruídas. Ao longo da história da sismologia, varias *escalas de intensidades* foram utilizadas para avaliar a "força" dos sismos. Esta avaliação depende não só da intensidade do sismo mas também da resistência das construções e da acuidade do observador. Por isso, o valor de intensidade atribuído localmente pelo observador é subjetivo. Por outro lado, a escala de intensidade é importante para avaliar as dimensões dos sismos, em particular dos sismos históricos. O primeiro físico a avaliar os sismos foi o italiano *Domenico Pignataro* nos anos 1783-1786. O segundo foi o irlandês Robert Mallet no século IXX. O engenheiro R. Mallet produziu uma lista de 6831 sismos classificados segundo uma escala de 4 classes para descrever os estragos (4 graus). No fim do século IXX, apareceu a escala dita de *Rossi-Forel*[12] baseada sobre 10 graus para descrever os efeitos dos sismos. O sismólogo italiano G. Mercalli[13] realizou, no ano 1902, uma escala de 12 graus conhecida pelo nome escala *Mercalli*. A *escala de Mercalli* foi modificada (*MM*[14]) e adaptada em 1931 às construções nos Estados Unidos de América. Em 1964, a escala *MSK*[15], com 12 graus, foi introduzida na Europa. Esta escala é diferente da escala *MM* somente nos pormenores. Finalmente em 1992, a Comissão Europeia de Sismologia introduziu uma nova escala chamada *EMS* (European Macroseismic Scale). A Escala Europeia Macrosismica, de 1992, é baseada na escala *MSK* mas é mais rigorosa e sobretudo tem em conta a vulnerabilidade (material e método de construção) das diferentes estruturas antigas e modernas.

Em 1935, C.F. Richter [25] criou de forma experimental a primeira *escala de magnitude* local para o Sul de Califórnia. A definição original da magnitude de Richter foi feita a partir de um sismómetro de tipo Wood-Anderson colocado a uma distância epicentral de 100 kms. No entanto, como os sismos ocorrem a distâncias variáveis dos sismómetros, foi necessário adicionar uma constante para compensar a atenuação do sinal sísmico com a distância. A magnitude 3.0 é definida como a dimensão do sismo que gera um movimento máximo de 1 mm para 100 kms de distância do epicentro [26]. Outras fórmulas de magnitude mais gerais, sem uma tão grande dependência do instrumento usado, são igualmente discutidas[16].

O *momento sísmico* (M_0), definido por K. Aki em 1966 [27], é o melhor parâmetro para medir a dimensão de um sismo, pois a sua determinação é totalmente independente do tipo de instrumento contrariamente às magnitudes que são determinadas empiricamente. Esta relação pode ser também utilizada com dados medidos à superfície, na zona da falha ou pode ser calculado através da forma de onda registada pelo

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[12] Michele Stefano Conte de Rossi (cientifico italiano) e *François-Alphonse Forel* (cientifico suíço, 1841-1912)

[13] Giuseppe Mercalli (1850 — 1914) foi um vulcanólogo italiano que desenvolveu a Escala de Mercalli.

[14] MM, Mercali Modified (Mercali Modificada)

[15] MSK=Medvedev, Sponheuer e Karnik foram os autores da escala.

[16] As relações mais utilizadas foram desenvolvidas por Gutenberg e Richter: a *magnitude das ondas de superfície* (M_s) e a *magnitude das ondas internas* (m_b). Outras relações serão também discutidas como, por exemplo, a *magnitude de duração* (M_D).

sismómetro. Os métodos utilizados são baseados na modelação ou inversão da forma de onda.

Os sismólogos desenvolveram, nos últimos 30 anos, uma escala de magnitude *standard* completamente independente do tipo de instrumento. Esta escala, introduzida por [28], é chamada *magnitude momento* (M_W), e é calculada a partir do *momento sísmico*, antes descrito. Há mais de 20 anos que esta escala (M_W) é utilizada para classificar os telessismos com $M_w \geq 5.5$. A ultima escala de magnitude momento recentemente desenvolvida por Kanamori e Rivera [29, 30] é baseada na fase W de ondas telesismicas.

7 Localização dos sismos e tomografia sísmica

É fácil constatar que a Sismologia é fundamentalmente dirigida para resolver problemas inversos relacionados com a fonte sísmica e a estrutura interna da Terra. Invertendo os registos sísmicos (sismogramas) acabamos por caracterizar o sismo que produziu as formas de ondas sísmicas e a estrutura atravessada por estas ondas. O interesse de determinar o foco (hipocentro) onde se produz o sismo e sua projeção sobre a superfície (epicentro) remonta aos sismólogos R. Mallet (ver seções 1 e 3), J. Milne (ver seções 1, 3 e 9) e F. Omori (ver seção 9). As primeiras localizações foram realizadas em base dos danos gerados pelos sismos. Esta metodologia baseia-se no estabelecimento de mapa de intensidade sísmica denominada mapa de isossistas ou mapa macrosísmico (ver sec. 6). Este mapa permite localizar o epicentro macrosismico no centro da zona de maior dano e a extensão da área danificada permite estimar o seu hipocentro.

As primeiras determinações instrumentais foram publicadas em 1904 pelo *Bureau Central de l'Association International de Sismologie* (BCIS, Estrasburgo, França). A partir de 1918, o *International Seismological Summary* (ISS, hoje em dia é o ISC[17]) publicou catálogos sísmicos com epicentros instrumentais. Mais tarde outras instituições dedicaram-se à localização dos sismos à escala global como *National Earthquake International Center*[18] (NEIC, USGS) e a *European-Mediterranean Seismological Centre*[19] (EMSC). No entanto, em cada país existe uma instituição com esta prerrogativa; em Portugal é o Departamento de Sismologia do *Instituto de Meteorologia*[20] (Lisboa).

Os primeiros métodos baseados em círculos (ou elipse), com centro em cada estação e curvas dromocrónicas, utilizam principalmente as ondas P e S. Os primeiros métodos numéricos foram desenvolvidos por L. Geiger, em 1910 e V. Inglada, em 1926. Estes métodos permitem reduzir as diferenças existentes entre os tempos de chegada teóricos e calculados para ondas sísmicas P e S, de maneira que os resíduos sejam minimizados num certo sentido mediante mínimos quadrados. Assim, a localização dos sismos, como um problema de optimização não linear, foi resolvido. Este método é parte essencial dos

[17] Internacional Seismological Center (desde 1964), Edimburgo, Inglaterra.
[18] http://earthquake.usgs.gov/regional/neic/
[19] http://www.emsc-csem.org/index.php?page=home
[20] http://www.meteo.pt/pt/sismologia/actividade/

diversos programas de localização utilizados frequentemente (*Hypo71*, *Hypoinverse*, *Fasthypo*, entre outros). Outro enfoque deste problema é a determinação conjunta de um grupo de hipocentros.

Vários métodos de tomografia sísmica (ou estrutura 3D) foram desenvolvidos desde meados da década de 70, quando o primeiro resultado [31] foi divulgado, cada um com suas vantagens e limitações sendo que a maioria destes métodos se baseia na teoria de inversão. O exemplo de aplicação desta teoria é para o método de tomografia sísmica de tempo de percurso, onde os dados utilizados são resíduos de tempo e os parâmetros são perturbações de velocidade para as ondas telessísmicas. Como estudo de caso serão mostrados os resultados da tomografia sísmica de tempo de percurso realizada, particularmente, em Portugal (Açores, Algarve) como exemplo de tomografia local e na zona Ibero-Magrebina como exemplo de tomografia telessismica.

8 Sismicidade, sismotectónica e risco sísmico

Todos os dias a Terra treme[21]. O estudo dos sismos, exposto nesta parte, permite compreender a tectónica das placas e a geodinâmica: a distribuição espacial dos epicentros sísmicos delimitou, de forma espetacular, as fronteiras das placas e a tomografia sísmica dá-nos uma imagem detalhada do interior da Terra.

No inicio do século XX, há que reconhecer o trabalho pioneiro de F. Montessus de Ballore [32], como foi já referido nas seções 1 e 3, que publicou uma obra sobre a distribuição da sismicidade mundial tanto nos continentes como nos oceanos. No mesmo domínio, em 1954, Gutenberg e Richter publicaram a distribuição da sismicidade mundial [33] melhorada e atualizada. No entanto para relacionar ainda melhor a sismicidade à tectónica, teremos que esperar a "revolução" nas Ciências da Terra, que constitui a partir dos anos 1960-1970 a emergência dos conceitos da "tectónica das placas". Os seus limites são marcados pela distribuição mundial dos sismos significativos e em alguns aspectos pela topografia terrestre, como o das cristas oceânicos (cadeias montanhosas submarinas) e as fossas oceânicas. Por outro lado, sismos de fortes magnitude, também podem ser devido à sismicidade intra-placas[22] em zonas longes dos limites.

Nos anos 70 a localização dos sismos permitiu observar que a maior parte da atividade sísmica do planeta se concentra ao largo de bandas estreitas que coincidem com os limites de placas. A dinâmica das placas é controlada por três tipos principais: os dois bordos podem deslizar horizontalmente (fronteira transformante); ou podem deslizar um relativamente ao outro e em sentido oposto ou ainda afastar-se (fronteiras divergentes) ou convergir (fronteiras convergentes) com velocidades médias anuais da ordem centimétrica ou decímétrica. A concentração dos sismos, em formato de franjas

[21] Um estudo baseado nas observações de sismos ocorridos entre 1900-2000, realizado pelo USGS (http://wwwneic.cr.usgs.gov), revela uma frequência de ocorrência de sismos de 49000 sismos/ano (com Magnitude: 3-3.9), 6200 s/a (M: 4.0-4.9), 800 s/a (M:5.0-5.9), 120 s/a (6.0-6.9), 18 s/a (7.0-7.9) e 1 s/a (M≥8.0).

[22] Cerca de 1% da sismicidade global é devida a sismicidade intra-placas.

relativamente estreitas, forma uma rede que divide a superfície terrestre numa séries de zonas, cujo interior é praticamente assísmico. Deste alinhamento de sismos, uns ocupem as margens dos continentes e outras estão situadas no interior dos oceanos, coincidindo com as cadeias montanhosas *submarinas*. A distribuição global dos sismos resume-se esquematicamente em três zonas ativas: o arco circum-Pacifico[23]; a zona mediterrânica-transasiática ou mediterrânica-himalaya[24] e o sistema das cristas oceânicas[25] (ou cadeias submarinas). Nem todas as margens continentais produzem sismos e nem todos os sismos se produzem à mesma profundidade o que permite, respectivamente, separar as margens ativas das passivas e classificar os sismos em superficiais (h < 60 kms), intermédios (60 kms < h < 300 kms), e profundos (h > 300 kms) sendo a profundidade maior dos sismos situada aproximadamente às 700 kms.

É sabido que a distribuição espacial dos sismos foi um dos factores mais importante para o estabelecimento da teoria tectónica das placas. A superfície da litosfera está dividida em placas, sendo as mais importantes sete, cujos bordos coincidem com as zonas ativas sismicamente. Duas partes agrupam-se numa só placa, uma continental e outra oceânica. Assim como a distribuição espacial dos sismos marca a localização das margens das placas ativas, o estudo dos seus mecanismos (focais), já descritos no capítulo 4, indica-nos a que tipo de margem pertence. Em geral, pode afirmar-se que nas margens de extensão (afastamento dos bordos) os sismos são gerados por falhas normais com tensões horizontais e perpendiculares à direção da margem. Nas margens de convergência (obdução ou colisão dos bordos) os sismos superficiais correspondem a falhas inversas, com eixos de pressão horizontais e normais. Estas falhas, quando conectam zonas de extensão ou de subducção, denominam-se falhas transformantes. Finalmente, nas zonas de transformação os sismos correspondem às falhas de desligamento, tanto os eixos de pressão como os de tensão são horizontais, o que da origem a um movimento de desligamento horizontal. Vários casos de estudo (Portugal, zona Ibero-Magrebina, a fronteira Euro-Asiática, América do sul, Peru-Equador, Sumatra, etc.) são utilizados para exemplificar este tema

A forma de estudar a distribuição temporal dos sismos de forte magnitude a nível global é diferente da dos sismos de fraca magnitude a nível regional. A distribuição de probabilidades de Poisson é a forma mas sensata de estudar a distribuição temporal dos sismos por considerar os sismos como uma sucessão independente de eventos.

A distribuição dos terramotos é fractal, logo invariante na escala. O que provoca pequenos terramotos é o mesmo que provoca grandes terramotos, se os considerarmos um fenómeno crítico. Mais tarde, Kanamori e Anderson mostraram em 1975, que existe uma relação linear entre o logaritmo da área de ruptura e a magnitude (M_s). A partir desta relação e uma simples consideração geométrica[26] encontraram a lei de Gutenberg-

[23] Com 75 - 80% da energia sísmica anualmente libertada.
[24] Com 15 - 20% da energia sísmica anualmente libertada.
[25] Com 3 - 7% da energia sísmica anualmente libertada.
[26] O produto do número de sismos pela área das falhas produzidas por sismos de magnitude M_s é uma constante.

Richter[27]. Este resultado é, em geral, verificado para a sismicidade do globo[28]. A variação do factor b com o tempo é utilizado para uma dada região como índice para ter conta a predição sísmica[29]. Os mesmos estudos podem ser realizados para a energia libertada pelos sismos. Neste mesmo tópico, podemos abordados outros pontos de vista, como por exemplo a natureza (ou dimensão) fractal dos sismos, que foi estudada pelo grupo de sismologia do Cento de Geofísica de Évora utilizando um protótipo mecânico (máquina dos sismos) desenvolvido por este mesmo grupo, desenhado de forma a reproduzir a estrutura da teoria do ressalto elástico [34].

Eventos precursores são aqueles que precedem imediatamente um sismo de grande magnitude numa dada região. Réplicas são sismos que geralmente ocorrem nos dias que se seguem a um sismo de grande magnitude chamado *sismo principal*. Não há nada que possibilite distinguir um evento principal duma réplica, pois as réplicas podem atingir uma magnitude superior à magnitude do evento principal. O termo *crise sísmica* não se encontra consagrado na literatura científica, no entanto é frequentemente empregue para designar uma atividade sísmica anormal que se destaca claramente da sismicidade média de uma dada região. Este termo é também usualmente empregue para designar a sismicidade associada à atividade vulcânica. No entanto nesta secção importa caracterizar os diferentes padrões de atividade sísmica, que são de três tipos, a saber: i) sismo principal associado a eventos precursores e réplicas; ii) sismo principal não precedido de eventos precursores; iii) sequência de sismos caracterizada pela ausência de um evento dominante designada por *enxame* (*swarm* em terminologia anglo-saxónica). Frequentemente, o termo *crise sísmica* é empregue para designar somente um padrão de atividade do 3º tipo.

A seguir ao sismo de Lisboa de 1755, Voltaire escreve um poema sobre a catástrofe de Lisboa. Para responder a Voltaire, que acredite na fatalidade dos fenómenos naturais, Jean Jacques Rousseau escreve numa carta, *Lettre sur la Providence*, que o Homem pode agir para melhorar a sua existência, particularmente não deve viver em lugares perigosos ou em condições desfavoráveis, como o superpovoamento. Esta controversa entre os dois escritores marca o começo da reflexão sobre a responsabilidade do Homem face aos riscos naturais, atribuídos antes à fatalidade.

Se a crosta terrestre estiver em estado crítico, torna-se praticamente impossível prever quando ocorrerá um terramoto e, além disso, quão destrutivo ele será. A previsão de terramotos vem sendo feita há pelo menos 100 anos com sucesso limitado [35]. Determinar o risco sísmico, é calcular a probabilidade e o nível de danos ao longo de um período de referência e no interior de uma dada região. As populações não são todavia

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[27] Com um factor b=1; log N = a – M. O factor b pode estar relacionado, numa região e para um período dado, ao grau de fracturação e/ou ao valor das tensões no meio. Este tópico ainda continua como objecto de investigação.

[28] O valor de do factor b varia regionalmente, para sismos fracos e fortes, entre 0.7 e 1.3.

[29] O factor b relaciona-se com as características físicas da cada região, de forma que um valor alto de b implica que predomina o número de sismos de pequena magnitude, o que significa que a crosta tem pouca resistência, e um baixo, que predominam os sismos de grande magnitude, indicando uma maior resistência do material da crosta.

iguais perante o risco. Com magnitude equivalente, um sismo será menos destrutor num pais preparado e que já integre na sua cultura a construção anti-sísmica (ex: EUA, Japão) que num pais desfavorecido (ex: Indonésia), onde as regras de construção civil básica não são respeitadas.

Não podemos impedir a ocorrência de um sismo, mas podemos preveni-lo e tomando as devidas precauções para minimizar as suas consequências, quer no plano económico, quer no plano humano. A prevenção sísmica baseia-se em três pontos: o conhecimento do risco regional, através do estudo da sismicidade histórica e instrumental; a adaptação das estruturas aos movimentos fortes prováveis e a preparação das populações e dos serviços de socorro. Os estudos da *perigosidade sísmica* deve ser conjugado com a inadequada capacidade de grande parte do nosso edificado a resistir satisfatoriamente a fortes solicitações sísmicas (*vulnerabilidade sísmica*). Uma parte considerável da população portuguesa vive numa situação de risco sísmico considerável. A análise da nossa história recente e remota permite-nos concluir que o território português tem sofrido o efeito de eventos sísmicos destruidores[30]. Zonas como Portugal continental e os Açores já foram atingidas por fortes sismos no passado e voltarão, inevitavelmente, a ser atingidas por eventos de elevado potencial destrutivo. Assim, o território português servirá de exemplo nesta secção. Por outro lado, dos estudos e análise dos mecanismos de geração dos sismos permite-nos igualmente concluir que os sismos são fenómenos recorrentes, cujo período de recorrência depende dos regimes de acumulação de tensões e da própria constituição da litosfera.

Apesar do elevado risco, a generalidade dos países - onde se inclui Portugal - pouco ou nada tem feito nesta área. Em geral os decisores encontram-se pouco motivados para investir uma elevada fatia do erário público em políticas de prevenção cujos efeitos ultrapassam amplamente o horizonte de uma legislatura. Terá, pois, de ser a sociedade civil a auto-mobilizar-se no sentido da exigência da tomada das necessárias medidas que permitam fazer face a este risco, sendo que esta mobilização envolve uma profunda tomada de consciência da necessidade de tal esforço. É neste contexto que uma aposta séria na educação e na divulgação, como meios de consciencialização social, se apresenta como o único e eficaz caminho para se atingirem os desejados objectivos. É necessário que o cidadão seja conhecedor do fenómeno sísmico, da sua génese e distribuição geográfica e esteja plenamente consciente do risco associado à região em que se insere. Deverá ser ainda instruído nas medidas preventivas a tomar em caso de catástrofe.

9 Instrumentação e Observação sismológica

Hoje em dia um sismo de grande magnitude é registado por centenas de estações sísmicas instaladas em todo o mundo. Existem diferentes tipos de redes sísmicas: redes locais, regionais e globais. Os dados obtidos das redes sísmicas (tempo de chegada da onda, amplitude máxima e forma da onda) permitem traçar o mapa sísmico para

[30] Com intensidades máximas superior a VIII. A título de exemplo temos o sismo da margem de 1755, os sismos do Vale Inferior do Tejo de 1531 e 1909 e, mais recentemente, os sismos dos Açores de 1980 e 1998.

identificar as falhas ativas responsáveis pelos sismos. Em Portugal, o *Instituto de Meteorologia*[31] é responsável pela monitorização sísmica do território nacional.

É só no século XIX que os primeiros sismógrafos, inspirados na oscilação (vertical e horizontal) do pêndulo[32], surgiram[33]. Em 1890, F. Omori concebeu com a colaboração de Bosch um sismógrafo, baseado no pêndulo inclinado, que se estendeu a toda Europa com o nome de Bosch-Omori. Em 1900, foi concebido o sismógrafo Wiechert[34] baseado num pêndulo invertido. Mais tarde, em 1922, H.O. Wood e J.A. Anderson construíram o sismógrafo[35] de referência para o estabelecimento da escala local de Magnitude (Richter). Em paralelo ao desenvolvimento dos aparelhos mecânicos, antes descritos, B. B. Galitzine desenvolveu, entre 1908 e 1920, o primeiro sismógrafo electromagnético[36]. Entre 1930 e 1960, foram concebidos dois sismógrafos electromagnéticos que substituíram todos os anteriores e constituíram a base da primeira rede sísmica mundial *World-Wide Standardized Seismographic Network* (WWSSN)[37] que funcionou, com dois tipos de instrumentos, entre 1961 e 1985: o primeiro de curto período por H. Benioff[38] [36] e o segundo de longo período por F. Press e M. Ewing[39] [37]. Hoje em dia todos os sismómetros foram substituídos por outros mais modernos, denominados sismómetros de banda larga, com uma grande dinâmica e uma resposta em frequência que inclui a maioria dos sinais sísmicos, tanto de sismos próximos como de longínquos. A primeira geração de sismómetro de banda larga (STS1) de retroalimentação[40] (ou realimentação) negativa, integrada pela rede mundial de banda larga (GEOSCOPE, [38]), foi concebida em 1983 por Wieland e Strekeisen.

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[31] A rede sísmica nacional (IM) é constituída por 54 estações digitais de curto período (11 de 1s e 0.5s), de período mais longo (20 de 5s) e de banda larga (23 de 120s): 28 no continente, 21 no Açores e 5 na Madeira na data de 29 de Outubro de 2012 (http://www.meteo.pt/pt/sismologia/redes/).

[32] O registo do movimento é baseado num estilete, ligado à massa, que marca as oscilações do solo sobre uma placa de cristal fumada.

[33] Os primeiros sismógrafos de registos contínuos foram desenvolvidos em Itália, num final do século XIX, por L. Palmieri e T. Bertelli.

[34] Do nome do seu autor Emil Wiechert (Alemanha, 1861-1928).
Consultar http://www.hp-physique.org/sdx/sriaulp/main.xsp?execute=show_document&id=IM67018619&q=

[35] Este sismógrafo, de registo fotográfico, foi concebido com uma pequena massa que oscila por torção com um período de 0.8 s e uma amplificação de 2800.

[36] Príncipe Boris B. Galitzine (Russia, 1862-1916).
Consultar http://www.hp-physique.org/sdx/sriaulp/main.xsp?execute=show_document&id=IM67018615&q=

[37] A rede WWSSN foi criada para monitorizar o cumprimento do tratado de proibição dos testes nucleares subterrâneos.

[38] Hugo **Benioff** (EUA, 1899–1968).

[39] William Maurice Ewing (EUA, 1906-1974), geofísica americano realizou o sismógrafo Press-Ewing com Frank Press no inicio dos anos 1950.
Consultar http://www.hp-physique.org/sdx/sriaulp/main.xsp?execute=show_document&id=IM67018614&q=

[40] Nome dado ao procedimento através do qual parte do sinal de saída de um circuito é transferida para a entrada deste mesmo circuito, com o objectivo de diminuir, amplificar ou controlar a saída do sistema. Quando a retroalimentação diminui o nível da saída, fala-se de retroalimentação negativa, e quando a retroalimentação amplifica o nível da saída fala-se de retroalimentação positiva. A retroalimentação é um procedimento existente em diversos tipos de sistemas, sejam eles biológicos, económicos, eléctricos, sociais ou outros. O termo é utilizado nas Teorias de Sistemas e de Controlo, na Engenharia Eléctrica, na Engenharia de controlo, na Psicologia, na Biologia e especificamente na Endocrinologia.

A *teoria do sismómetro* é dividida em três partes: 1) o princípio físico do sismómetro, 2) o sismómetro mecânico e 3) o sismómetro electromagnético. O princípio físico de todos os sismómetros (mecânicos e electromagnéticos) é baseado nas propriedades de um pêndulo que se desloca devido ao movimento do solo. Em alguns modelos a parte móvel é o íman enquanto noutros é a bobina[41]. O sismómetro vertical simples é formado por uma massa pendurada numa mola. Quando o suporte fixado à superfície do solo recebe uma vibração, a massa move-se com um movimento de forma que o deslocamento relativo da massa relativamente ao suporte seja a diferença entre os deslocamentos da superfície e da massa, e dai escrevemos a equação (diferencial) do movimento da massa e determinamos a sua solução. No caso do sismómetro electromagnético, consideramos duas equações, a do sismómetro (mecânico) e a do galvanómetro. Basta neste caso descrever a equação do galvanómetro, tendo em conta que a primeira é idêntica á do sismómetro mecânico já estudada anteriormente. Na equação do galvanómetro, introduzimos uma nova força (de reação) produzida pela corrente eléctrica induzida na bobina. Desta forma, a equação resultante fica com mais um termo definido pelo momento desta força relativamente ao centro de suspensão[42]. A curva da resposta do sistema sismómetro-galvanómetro permite determinar o deslocamento do solo, mediante o sinal registado. A representação mais usada é a da amplificação, ou seja o quociente entre a amplitude do registo e a do deslocamento do solo.

Hoje em dia o sistema de amplificação é totalmente electrónico e é assim possível atingir sensibilidade muito superior á obtida com sistemas convencionais com o do sismómetro-galvanómetro antes descrito. Neste caso os sinais amplificados são registados em sistemas convencionais visíveis (papel em tambor) e em banda magnética (analógica ou digital). Este sistema é agora totalmente generalizado por permitir a existência de base de dados digitais e por facilitar posteriormente a análise e o processamento do sinal. As características mais importantes de uma *estação sísmica* são: 1) a largura de banda correspondente ao intervalo de frequência da qual vá resultar a sensibilidade do instrumento, 2) a dinâmica definida pelo quociente entre o maior e menor sinal registado, 3) a resposta instrumental ou função de transferência, a qual contem toda a informação relativa ao comportamento do sismómetro sujeito a um terramoto. Concluímos esta parte do capítulo 7 sublinhando que os sistemas seletivos têm um pico estreito para um período determinado, enquanto as respostas de banda larga (*Broad Band*, BB) têm a mesma amplificação mas para um espectro de frequências mais amplo. Os sismómetros de banda

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[41] Ao produzir um movimento, gera-se uma corrente eléctrica na bobina proporcional à velocidade relativa entre a bobina e o íman, a qual passa a um galvanómetro, em qual produz-se uma deflexão do espelho. Por consequência, o feixe de luz que incide no espelho sofrerá um desviou que incidira num papel fotográfico onde será registado o movimento da massa ou do íman, ou seja do sismómetro.

[42] Assim, um movimento do sismómetro, produzido por um deslocamento vertical da superfície, gera uma corrente eléctrica que, mediante um circuito, passa à bobina do galvanómetro produzindo a este uma deflexão. Para obter a sensibilidade em deslocamento há de multiplicar a velocidade pela frequência angular. De forma análoga obtemos a sensibilidade em aceleração dividindo esta mesma velocidade pela frequência angular.

muito larga[43] (*Very Broad Band*, VBB) têm uma resposta em amplitudes praticamente plana entre 0.1 e 1000 s.

Continuamos este capítulo com uma breve descrição da evolução das *redes sísmicas*: da primeira, instalada no Japão por J. Milne em 1890 até às mais modernas redes e corporações mundiais e regionais como GEOSCOPE[44] (França), IRIS (*Incorporated Research Institutions for Seismology,* USA), ORFEUS (*Observatories and Research Facilities for European Seismology,* Europa), *EMSC (Euro-Mediterranean Seismological Center,* Europa*)* Geofone (Almanha), MedNet (*Mediterranean Network*, Italia), Poseidon (Japão) WM (*Western Mediterranean*, Ibero-Magreb). Entre 1930 e 1950, a rede de observação sísmica era heterogénea com uma mistura entre instrumentos antigos (Wiechert e Mainka) e mais modernos (Galitzin e Benioff). Há que realçar que a situação mudou completamente, em 1961, com a instalação da rede sísmica mundial *World-Wide Standardized Seismographic Network* (WWSSN), que atingiu um máximo de aproximadamente 125 estações[45]. A nível internacional foi constituída a *Federation of Digital Seismograph Networks*[46] (FDSN).

A *anatomia de um sismograma*, registo gráfico de um sismo, obtido numa estação sísmica depende da distância epicentral (distancia estação-epicentro), da magnitude, do hipocentro e do tipo do instrumento utilizado. A magnitude determina a faixa de distâncias na qual é possível detectar um sismo com um instrumento de uma determinada amplificação. A distância epicentral e o hipocentro determinem a distribuição dos tempos de chegadas e as amplitudes das distintas ondas sísmicas detectadas. Com estas características estudamos os sismogramas dos sismos próximos (ou locais)[47] e longínquos (ou telessismos)[48]. Nas distâncias próximas registam-se principalmente as ondas transmitidas e reflectidas[49] na crosta e no manto superior. As amplitudes destas ondas são utilizadas para calcular a magnitude dos sismos locais. No caso dos telessismos são estudados dois tipos: aquelas com distâncias epicentrais compreendidas entre 10º e 105º (as transmitidas P e S, as de superfícies, as reflectidas pelo núcleo ou uma ou mais vezes pela superfície, as refractadas no interior do núcleo) e os que tem distancias epicentrais compreendidas entre 105º e 180º (as que penetram o núcleo, difractadas, reflectidas e

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[43] Presentemente, existem conversores analógicos digitais de 24 bits que permitem cobrir uma gama dinâmica de 140 db, o que permite que o sismómetro só satura com sismos locais de M > 5 a 10 kms de distancia ou telessismos a 3330 kms de M > 9.

[44] GEOSCOPE foi a primeira (1982) rede constituída por estacões sísmicas numéricas de banda larga, beneficiando a comercialização do sismómetro STS1. Este rede foi equipada por um instrumento (STS1) caracterizado por uma grande dinâmica e um amplio espectro de frequências permitiu eliminar a tradicional fronteira entre sismologia de longo e curto período [39].

[45] Equipada por instrumentos electromagnéticos (3 componentes) de curto e longo período

[46] A FDSN é constituída por membros, de 65 organizações de 52 países, dotados de mais de uma estação de banda larga. Hoje em dia, a maior parte das redes são dotados de sistemas telémetricos que permitem a transmissão dos dados em tempo real.

[47] Os sismos locais são os sismos com uma distância epicentral menos de 1000 kms (10º).

[48] Os telessismos são divididos em dois tipos, os com distancia epicentral compreendida entre 10º e 105º e os entre 105º e 180º.

[49] Dada a grande diferença na estrutura da crosta de uma zona a outra, existe uma certa variedade da distribuição destas fases, como por exemplo as transmitidas pela crosta granítica Pg, Sg e as refractadas no Moho, Pn, Sn.

refractadas no núcleo interno, e no nos sismogramas de longo período são presentes as ondas R2, R3,…e G2, G3,…).

10 Palavras Finais

A Terra é um "objecto" fascinante e descobri-lo sob o ponto de vista físico é uma aventura ainda maior. A compreensão da sua estrutura, da sua dinâmica e da sua forma impõe a resposta a várias questões pois encontram-se envolvidos vários fenómenos físicos de várias escalas, desde a interação com outros corpos celestes até à simples emissão radioativa. E a aventura é ainda maior porque conhecer o interior do nosso planeta continua a só ser possível através de observações e registos feitos à superfície, já que viajar até ao centro da Terra permanece um sonho à moda de Jules Verne[50], isto é, só os métodos indiretos permitem ter acesso à composição e à estrutura interna do globo.

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[50] Viagem ao Centro da Terra, Júlio Verne (titulo original: Voyage au Centre de la Terre, Jules Verne).

vários projetos de investigação e de divulgação científica que permitiram a realização de muitos dos trabalhos em que liderei/participei.

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UMA REVISTA DE GEOFÍSICA EDITADA NOS ANOS TRINTA DO PORTUGAL DO SÉCULO PASSADO

JORGE FERREIRA

Escola Secundária de Serpa, Doutorando em História e Filosofia da Ciência na Universidade de Évora, jmferreira68@mail.pt

AUGUSTO J. SANTOS FITAS

Professor da Universidade de Évora, investigador do Centro de Estudos de História e Filosofia da Ciência, afitas@uevora.pt

Faz o Centro de Geofísica de Évora vinte anos de existência, o que constitui um pretexto para assinalar esta efeméride científica com a pompa e circunstância devidas. No trabalho efetuado apresenta-se uma nota sobre a primeira, e única, revista de Sismologia e Geofísica editada em Portugal que ocupou os escaparates livreiros ao longo de sete anos. Trata-se do periódico intitulado «A TERRA» com o subtítulo «Revista de Sismologia e Geofísica». No texto escrito não se pretende fazer a história deste periódico científico, dá-se simplesmente a notícia de alguns dados relevantes, caracterizadores da sua atividade e que corresponde a uma curiosa singularidade na vida científica nacional.

1 A revista

O primeiro número de A TERRA viu a luz do dia em Outubro de 1931 e o seu diretor fazia a apresentação desta «Revista de Sismologia e Geofísica» num editorial de abertura onde lia:

> «Os problemas variados da Geofísica e especialmente os de sismologia, têm despertado e atraído o nosso espirito, pela sua magnitude e interesse crescentes (...) Em Portugal, faltava uma publicação, na qual fossem tratados estes problemas, quer sob o aspeto de ordem prática, quer sob o de pura especulação ou ainda, somente, na sua feição vulgarizadora (...) Englobados no continente europeu, só por indiscutíveis fatores geográficos, a ele pertencemos (...)De resto, no campo da cultura e do pensamento, no progresso das ciências e das ideias, na supremacia do animo criador e na investigação séria e cuidada, achamo-nos desmedidamente afastados da Europa (...) Entendemos preencher uma lacuna e assim, a necessidade de lançarmos esta Revista, onde os três aspetos citados da geofísica se congregassem, impôs-se ao nosso espirito, há muito tempo já e a primitiva ideia, adensando-se, tomando consistência, materializou-se hoje, com o aparecimento da «Terra» (...) Nas suas formas múltiplas, a física do globo, será tratada com o possível desenvolvimento, embora à sismologia nós entendamos dar um relevo mais acentuado e muito especial. «A Terra», terá um carácter universalista (conceção abstrata dos problemas no seu campo de investigação pura), ao mesmo tempo que estudará as questões geofísicas na sua aplicação a Portugal e manterá uma secção de vulgarização, que e necessariamente precisa,

> para ampliar o âmbito de receção no espirito humano, dos problemas, como estes. de caracter acentuadamente científico (…)» (1931,1:1)[51] [1].

Estava-se perante um periódico cuja preocupação primeira era a investigação pura e aplicada de um domínio científico e, em segundo lugar, procurava-se também a vulgarização científica no sentido de «ampliar o âmbito da receção» aos problemas de carácter científico. O seu diretor e, sublinhe-se, proprietário (tal como aparece impresso na folha de rosto dos diversos números da revista) era Raul de Miranda (1902-1978) que se apresentava como «Assistente de Geografia Física e de Física do Globo da Universidade de Coimbra» e «Sócio da Sociedade Espanhola de Historia Natural e da Societá Sismologica Italiana». Era a única revista portuguesa de carácter científico, incluindo nela a vulgarização, editada por iniciativa individual, sem o apoio organizativo de qualquer instituição (Faculdade ou Instituto) ou sociedade científica. Era uma revista que se propunha a lançar iniciativas nacionais relacionadas com a geofísica e que, como reclama no terceiro número o seu diretor, e proprietário, não era alvo de qualquer auxílio ou subsídio das entidades oficiais. Esta ausência de «ajuda material ou moral», facto realçado por Raul de Miranda, só desaparecerá no sétimo, e último, ano da vida efémera deste jornal científico: os últimas quatro números foram subsidiadas pelo Instituto para a Alta Cultura (indicação mencionada na capa), um apoio que permitiu o aumento do material impresso, passando de 32 para 40 páginas.

Ao longo da sua curta existência, a revista manteve uma periocidade de cinco números por ano (publicados em Janeiro, Março, Maio, Julho e Novembro), apresentando no último número anual um índice (por autores) relativo aos trabalhos incluídos nessa série. O primeiro número da revista foi publicado em Outubro de 1931 (o único publicado no mês de Outubro) e o último em Maio de 1938. Em todos os números eram reservadas algumas páginas para publicação da Bibliografia recebida, bem como para noticiário científico diverso relacionado com a temática de A TERRA.

No início da publicação da revista, Raul de Miranda previa dar maior relevo à sismologia, não deixando, contudo, de tratar, com o desenvolvimento possível, as outras disciplinas relacionadas com a física do globo (1931,1:1) [1]. Numa análise da tipologia dos artigos publicados verifica-se que a meteorologia foi a área com maior número de trabalhos publicados (55), registando-se em segundo lugar a sismologia com 41. Destacavam-se em seguida outras áreas científicas: geologia (11), geografia (9) e astrofísica (2). Se se pormenorizar um pouco mais, verifica-se, dentro da sismologia, uma distribuição dos artigos pelas especialidades seguintes: sismicidade (17), desenvolvimento de instituições/equipamentos (11), previsão/prevenção (9), desenvolvimento do conhecimento científico (3) e dimensão pública (1). O trabalho considerado na "dimensão pública", intitulado "A influência dos fenómenos sísmicos no espírito poético português", é da autoria do próprio Raul de Miranda, que o considera como sendo um trabalho no âmbito da "etnografia sísmica". O autor acrescenta que a literatura associada aos fenómenos sísmicos, em Portugal, permite "o conhecimento sísmico do continente

[51] De ora em diante utilizar-se-á esta indicação para referir o número da revista ([ano], [número]: [página]).

português" (uma das fontes para a sismicidade histórica) e também o conhecimento da "influência poético-filosófica que os tremores de terra exerceram no espírito nacional" (1937:31, 31) [1].

Quanto aos autores, Raul de Miranda, o seu Diretor, publicou vinte e cinco trabalhos, dezoito dos quais sobre sismologia (não se incluindo neste cômputo os editoriais, as notas bibliográficas e outras notícias por ele assinadas); a sua participação é mais assídua nos primeiros quatro anos da revista. O colaborador com mais trabalhos publicados é Augusto Ramos da Costa, engenheiro hidrógrafo e oficial da Marinha, autor de dezasseis trabalhos, sete dos quais sobre Meteorologia e que será o futuro Presidente da Direção da Sociedade de Meteorologia e Geofísica de Portugal, uma agremiação cuja organização foi promovida pela própria revista. Muitos colaboradores são professores universitários, também os professores liceais colaboraram nos vários números da revista (Fernando Machado, com seis artigos, Carlos Santos, João Almeida, João Costa que também é naturalista da FCUP).

A revista organizou um corpo de «representantes» ou correspondentes em várias capitais distritais (Aveiro, Bragança, Santarém e Setúbal), tarefa que era desempenhada por professores do ensino liceal; esta rede estendia-se aos Açores, Moçambique, Espanha e México.

2 A proposta de criação do Instituto Nacional de Geofísica

A revista encabeçou várias iniciativas com alcance nacional, de que é exemplo o que consta no seu número 7 (janeiro de 1933) onde se dá conta do seguinte:

> «Por iniciativa da nossa Revista, fundou-se em Coimbra a Sociedade de Meteorologia e Geofísica de Portugal. As grandes dificuldades que de início surgiram, foram, depois de bastantes esforços, uma a uma removidas, estando atualmente a Sociedade em franca catividade. Os fins da Sociedade são: a) trabalhos de investigação; b) melhoramento dos serviços meteorológicos e geofísicos no país e por isso melhor apetrechamento dos observatórios; c) conferências de cultura; d) edição de livros e folhetos de vulgarização; e) aplicação prática da meteorologia e climatologia do país à agricultura, terapêutica e turismo. A sede oficial da Sociedade é em Coimbra, funcionando provisoriamente o Secretariado Geral, na redação da nossa Revista. Alem da direção tem a Sociedade núcleos no Porto, Coimbra e Lisboa. Atualmente conta algumas dezenas de sócios, entre eles as maiores sumidades do nosso pais que, à Meteorologia e Geofísica tem dedicado, grande parte da sua vida. Possui quatro categorias de sócios: honorários, efetivos, correspondentes e auxiliares. Segundo os estatutos a esta ultima categoria podem pertencer todos os indivíduos nacionais ou estrangeiros, que não podendo inscrever--se em nenhuma das outras, queiram no entanto auxiliar monetariamente a Sociedade (…)» (1933,1:1) [1].

Os trabalhos desta sociedade iniciaram-se com uma conferência no dia 6 de Janeiro de 1933de Anselmo Ferraz de Carvalho, seu presidente honorário, diretor do Instituto

Geofísico de Coimbra e Professor da Faculdade de Ciências de Coimbra. Da direção desta Sociedade faziam parte, como presidente, o Vice-Almirante Augusto Ramos da Costa e o próprio Raul de Miranda enquanto Secretário Geral. No número de A TERRA do final do ano seguinte, Raul de Miranda surge sem cargo na referida sociedade, apenas como um mero sócio.

No último número de 1937 da revista, o diretor, através de um editorial intitulado «No limiar de um novo ano», vai enfatizar a necessidade de criação de um instituto responsável pelas observações geofísicas e também capaz de fornecer a informação adequada a todos os sectores da atividade nacional que dela necessitem. Escrevia:

> «A fundação do Instituto Nacional de Geofísica que ainda não teve realidade, afigura-se-nos como sendo a base de toda a organização que deverá orientar a meteorologia, climatologia, sismologia, magnetismo e gravimetria nacionais e só então poderemos vir a ter um serviço capaz de fomentar o desenvolvimento da agricultura, turismo, estações de cura e aviação, além do progresso a que o nosso território colonial, com esse Instituto, poderia aspirar, por um mais perfeito conhecimento das qualidades climáticas das suas diversas regiões, às quais assim pertenceria uma melhor, mais científica e regular distribuição das diversas catividades agrícolas, pecuárias e de povoamento (…) A Terra, à qual pertence desde 1931 o papel de coordenadora das vontades então dispersas, nos vários ramos da Geofísica, aguarda que essas mesmas vontades se unam para que a finalidade que se impõe não demore e o Instituto Nacional de Geofísica realize em Portugal, a função para que está naturalmente indicado: orientar e propulsionar no quadrante das ciências de que trata, todas as suas catividades e unificar os trabalhos imprimindo-lhes assim, mais coesão, mais consistência e maior facilidade de conclusões(…)» (31,1) [1].

Esta era uma das preocupações, ao nível da organização científica, veiculada pela revista e que já fora abordado num número anterior. O Diretor fizera publicar um relatório referente ao projeto de Organização dos Serviços Meteorológicos elaborado por uma comissão criada para o efeito, em 1921 (quinze anos antes!). Raul de Miranda, no editorial que abria esse número de 1936 e intitulado «Uma questão nacional», iniciava a sua prosa com as palavras seguintes,

> «Pelo decreto n.º 7790 publicado no Diário do Governo de 8 Novembro de 1921, foi nomeada uma Comissão Técnica de Meteorologia, da qual faziam parte os ilustres Professores Doutor Anselmo Ferraz de Carvalho, Doutor Álvaro Machado, Doutor Azevedo Gomes e os distintos oficiais e cientistas Comandante António Carvalho Brandão e Comandante Aires de Sousa, para estudar a Organização dos Serviços Meteorológicos em Portugal. Publica agora A Terra o notável trabalho dessa Comissão, achando que ele hoje possui ainda mais atualidade e interesse e que muito bem poderá servir de base a uma larga organização não só dos serviços meteorológicos, mas também de todos os ramos da Geofísica» (1936, 22:1) [1] .

Não se eximindo, em forma de conclusão, a clamar para a atualidade do problema:

> «Ao publicarmos o importante diploma que se segue, prestamos desta forma homenagem à Comissão que o elaborou e chamamos sobre ele a atenção dos cientistas portugueses da especialidade, certos de que o Relatório e Projeto que agora se inserem, serão o ponto de apoio para se levar a efeito a criação do Instituto Nacional de Geofísica» (1936, 22:1) [1] .

Só em 1946, com a criação do Serviço Meteorológico Nacional, se irão cumprir parte dos desejos expressos por Raul de Miranda nas páginas de «A TERRA». Integrando este serviço todos os organismos de observação meteorológica que estavam dispersos por diversos instituições, entre os quais os Institutos Geofísicos ligados às Universidades de Coimbra, Lisboa e Porto.

3 «Introdução à Sismologia»

É no início dos anos quarenta do século passado que é organizada a célebre «Biblioteca Cosmos», sob o impulso e direção do Prof. Bento de Jesus Caraça. Esta coleção dividia-se por várias secções temáticas: «Ciências e Técnicas»; «Artes e Ideias»; «Filosofia e Religiões»; «Povos e Civilizações»; «Biografias»; «Epopeias Humanas»; «Problemas do nosso Tempo». E, pelo conteúdo e qualidade dos seus textos, esta «Biblioteca» foi precursora na promoção de um plano organizado de obras de difusão e divulgação cientificas, chamando também a si o mérito de atribuir a redação dos seus títulos a autores nacionais, desde professores universitários a publicistas de reconhecido mérito. Foi durante largos decénios o único projeto organizado de divulgação cultural, onde a ciência e a técnica tiveram um peso bastante significativo e que mobilizou largos sectores da intelectualidade nacional.

É neste contexto que se vai encontrar o Dr. Raul de Miranda como autor do opúsculo nº 30 desta coleção, intitulado «Introdução à Sismologia». Deste livro constam nove capítulos, a saber: 1-Da evolução das teorias e conceitos sismológicos; 2- Estudo microssísmico dos tremores de terra; 3- Ondas sísmicas e aparelhos de registo; 4- Tremores submarinos e vagas sísmicas; 5- Escalas sísmicas; 6- Construções antissísmicas; 7-Os grandes tremores de terra destruidores; 8- Geografia sísmica; 9- A sismicidade em Portugal. E, no último capítulo, quase a terminar o livro, o autor escreve:

> «É fácil ver que os observatórios do Porto, Coimbra e Lisboa não podem, só por si, satisfazer o encargo do estudo exato da sismicidade do país, quer pela sua posição, quer ainda, como acontece no primeiro, por não existir um aparelho de categoria para a inscrição dos abalos. Há necessidade de estender a rede das estações sísmicas a todo o continente português, impondo-se para inicio e desde já, uma no Algarve, outra no Alentejo, e outra no Minho. Como organizar, duma forma conveniente, o serviço sismológico em Portugal? O progresso da Sismologia e a necessidade que temos de atender, com cuidado, à proteção do nosso pais sob o ponto de vista sísmico, impõem-nos que tratemos duma forma decisiva deste problema. A criação dum Instituto Nacional de Geofísica é duma imperiosa urgência, se atentarmos um pouco nos numerosos problemas que

> poderiam ser resolvidos por este organismo, do qual, a parte sismológica seria apenas um dos seus diversos ramos. A meteorologia, a eletricidade atmosférica e telúrica, a climatologia, a gravimetria e o magnetismo, seriam outras tantas secções a estabelecer nesse organismo, que viria a desempenhar uma função coordenadora e orientadora de trabalhos a propor e a realizar integralmente (…) Compreenderia o serviço sismológico, um conjunto de estações sísmicas de 1º e 2.ª classes, assim distribuídas: Estações de 1ª classe: Faro, Lisboa, Évora, Porto e Coimbra (estação central) (…) Estações de 2.ª classe: Setúbal, Santarém e Viana do Castelo. Aos atuais Observatórios Meteorológicos de Lisboa e Porto e Instituto Geofísico da Universidade de Coimbra, ficariam ligadas as estações sísmicas correspondentes, mantendo-se-lhes a liberdade de ação de que gozam, para poderem desempenhar a sua dupla missão científica e pedagógica» [2].

Para Raul de Miranda o Instituto Nacional de Geofísica continuava a ser de «imperiosa urgência»…

Agradecimentos

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PHYSICS OF SEISMO-ELECTROMAGNETIC PHENOMENA: TWENTY YEARS AFTER

HUGO GONÇALVES SILVA

Geophysics Centre of Évora and Physics Department, University of Évora, Rua Romão Ramalho, 59, 7002-554 Évora, Portugal, hgsilva@uevora.pt

MOURAD BEZZEGHOUD

Geophysics Centre of Évora and Physics Department, University of Évora, Rua Romão Ramalho, 59, 7002-554 Évora, Portugal, mourad@uevora.pt

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 ≤ 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 ≥ 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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SEISMICITY OF AZORES AND GEODYNAMIC IMPLICATIONS

JOSÉ FERNANDO BORGES
University of Évora Department of Physics / CGE, Évora
jborges@uevora.pt

MOURAD BEZZEGHOUD
University of Évora Department of Physics / CGE, Évora

BENTO CALDEIRA
University of Évora Department of Physics / CGE, Évora

Over the past thirty years, several seismological studies have been carried out in the Azores region in order to characterize the geodynamic complexity of this region. In this work, we summarize these studies and highlight their main conclusions. The analysis of the focal mechanisms of large earthquakes reveals that there are two zones in the Azores, namely, zones I and II, with different stress pattern and strain rates. In zone I, which is located between 30º W and 27º W, faulting motion corresponds to a left-lateral strike slip with horizontal E-W compression and N-S extension and a strain rate of 6.7 mm/yr. In zone II, which is located between 27º W and 23º W, the seismic moment tensor indicates normal faulting with horizontal NE-SW extension and a strain rate of 3.1 mm/yr..

1 Introduction

Throughout history, the lives of the Azorean people have been marked by earthquakes that have had different effects depending on their proximity and magnitude. This seismic activity, which may have volcanic or tectonic origins, has affected the population of these islands by destroying infrastructure and claiming lives. The social and economic impacts of these phenomena are great—note the consequences of the recent 1980 Terceira and 1998 Faial earthquakes. Therefore, the following measures are necessary to minimize the risks associated with this seismic activity: **(i) Increase the capacity to monitor seismic phenomena on different space-time scales**: It is true that, in recent decades, there has been a substantial improvement in seismic activity monitoring in the Azorean region. However, in some areas, more work needs to be done to improve this type of monitoring. Such work includes improving the compatibility of data and sensors, providing data in real time, reducing azimuthal gaps in the network by installation of OBS, monitoring intense seismic motions and establishing the capability of seismic monitoring by installing mobile networks and homogeneously upgrading seismic catalogues.

(ii) Improve seismotectonic and geodynamic models: There is still no established consensus on the type of geodynamic model that would be

able to provide a full explanation of the observed phenomena, especially the focal mechanisms of the more energetic earthquakes [1], their morphology [2] and geodetic observations [3]

(iii) Develop simulation tools for predicting the ground's motion and its consequences on the level of built stock: Simulations are mainly based on source characteristics and are heavily dependent on the medium, which is still poorly understood [4,5,6].

On the basis of these considerations, we conclude that the characterization of the seismic source of earthquakes in this region is an essential contribution. In this paper, we present a brief seismotectonic characterization of the Azores region in the context of the Azores-Gibraltar plate boundary using the results of works from the past 36 years. We include some results of the recent seismic activity to define the current state of the seismic stress pattern and the seismological cortical deformation in the region.

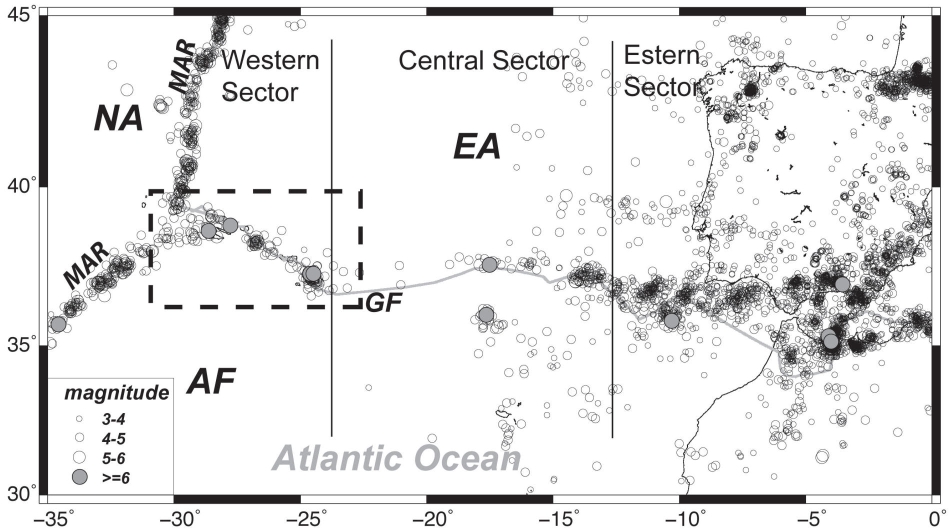

Figure 1 - Seismicity of the Azores–Gibraltar region during the period of 1973–2012 for a magnitude of M≥4.3 (NEIC Data File, USGS); GF=Gloria Fault; MAR=Mid-Atlantic Ridge; NA=North American plate; EA=Eurasian plate; AF=African plate.

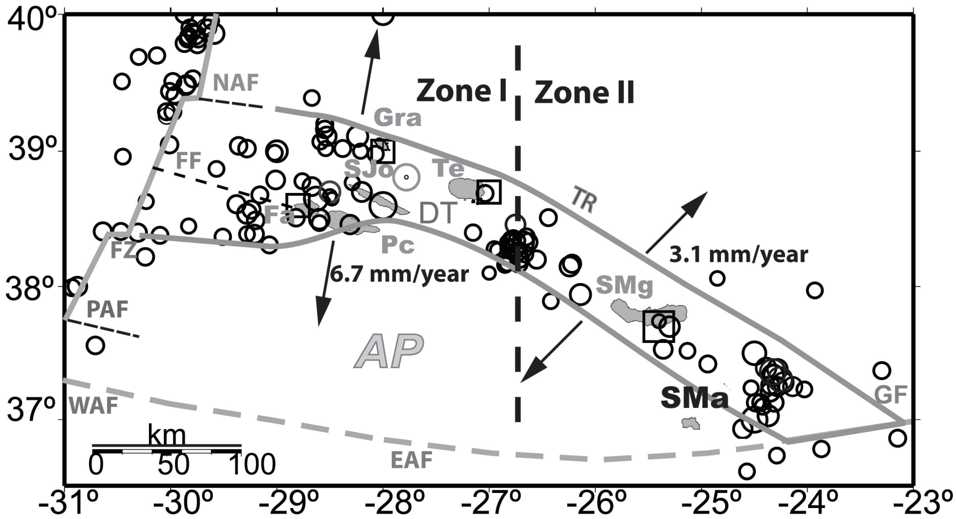

Figure 2 - Instrumentally (circles) and historically (squares) determined seismicity for the Azores region. The island names are Fa=Faial, Pc=Pico, SJo=San Jorge, Gra=Graciosa, Te=Terceira, SMg=San Miguel, SMa=Santa María. The grey stars show the epicentres of the three earthquakes studied. MAR=Mid-Atlantic Ridge; TR=Terceira Ridge; NAF=North Azores Fracture Zone; FF=Faial fracture; AF=Azores fracture; PAF=Princess Alice fracture; WAF=West Azores fracture; EAF=East Azores fracture; GF=Gloria Fault; AP=Azores plateau. Arrows shows the direction of the T Axis (traction) for and the strain rate for both zones.

2 Seismotectonics and geodynamics of the Azores-Gibraltar region

The study of seismic activity in the Azores-Gibraltar region (Figure 1) includes instrumental data recorded by local and regional networks. For the larger earthquakes, data from global networks were also used. The hypocentre determinations and magnitudes of earthquakes give us an image, even if incomplete, of the activity associated with the main active tectonic features, plate boundaries, and fracture zones.

The historical record of the region's seismicity, a supplement to the instrumental seismicity, is of crucial importance for the characterization of its seismic activity. The historical seismicity is often the only source of information of major earthquakes with recurrence periods larger than the period of the first instrumental records. The historical information available, which describes the destructive effects caused by the earthquakes, shows spatial and temporal gaps that are due, in large part, to the geographical distribution of the population. Thus, for the Portuguese Continental territory, there are historical reports of earthquakes dating back to the year 33 B.C., but in the Azores region, such information is not available before the beginning of the sixteenth century, when a sizable population began to occupy the islands. For these reasons, the entire oceanic region between the islands and the mainland shows a lack of historical information that cannot be provided. The epicentre map (Figure 1) shows that the three branches of the triple junction of the Azores region are well defined up until 24° W, after which a lack of seismicity is observed (seismic gap) that extends to 18º W. To the east of this meridian, epicentres are scattered over a wide area, setting a track of intense seismic activity up to the Gibraltar region.

Based on the historical and instrumental seismicity, the Azores-Gibraltar region has been divided into three sectors [7]: the West Sector, which includes the Azores plateau (AP) and extends from the Mid-Atlantic Ridge (MAR) to 24º W; the Central Sector, which begins at the GLORIA Fault (GF) and extends up to 13º W; and the Eastern Sector, which extends from the Tore-Madeira Ridge (at approximately 13º W) to Gibraltar.

The Azores Islands are located in the West Sector. The area located the furthest to the west is the AP. Morphologically, the AP is a triangular shaped structure with an area of approximately 400,000 km^2 that is roughly bounded by a 2,000 m bathymetric line (Figure 2). The AP clearly stands out from the abyssal plain, whose depths can exceed 3,500 m, and presents a strongly irregular topography consisting of peaks and volcanic ridges that reach the surface in seven places that are coincident with seven of the nine Azores islands (the Corvo and Flores islands are within the NA plate).

The Azores plateau is traversed in a NS direction by the Mid-Atlantic Ridge (MAR) and its boundaries are: the magnetic anomaly 6 (20 Ma) in the west; the North Azores Fracture Zone (NAF) with an EW trend, which continues into the Terceira Ridge (TR), trending SE and including the S. Miguel–Terceira–Graciosa, Faial–Pico and S. Jorge alignments, and the East Azores Fracture (EAF) striking E–W to the south, continuing to the Gloria Fault (GF) [7,8].

The main tectonic accident of this region is the MAR, which approximately intersects the midpoint between the Flores and Graciosa Islands. Its trend (Figure 2) varies from N10º E to N20º E and as it progresses south it undergoes morphological changes: (i) it becomes less rugged, to the point where its median valley, well emphasized in other latitudes, essentially ceases to exist, possibly due to the influence of a mantle plume under the basis of the AP hot-spot [2,9], (ii) its thickness is sharply reduced [8], and (iii) the median valley, which characterizes this feature in other latitudes, is largely absent here.

The MAR is offseted by five transform faults that have a general E–W trend (Figure 2). They are, from north to south: the North Azores Fracture Zone (NAF), the Faial Fracture Zone (FF), the Azores Bank Fracture Zone (FZ), the Princess Alice Fracture Bank (PAF), and the West Azores Fracture Zone (WAF), which is also called the Azores Fracture. The WAF extends to the east of the EAF (dotted line, Figure 2), up to the GF, which defines the southern limit of the AP, where there are no records of any significant seismic events.

The Azores Plateau, which is formed by an abnormally thick oceanic crust, may be related to the existence of a mantle plume. The arguments in favour of the existence of the mantle plume are based on observations of an anomalous topography, gravitational distribution, crustal thickness, S and P wave velocities, and geochemical signatures [9,10,11,12,13] Reinforcing this hypothesis is the fact that there are strong similarities between the type of lava found in the Azores and the lava types found in regions such as Iceland, whose origin is clearly associated with a *hot-spot* [14].

Azimov et al., [15] proposed an alternative model: the *wet-spot model*. According to this model, the so-called *Azores hot-spot* could be explained by a melting anomaly that is not due to a thermal anomaly, but is a result of the presence of water in the mantle. The authors argued that the proposed model would be able to simultaneously explain the anomaly of the crustal thickness and the presence of certain chemical elements observed along the MAR in the vicinity of the Azores plateau, whose origin is usually associated with a hot-spot. In contrast, [16] argued that negative anomalies in the propagation velocity of seismic waves do not necessarily indicate the existence of a hot mantle. The chemical composition, the mineralogy, the presence of volatile activity, the inelasticity, and the anisotropy can also cause this low velocity. Mantle plumes have been the focus of intense debate, and the controversy concerning their origin continues today [16].

Global kinematic models provide expansion velocities for the Mid-Atlantic Ridge. From north to south, these velocities are as follows: (i) in accordance with the Nuvel-1A model [17]: north of the platform, the expected velocity is about 1.7 cm/yr, and the average value to the south is 1.2 cm/yr (parallel to the transforming faults); (ii) Luis et al. (1994) proposed a model in which the relative plate motion at the MAR in the Azores region decreased from 4 cm/yr to 1.4 cm/yr, in the interval from 10 to 3.85 Ma, and then increasing then to a value of 2.5 cm/yr according to the N100° W azimuth. The same models [8,17] suggest that in the third arm of the ATJ, there is a relative motion between the EA and AF plates of the right disconnection of the trans-tension type with a length component of 3 mm/yr. This is a considerably lower rate of expansion, which indicates this border has ultra-slow expansion characteristics (<10 mm/yr).

Different explanations have been proposed for the origin of the Terceira Ridge. According to some authors, this ridge corresponds to an extensional zone normal to the MAR [7,18] or an oblique extension [19,20]. Madeira and Ribeiro [21] proposed a leaky transform model. Lourenço et al. [2] proposed that a diffuse boundary simultaneously acts as an ultra-slow spreading centre and as a transfer zone between the MAR and the dextral Gloria Fault, because it accommodates the differential shear motion between the Eurasian and African plates. Recently, Vogt and Jung (2004) suggested that the Azores axis, with a length of 550 km, is the slowest spreading organised accreting plate boundary in the world, with a typical mixture of faulting mechanisms. Understanding the dynamics of the Azores triple junction due to the very slow seafloor spreading rates at the Terceira Ridge (<1 cm/yr). Nevertheless, the high level of seismicity along the MAR and the Terceira Ridge (Fig. 1 and 2) is strongly associated with seafloor spreading and the northeastward motion of the Eurasian plate with respect to the African plate [8] (Fig. 1). This argument was also supported by [22], who proposed an elastic model with two possible locations of the Azores triple junction: along the extension of the Terceira Ridge at the same latitude as Graciosa Island or on the Faial fracture zone at the same latitude as Faial Island (Fig. 1).

3 Seismotectonics and geodynamics of the Azores-Gibraltar region

The seismicity of the Azores region is associated the plate boundary between the Eurasian (EA), African (AF), and North American (NA). In general, the seismicity is of low ($M < 5$) and moderate ($5 \leq M \leq 6$) magnitude and is located at shallow depths ($h < 20$ km). Since 1920, only two earthquakes have had Ms~7: one on 8 May 1939, with an epicentre east of Santa Maria Island, and the other on 1 January 1980, with an epicentre between the Terceira and Graciosa Islands. Most of the seismic activity is located on the MAR; a second zone with important seismic activity is located along the NE–SW direction from the ridge to Graciosa Island, through Pico and the Faial islands and continuing into the Terceira Ridge (Fig. 2); the East Azores fracture zone is practically inactive. From the historical seismicity, we know that large shocks occurred in the Azores with maximum intensities of X (modified Mercalli — MM) [23]. The data compiled by [23] since the beginning of the settlement lead us to conclude that the Azores region has been affected by 13 earthquakes with intensities equal to or greater than VII (Table I); these earthquakes caused about 6,000 deaths and the destruction of some islands in the archipelago. Table 1 and Fig. 2 show historical earthquakes with a maximum intensity of VII or larger and earthquakes with magnitudes greater than 4.0 for the period of 1973–2012 (National Earthquake Information Centre Data File — NEIC). Figure 2 shows that the historical and instrumental seismicity follow the same trend as the islands: approximately ENE from the MAR

Table I. Historically and instrumentally determined epicentres reported in the studied area, based on Nunes and Ribeiro (2001). I_o = maximum intensity, MM = Modified Mercalli, mb = body wave magnitude, Ms = surface wave magnitude, Mw = moment magnitude.

Date (d/m/y)	Latitude	Longitude	I_o (MM)	Magnitude	Location
22/10/1522	37.7°N	25.4°W	X	-	S. Miguel
24/05/1614	-	-	IX	-	Terceira
09/07/1757	38.6°N	28.0°W	XI?	-	S. Jorge
21/01/1837	-	-	IX?	-	Graciosa
15/06/1841	-	-	IX	-	Terceira
31/08/1926	38.5°N	28.6°W	X	-	Faial
08/05/1939	37.0°N	24.5°W	VII	7.0-7.1	S. Maria
26/06/1952	37.7°N	25.3°W	VII	-	S. Miguel
26/06/1952	38.7°N	28.2°W	VIII	5.5 mb	S. Miguel
13/05/1958	38.6°N	28.8°W	VIII/IX	-	Faial
21/02/1964	38.7°N	28.2°W	VIII	5.5 mb	S. Jorge
01/01/1980	38.8°N	27.8°W	VIII/IX	7.2 Ms	Terceira
09/07/1998	38.7°N	28:5°W	VIII/IX	6.2 Mw	Faial

(30° W) to Terceira Island (where the 1980 and 1998 shocks were located) and SE from Terceira Island to San Miguel Island (the 1997 earthquake was located SE of Terceira Island). The seismicity stops at 24° W, where the Terceira Ridge joins with the Gloria Fault, which is considered seismically inactive (Figure 1).

Despite the fact that instrumental seismic information has been recorded in the Azores since the beginning of the twentieth century, the regional network was not reformulated until the earthquake on 1 January 1980; there have increases in both the number of stations and their capacities, enabling a considerable improvement in the accuracy of locations and the network’s detection sensitivity.

4 Focal mechanisms

The study of the focal mechanisms of Azores earthquakes is the basis of seismotectonic research that enables a characterization of its complex geodynamics. Since 1972, several studies of seismic sources have been carried out in the Azores-Gibraltar region. Some of these studies were based on polarities, and some focused on modelling the form of the body waves.

Table II. Focal parameters of the Azores area used to plot the focal mechanisms and the seismic moment tensor shown in Figs. 3 and 4. CMT = centroid-moment tensor (Harvard); BUF=Buforn et al., 1988; BOR = Borges et al., 2007. For the magnitudes of w and s, we write Mw and Ms, respectively.

Nº	Date (d/m/y)	Lat (°N)	Lon (°E)	Depth (km)	M	Mo ($x10^{17}$ Nm)	Strike	Dip	Rake	PF	PQ	TF	TQ	REF.
1	20/01/1993	38.39	-29.34	15	5.4w	1.20	132	33	-59	151	67	20	16	CMT
2	11/12/1973	38.74	-28.67	15	5.0w	0.34	329	58	-20	294	35	197	10	BUF
3	09/07/1998	38.65	-28.63	7	6.0w	14	153	85	6	288	1	18	8	BOR
4	23/11/1973	38.46	-28.31	15	5.1s	2.0	23	90	-179	247	1	157	1	BUF
5	01/01/1980	38.81	-27.78	7	6.8w	190	149	85	-2	104	5	14	2	BOR
6	28/06/1997	38.41	-26.64	15	5.1w	0.58	290	44	-114	1	88	243	1	CMT
8	20/04/1968	38.30	-26.60	15	4.6w	0.09	117	42	89	28	3	220	87	BUF
7	06/09/1964	38.30	-26.60	15	5.1w	0.54	185	62	3	142	17	46	21	BUF
9	27/06/1997	38.33	-26.68	7	5.8w	7.0	290	44	-114	115	73	216	3	BOR
10	21/11/1988	38.34	-26.27	15	5.9w	7.10	345	29	-37	348	55	217	25	CMT
11	27/06/1997	38.26	-26.16	15	5.2w	0.62	284	27	-147	102	54	236	27	CMT
12	02/12/1981	38.38	-26.13	15	5.6w	3.20	141	42	-80	162	82	43	3	CMT
13	21/01/1989	37.92	-25.92	15	5.7w	3.40	131	41	-87	195	85	39	5	CMT
14	16/10/1988	37.38	-25.16	15	5.3w	0.89	303	90	180	168	0	258	0	CMT
15	05/07/1966	37.60	-24.70	18	5.0w	0.41	180	48	30	129	12	24	48	BUF
16	04/07/1966	37.50	-24.70	10	5.5w	1.90	341	49	-42	318	55	219	6	BUF
17	08/05/1939	37.40	-23.90	15	7.1s	199	41	35	-154	234	49	355	24	BUF
18	09/03/1996	37.13	-23.85	15	5.7w	3.80	319	28	-106	85	71	241	18	CMT
19	09/12/1991	37.22	-23.61	15	5.2w	0.82	330	45	-90	180	90	240	0	CMT
20	09/09/1984	36.93	-24.60	12	5.3w	0.95	178	37	-79	221	79	81	8	CMT
21	26/06/1989	39.11	-28.32	15	5.8w	5.40	105	32	-110	248	72	29	14	CMT
22	23/09/1989	39.27	-29.24	15	5.1w	0.44	233	45	-90	180	90	143	0	CMT
23	01/08/2000	38.79	-29.01	15	5.1w	0.51	97	62	-170	316	26	53	13	CMT
24	30/11/2002	39.25	-28.45	15	5.1w	0.52	106	45	-129	300	63	42	6	CMT
25	05/04/2007	37.45	-24.62	12	6.2w	41	129	44	-89	0.	90	38	1	CMT
26	04/11/2007	37.40	-24.39	12	6.0w	11	133	44	-87	0	90	41	1	CMT

Due to the moderate nature of the seismic activity in the Azores, together with the poor azimuthal coverage of the seismic area (unfavourable azimuthal distribution of stations regarding the epicenters), it is often a difficult task to obtain the focal mechanisms for this area. Hence, the number of focal mechanisms currently available is relatively small in comparison with the data in Portugal Mainland and other parts of the globe. Consequently, almost all of the currently available solutions calculated by global or regional institutions (NEIC-National Earthquake Information Centre; USGS - U.S. Geological Survey; the seismology group at Harvard University; EMSC - European Mediterranean Seismological Centre) correspond to events of moderate to greater magnitudes (M>5.5) or were obtained by studies of regional and teleseismic data. It is important to highlight some of the studies that have significantly contributed to the understanding of the geodynamics in this region.

The first studies of focal mechanisms were performed by [19] . Based on their results and previous knowledge of the region's seismicity, they established the first geodynamic model for the Azores-Gibraltar region. Arroyo and Udías [24] studied the focal mechanism of the 1969 earthquake (Table II) and its aftershocks. They estimated the fault dimensions and the source parameters for this earthquake and, using the focal mechanisms of four earthquakes that occurred near the Mid-Atlantic Ridge and the Azores region, they interpreted these results in the context of the Azores-Gibraltar seismotectonics. Udías et al. [25] studied the seismicity and the focal mechanisms of the Azores-Alboran region using new data, and they proposed a new seismotectonic model for the whole region based on changes in the seismicity and focal mechanisms. They suggested a division into four different parts, along the boundary from the MAR in the west to Gibraltar in the east. Later, Grimison and Chen [26], using the World Wide Standardized Seismograph Network's (WWSSN) long-period records, obtained the focal mechanism of the January 1st 1980 earthquake from body-wave modelling, bringing to light, for the first time, the complex nature of the rupture process that characterises the earthquakes in this region.

The distribution of more than 400 aftershocks of the 1 January 1980 earthquake recorded at the telemetric seismic network installed on the Terceira, S. Jorge, Graciosa, and Pico Islands showed a N150° E trend; this agrees with one of the fault planes estimated for the main shock and indicates a pure left-lateral strike–slip motion with a vertical plane between 149° and 154° [7, 26, 27]. Hirn et al. [27] obtained a composite solution for the aftershocks that coincides with the main event using polarities recorded by a temporary network. Buforn et al. [7] analysed, among others, eight focal mechanisms for the events located on the Azores Plateau (where they found a diversity of mechanisms without any identifiable patterns) and eleven earthquakes on the MAR (where normal and strike-slip fault mechanisms are typically associated with an expanding dorsal). These results provided a more detailed outline of the geodynamic behaviour of the area and determined its seismic deformation rate.

An ocean bottom seismometer survey was carried out for 27 days in the Azores region in 1992. This survey showed a concentration of hypocentres along the islands themselves, with a maximum depth of 15 km. The distribution of epicentres confirmed that the seismicity is distributed along the strip corresponding to the Terceira axis [28]. A more detailed analysis of the distribution of epicentres allowed for the identification of alignments with azimuths that agree with the fault of the January 1st 1980 earthquake. During the recording period, there were two events of moderate magnitude (magnitudes 3.2 and 3.4), with epicentres located near that of the January 1st 1980 earthquake. The focal mechanism solution obtained describes a strike-slip motion with nodal planes similar to those of the January 1st 1980 earthquake [1,7].

After the 1998 earthquake, a temporary seismic network composed of seven short-period stations was installed on the Faial, Pico, and S. Jorge Islands. More than 1200 aftershocks were recorded, showing NNW–SSE to ENE–WSW alignments [29]. The good azimuthal coverage offered by this network and the dynamic ability of the stations provided the locations of the aftershocks of this earthquake with high accuracy. Unlike the January 1st 1980 earthquake, the alignments defined by the aftershocks of the 1998 earthquake occurred in two preferred directions, roughly coinciding with the nodal planes of the mechanism of the main event, thus making it impossible to identify the fault plane responsible for the main quake [29]. Given the large number of aftershocks of this earthquake, it was still possible to calculate 18 focal mechanisms in which strike-slip motions clearly dominated [30,31].

The first study of Azorean earthquakes using extensive source models was carried out by [1,2]. This work was made possible by the existence of digital records of the long period of the 1980 earthquake (Mw = 6.8), obtained by the GDSN network, and the broadband data of the July 27th 1997 (Mw = 5.9) and July 9th 1998 (Mw = 6.0) earthquakes, obtained by worldwide networks (IRIS – Incorporated Research Institutions for Seismology).

Two important results of this study [1] are (i) the determination of the fault plane using the directivity effect and (ii) a description of the rupture using an extended source model. From the directivity study, these authors obtained a NNE-SSW fault plane with left-lateral motion for the 1980 and 1998 shocks. The focal mechanisms defined the seismotectonic regime of each region, providing correlations between the geophysical information and the geological data. In some cases—in particular, the three events in the studied Azores region—it was possible to analyse the rupture process [1], which helps to identify the heterogeneities in the focal area. The main directions of the stress pattern can be obtained from the focal mechanisms (the directions of the P and T axes of the mechanisms) and allow us to define an average extension orientation in the region.

5 Seismic deformation

In Table II and Figure 3, the focal mechanisms (magnitude ≥ 5) of the Azores region are given. These mechanisms were obtained from waveform inversion, centroid-moment tensor inversion, and body-wave polarities. Note that most of the mechanisms from the triple junction to Terceira Island correspond to strike–slip solutions with planes along the NNW–SSE and NNE–SSW directions (Zone I, Fig. 2). Events are mostly located between the Terceira Ridge and the Gloria fault (Zone II, Fig. 2). The 1980 earthquake is the largest in the studied area (with the exception of the earthquake located SW of the Azores Islands), with a magnitude Mw=6.8. One problem for this region is the selection of the fault plane for the 1980 and 1998 shocks. The aftershock distribution obtained for the 1980 event by [27] suggests a NNW–SSE fault plane. For the 1998 shock, Vales et al. [29] obtained two alignments for the aftershocks, both with the same trend as the two planes obtained from the focal mechanism study. In this study, the directivity function indicates that the NNW–SSE plane was the fault plane for both events, with the rupture propagating to the SSE.

The 1939 and 1980 shocks had magnitudes of Ms~7; because the other earthquakes had magnitudes between 5.0 and 6.0, it is difficult to quantify the stress regime in this area (Table II and Fig. 2). One approach is to use the total seismic moment for the area, which is defined as the sum of the moment tensors calculated from individual solutions:

$$M_{ij}^{total} = \sum_{k=1}^{N} M_0^k m_{ij}^k \qquad (1)$$

where N is the number of earthquakes, M_0 is the scalar seismic moment of each event, and mij represents the seismic moment tensor components. Larger earthquakes with high values of Mo make larger contributions to the estimation of the total seismic moment tensor. Using the solutions given in Table 2 and Eq. (1) we estimated the components of Mij for the two regions represented in Figure 2: in Zone I, the total seismic moment tensor corresponds to strike–slip faulting with horizontal pressure and tension axes along the E–W and N–S directions, respectively. The compensated linear vector dipole component (CLVD, which is the amount of non-DC) is 8%, which confirms that the focal mechanism presented in Figure 3 is representative of the faulting type in Zone I. For Zone II, the total moment tensor corresponds to normal faulting with a horizontal tension axis along the NE–SW direction, normal to the Terceira Ridge, with a CLVD of 14%. The low amount of CLVD obtained for both zones confirms that both dominant mechanisms are representative of the stress regimes and, consequently, of the changes between the two zones.

Table III - The rate of deformation calculated from relation (2) (in the text) for the two zones (I and II) based on the data listed in Table II: T=84 years, μ=3.3x1011 dyne cm-2, the value of W is chosen based on the slope of the fault plane, assuming that this plane covers the entire seismogenic layer (height of 10 km).

Zones	L(km)	W(km)	M_o	Dip (°)	Rate of deformation (mm/yr)
Zone I	172	10	22	90	6.7
Zone II	250	14	30	45	3.1

The rotation of the tension and pressure axis from Zone I to Zone II is in agreement with the results obtained by Lourenço et al. (1998), who used the morphological characteristics of the ocean floor based on the linear volcanic ridge orientations.

From the seismicity and focal mechanisms, we estimated the average slip velocity for Zones I and II, using data from earthquakes with a magnitude of Ms≥4.0 that occurred between 1923 and 2007 and the following expression [1,7,33]:

$$\Delta \dot{u} = \frac{\sum M_0^i}{\mu LWT} \qquad (2)$$

where M_0 is the total scalar seismic moment, μ is the rigidity coefficient, LW is the fault area, and T is the period. For earthquakes without an estimation of the seismic moment Mo, an empirical relation between Mo and Ms was derived for Azores earthquakes with magnitudes greater than Ms=4.4 [32] for the period of 1973–1997 (ISC catalogue). Table III presents the parameters used to calculate the rate of seismic deformation for the two areas, as given by equation (2).

From these results and the seismic moment tensor we can conclude that the average rates of slip for Zone I and Zone II are 6.7 mm/yr and 3.1 mm/yr, respectively, which corresponds to a horizontal extensional rate of 2.3 mm/yr in Zone II in a N46° E direction, as deduced from the total seismic moment tensor (Fig. 10). In Zone I, the relation between the strain rate and the relative plate movement is more complex because the strain release essentially occurs by strike–slip motion. Nevertheless, if we assume that Zone I is a large area of deformation confined by the EA and AF plates, where their relative movement is accommodated by block rotation McKenzie and Jackson [34], we could conclude that, for this zone, the deformation is accommodated by seismic strain with an extensional component of movement in the N53° E direction, as deduced from the total seismic moment tensor. The value of the horizontal extensional rate for Zone I depends on the choice of the distributed deformation model [34], a problem that is not the focus of this work.

The average seafloor spreading rate for Zones I and II is 4.2 mm/yr, similar to the value (~4.2 mm/yr) obtained from GPS data [35,36]. This value is supported by the relative rate of motion (~4.5 mm/yr) predicted by the Nuvel-1A model [27] in the central and eastern islands of Azores. One difference between the direction of extension obtained in this work (toward N53° E and N46° E in Zones I and II, respectively) and that predicted by Nuvel-1A (toward N71°E) has been found. Some displacement is caused by a seismic process, which takes the form of folding, thickening, plastic deformation, or slow slip—these are not included in our estimation, suggesting that our seismic strain analyses may underestimate the geological deformation. Due to the uncertainty surrounding large historical earthquakes (Table 1), we have used only the instrumental period in this estimation. Discrepancies between the seismic deformation rates and geodetic values may be explained in terms of other types of deformation that were caused by seismic processes (folding, thickening, plastic deformation, or slow slip) that occur on the Azores Plateau but that were not considered. As a result, the seismic strain analyses may underestimate the geological deformation. Moreover, the seismic catalogue used for the calculations presented here may not be able to take into account the events of the high recurrence period. Given the shortness of the catalogue duration used in this study and the variability in the absolute rate, we do not necessarily expect spatial similarity between the geodetic deformation and the seismicity.

6 Current and future seismologic developments in the Azores Area

Prediction of ground motion in future earthquakes is the central challenge of seismology. Whoever, due to multiple spatial and temporal scales characterize earth response and due highly heterogeneous material properties and uncertainty in their geologic, this can be a complex task. Large limitations could be found when current methodologies for estimation of ground motion are applied to regions like the Azores Area for different kind of reasons: i) seismological data are sparse and do not cover sites were site effects could occur; ii) spatio–temporal description of the rupture and directivity is not known and they strongly influence the generation of near–field seismic motion; iii) Simple Peak Ground acceleration (PGA) and Peak Ground Velocity (PGV) description of the seismic motion does not satisfactorily response to the actual needs.

In the last years, due to 3D structural model improvement in SW Iberia and Lower Tagus Valley area several studies have successful obtained strong-ground motion synthesis for a rage of frequencies up to 1 Hz [4, 6,37]. However, due to the existence of small-scale heterogeneities in the earthquake source process and crustal properties, matches the high-frequency. We can say that observed high-frequency motions (T≥1s) behave stochastically and on this base many authors have developed stochastic models [38]. A current project for the Azores Region (SIGMA project, funded by FCT) are focused on broadband strong motion simulation by combining deterministic low-frequency waveforms with stochastic high-frequency synthetics seismograms. The merge of the two models will allow a broad band and a credible model for computing strong ground motion and it will contribute to a significant progress in strong ground motion modeling of earthquakes for the Azores Area.

7 Conclusions

Two types of seismic behavior in the Azores region divide the region into two zones: Zone I (from 30° W to 27° W) and Zone II (from 27° W to 23° W). The seismicity is along the ENE-WSW direction in Zone I and the NW-SE direction in Zone II. Earthquakes located in Zone I reveal a predominant strike-slip motion with horizontal extension along the N-S to NNE-SSW direction and horizontal compression in the E-W direction. The change in the stress direction in the Azores region is based on all the available seismological data and shows the complexity of the region. This difference in the stress pattern for regions I and II is also present in the velocities estimated from the seismic data, because the velocity is higher in region I with strike–slip movement, 6.7 mm/yr, compared with 3.1 mm/yr for region II with normal faulting. The overall regional stress pattern for both zones corresponds to a horizontal extension with an average velocity of 2.3 mm/yr for the whole region. The deformation of the Azores region is accommodated by an average seismic strain rate of about 4.4 mm/yr along the NW direction.

The Azores archipelago can be considered a moderate seismic region. Its location near the triple junction, which is associated with a slow rift, gives it this characteristic. Understanding the seismic phenomenon of the Azores requires a geodynamic model that describes the observable phenomena on different space and time scales, whether the phenomena are of a seismic, magmatic, geomorphologic, geodetic, or geomagnetic nature. Seismic source studies appear to be the most direct way to achieve this objective due to the following: i) identification and qualification of faults, ii) characterization of the stress field, and, consequently, iii) estimates of the deformation rates. Although the importance of this problem has been recognized and although there has been quality work on this subject over the past 36 years, the number of focal mechanisms existing in the region is small compared with that of other regions of the world with similar characteristics. The main reason for this scarcity of focal mechanisms is the poor azimuthal distribution of seismic stations. The solutions currently available correspond almost exclusively to events of greater magnitude that are capable of producing data on a global scale.

Because this seismic knowledge is important for reducing various types of risks in this region, efforts need to be made at various levels. First, better data needs to be compiled, and the capacity of seismic observation in the Azores should be increased. Furthermore, there should be studies of the improvement of seismotectonic and geodynamic models and a development of the ability to simulate scenarios with the goal of forecasting strong ground motions and their consequences on the associated building stock.

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"TRANSIENT KNICKPOINTS" NO LEITO DOS RIOS, SIGNIFICADO NA EVOLUÇÃO DA PAISAGEM

ANTÓNIO MARTINS
Departamento de Geociências, Centro de Geofísica de Évora,
Universidade de Évora, Rua Romão Ramalho, 59,
7000-671, Évora, Portugal. aam@uevora.p t

BENTO CALDEIRA
JOSÉ BORGES
Departamento de Física, Centro de Geofísica de Évora,
Universidade de Évora, Rua Romão Ramalho,
59, 7002-554 Évora, Portugal

Neste trabalho apresenta-se uma síntese sobre a relevância dos knickpoints na estruturação do perfil longitudinal dos rios e indirectamente, na evolução da paisagem. Aborda-se o significado dos knickpoints relativamente aos conceitos de equilíbrio e desequilíbrio do perfil longitudinal, difundidos na literatura. Leis que regem a incisão fluvial, testadas em modelos físico-matemáticos, estabelecidos nas duas últimas décadas, são também referidas. Salientam-se as potencialidades que decorrem deste tipo de análise quantitativa dos perfis longitudinais dos rios, nomeadamente: a identificação de troços relíquia e troços ajustados a novas condições de equilíbrio; a reconstituição de antigos leitos (erodidos) a jusante de knickpoints transitórios e a correlação com outras unidades geomorfológicas, como sejam os terraços fluviais. A relação entre o comportamento das vagas de erosão com a morfologia dos knickpoints e com certos modelos de evolução da paisagem é salientada neste trabalho.

1 Introdução

Na geomorfologia fluvial, termo "knickpoint" (kp) aplica-se a mudanças abruptas no declive dos rios, geralmente manifesto através de rápidos e quedas de água no perfil longitudinal. Além da espectacular atracção turística, de constituírem obstáculos à navegação, ou de potenciarem o aproveitamento hidroeléctrico, estes detalhes geomorfológicos, representam igualmente um importante significado na evolução da paisagem e, desde cedo, suscitaram a curiosidade dos geomorfólogos [1], [2][6], [18].

Nas últimas duas décadas o termo knickpoint tem merecido várias definições, sendo importante distingui-lo do termo "knickzone" (kz), muitas vezes confundidos. A kz aplica-se a um troço do perfil longitudinal do rio mais inclinado do que os troços adjacentes, a montante e a jusante [9]. A rotura do declive situada na extremidade superior da knickzone constitui um kp [4]. Deste modo, um kp corresponde ao ponto de inflexão, entre um troço com forte declive (kz) e um troço com menor declive, situado a montante [8]. À escala local, a morfologia do kp divide-se no lábio superior, "knickpoint lip", na face do knickpoint, "knickpoint face"e na rotura de declive basal,"basal knick" [5].

No que respeita aos processos operantes, os kp e as kz são locais de acentuada incisão do rio [19], e por isso, têm um significado especial na geomorfologia fluvial e na evolução da paisagem. Deste ponto de vista, um kp corresponde à expressão geomorfológica de um desequilíbrio no perfil longitudinal do rio, provocado por factores externos ao sistema fluvial (variações do nível de base, tectónica local ou regional etc). Por este motivo, muitos kp situam-se no limite de dois troços do rio com características geomorfológicas completamente distintas: um troço a montante do kp, ainda não afectado pelas condições de desequilíbrio (troço relíquia) e outro troço, a jusante do kp, ajustado a novas condições de equilíbrio, impostas por variações dos factores externos ao sistema fluvial (Fig. 1). O exemplo mais paradigmático desta situação é a sucessão de rápidos e quedas de água do rio Guadiana no local conhecido por "Pulo do Lobo". É este tipo de kp que mais interessa na evolução da paisagem, precisamente por serem móveis no perfil longitudinal do rio. São por isso designados kp transitórios "transient knickpoints" na literatura anglo-saxónica. Estes kp migram no sentido da desembocadura para as cabeceiras da bacia hidrográfica, transmitindo a toda a bacia as novas condições de equilíbrio do sistema fluvial, impostas pelas variações dos mecanismos exteriores que controlam o sistema fluvial.

Outros kp, estão relacionados com as diferenças litológicas. Estes encontram-se em troços de rios, na transposição rochas de elevada resistência para litologias mais brandas. Este tipo de kp permanece estacionário no leito dos rio, são designados "permanent knickpoints". Um exemplo deste tipo de kp é o Cachão da Valeira no rio Douro, situado na bordadura de uma maciço granítico e que ficou célebre pelos trágicos naufrágios ocorridos naquele local.

A formação dos knickpoints deve-se a vários mecanismos, tais como, variações do nível de base, variações de caudal relacionadas com processos de captura fluvial, variação no fluxo de sedimento, deformações tectónicas e, como foi referido, à resistência do bedrock.

Neste trabalho aborda-se, muito sucintamente, algumas leis que regem a migração dos knickpoints transitórios e suas implicações na evolução do relevo.

2 Importância dos "knickpoints" na evolução da paisagem

Os canais de fluviais correndo em litologia uniforme tendem a desenvolver, no longo prazo, um perfil longitudinal com um declive delicadamente ajustado para fornecer, com o caudal disponível e as características prevalecentes do canal, a velocidade de fluxo necessária para o transporte da carga vinda de montante.

Este conceito de perfil equilíbrio [13] tem associado, em muitos casos, o desenvolvimento de um perfil longitudinal, onde o gradiente do rio diminui gradualmente para jusante. Além disso, o conceito de equilíbrio nos sistemas fluviais significa que outros parâmetros como clima, fornecimento de sedimento, caudal e levantamento tectónico têm de estar ajustados para alcançar tal condição de equilíbrio dinâmico [13], [21], [22]. As condições de desequilíbrio manifestam-se nos sistemas fluviais através de processos de agradação, ou de incisão como acontece nos locais dos knickpoints, que são sítios de acelerada erosão.

A forma côncava ("concave up") do perfil de equilíbrio pode ser definida por equações matemáticas que relacionam a variação do declive com a distância, ou variação do declive com a área da bacia. Nas duas últimas décadas, tem sido largamente difundido na literatura que o gradiente do rio, na situação de equilíbrio, diminui segundo uma função potencial da área de drenagem [3], [16], [21], [22]. Uma nova formulação do perfil de equilíbrio, baseada na diminuição potencial do gradiente do rio com o aumento da distância para jusante, foi também estabelecida durante a última década [7]. Mais concretamente, é condição do perfil de equilíbrio, ajustar a uma relação bi-logritmica linear entre o declive do perfil e a distância. Os troços em desequilíbrio, como os knickpoints, ou os que não atingiram ainda a situação de equilíbrio aparecem representados com pontos distribuídos de forma aleatória nas representações gráficas da distância versus declive [7]. A formulação de um modelo matemático do perfil idealizado permite identificar facilmente os troços que atingiram a situação de equilíbrio dinâmico e reconstituir o perfil de equilíbrio para os troços a jusante, onde a passagem prévia do knickpoint já destruiu esse perfil de equilíbrio (Fig. 1).

Lembramos que os "transient kp" se comportam como vagas de erosão que viajam ao longo do perfil longitudinal, no sentido oposto ao da corrente. A reconstituição do perfil de equilíbrio permite calcular o valor incisão em cada ponto a jusante do kp, e estimar a quantidade de material erodido em termos de área (2D) e volume (3D). Existe hoje à disposição dos investigadores, fontes de dados topográficos digitais, software específico e equipamento informático com uma capacidade de tratamento de dados muito superior ao que existia há duas décadas[8] .

Em termos de evolução da paisagem, à escala de milhares a centenas de milhares de anos, é interessante verificar a relação dos kp com os terraços fluviais [15]. Nos leitos rochosos, os terraços de rocha, "strath terrace", correspondem a situações de equilíbrio dinâmico. Considerando este facto, faz todo o sentido correlacionar o perfil relíquia a montante de um kp com terraços de rocha suspenso sobre o leito actual, a jusante do kp. Numa eventual correlação destes elementos geomorfológicos, é crucial a determinação da idade do terraço no cálculo da velocidade média de propagação do kp.

A vaga de erosão e velocidade de propagação são analisadas em vários trabalhos [10], [11], [20], [26], [27] podendo ser escritas segundo as equações 1 e 2

$$\frac{\partial h}{\partial t} = KA^m S^{n-1} \left|\frac{\partial h}{\partial x}\right|, \quad \frac{\partial h}{\partial x} < 0, \qquad (1)$$

onde *h* é a elevação do leito do rio relativa à coluna rochosa subjacente, *t* é o tempo, *S* é o gradiente do canal, *A* é a área de drenagem e *K* representa o factor de eficiência erosiva relacionado com a litologia, clima e geometria do canal, os expoentes *m* e *n* são dois parâmetros cujos valores se relacionam com propriedades físicas e morfológicas do meio (rigidez dos materiais, agentes de erosão, morfologia)

$$C \simeq KA^m S^{n-1} \tag{2}$$

onde C é a velocidade da vaga de erosão.

Em leitos rochosos, a vaga de erosão assume um comportamento cinemático não linear. Por exemplo, a distância percorrida a partir da desembocadura é maior nos cursos de água com maior bacia de drenagem, mas a velocidade de propagação vai diminuindo com a distância percorrida, à medida que a área de bacia, a montante do kp, vai sendo cada vez mais reduzida. A partir de uma determinada área mínima (área crítica) o kp não progride mais.

Os valores assumidos pelo expoente n (equação 1) são determinantes na morfologia do kp [23], [25]. Aquele expoente pode assumir valores de n =1, $n < 1$ e $n > 1$. Com valores de $n = 1$ a equação (1) reduz-se a uma função linear, constante. Em termos morfológicos, traduz-se no retrocesso paralelo do kp. Com valores de $n < 1$ a velocidade de propagação da vaga de erosão é maior nos troços de menor declive, traduzindo-se em kp com fortes abruptos na base "abrupt basal knick" e declive mais suave no topo. Com valores de $n > 1$ a vaga de erosão progride mais rapidamente nos troços com maior declive, neste caso, o segmento com maior declive situa-se no topo do kp (knickpoint lip), adquirindo o segmento abaixo uma forma mais suave com a concavidade voltada para cima "smooth graded-like morphology" [24].

Estas formas de comportamento da vaga de erosão podem ter implicações na evolução tridimensional do relevo a escalas mais alargadas, podendo constituir os fundamentos da evolução de paisagens, com morfologias mais próximas do modelo de retrocesso paralelo das vertentes "back wearing model" [12, 17], ou das que seguem o modelo mais próximo do rebaixamento das vertentes "down wearing model" [2].

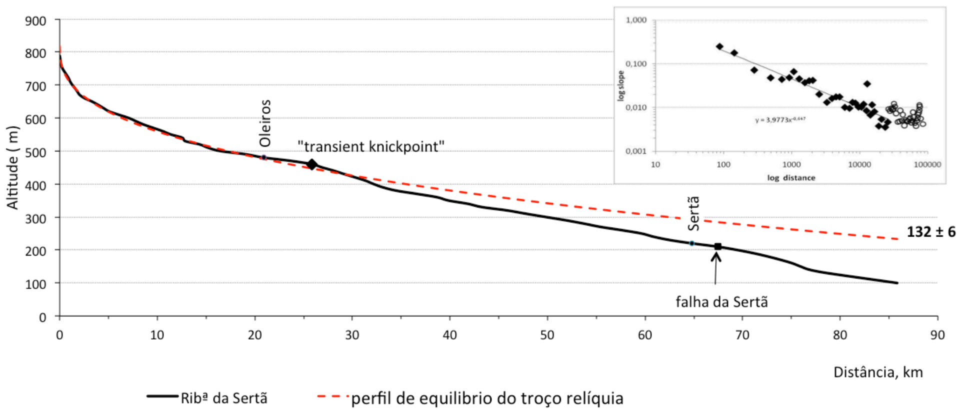

Fig. 1 Perfil longitudinal da Ribª da Sertã. O perfil relíquia situa-se a montante do knickpoint transitório "transient knickpoint". A jusante do knickpoint, encontra-se o perfil ajustado a novas condições de equilíbrio, impostas pela variação do nível de base. O gráfico inserido mostra que o perfil relíquia (losangos pretos) se encontra próximo da situação de equilíbrio, enquanto o troço a jusante do knickpoint (círculos brancos) se encontra ainda numa situação de desequilíbrio. A projecção para jusante do perfil relíquia permite estimar o valor da incisão na desembocadura do rio Zêzere (132 ± 6 m).

3 Conclusões

Nas últimas duas décadas, a investigação sobre roturas de declive no perfil longitudinal dos rios, designados na literatura geomorfológica por knickpoints, progrediu de forma assinalável. Este facto deve-se, em grande medida, à enorme capacidade de extracção e tratamento de dados topográficos digitais a partir de várias fontes, situação que não existia nas décadas anteriores. A colaboração entre investigadores com diferente formação permitiu uma abordagem quantitativa a partir da observação/medição geomorfológica. Assim, foram deduzidas leis que regem a incisão fluvial, quantificadas pelos modelos físico-matemáticos difundidas na literatura especializada. Uma das mais interessantes equações é a que define o perfil de equilíbrio dinâmico, cuja projecção para jusante permite reconstituir o antigo leito do rio nos troços ajustados ou em vias de ajustamento a novas condições de equilíbrio.

A escala de análise feita aos perfis longitudinais dos rios e a regularização dos mesmos, a um nível muito próximo do perfil de equilíbrio, pressupõe escalas temporais de milhares a centenas de milhares de anos. A esta escala temporal, a correlação de troços relíquia, separados por knickpoints transitórios, com sequências de terraços fluviais, situados a jusante, afigura-se coerente. Taxas de incisão fluvial e de migração média dos knickpoints poderão ser estimadas, desde que se conheça a idade de terraços fluviais correlativos de troços relíquia, ou o momento da partida do knickpoint na desembocadura. No mesmo curso de água, a identificação de troços relíquia e de troços ajustados às condições actuais revela-se fundamental no reconhecimento de paisagens cuja morfologia reflecte sobretudo condições herdadas e paisagens que reflectem o ajustamento às condições prevalecentes nas últimas dezenas de milhar de anos [14].

A natureza das vagas de erosão, nomeadamente, o carácter não linear da sua propagação, parecem ter forte implicação na morfologia dos knickpoints, mas também nos modelos de evolução de paisagem ("back wearing" versus "down wearing models"), os quais motivaram aceso debate entre geomorfólogos na primeira década do século passado.

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CENTRO DE ATIVIDADES LITOSFERA, MANTO E RECURSOS MINERAIS: O PERCURSO DA GEOLOGIA NO CENTRO DE GEOFÍSICA DE ÉVORA

CARLOS RIBEIRO

CGE – Dep.Geociências, University Evora, Apt. 94
7002-554 Evora, Portugal, cribeiro@uevora.pt

Geological research in Centro de Geofísica de Évora begun 12 years ago and has grown with the stabilization of the team. After 12 years of activity new challenges are facing the researchers devoted to the geological processes. This text presents a brief history of the Geology in the Centre, a synthesis of its current state and also has the expectation to contribute to the necessary reflection for its development in these changing times.

1 Enquadramento Histórico

Na sequência da reestruturação do Centro de Geofísica de Évora (CGE), a Linha de Investigação Terra-Sólida incluiu na sua estrutura o Centro de Atividades designado por Litosfera, Manto e Recursos Geológicos, dedicado ao estudo dos processos de Geodinâmica Interna e Externa que afetam a esfera sólida mais externa da Terra, ao estudo dos processos mantélicos e ao estudo dos Recursos Geológicos, tanto na vertente da sua exploração como na vertente da mitigação dos efeitos da sua utilização.

Parte relevante da investigação realizada neste Centro de Atividades é do âmbito da Geologia, incluindo a sua equipa investigadores dos mais diversos ramos como a Cartografia Geológica, a Geologia Estrutural, a Mineralogia, a Geoquímica, a Petrologia, a Sedimentologia e a Hidrogeologia.

Ao longo dos 12 anos em que a equipa do CGE (tanto na antiga estrutura como na atual) incluiu investigadores dedicados à Geologia, a pesquisa realizada pode ser separada em geologia de base, área na qual se incluem os estudos genéricos como os de cartografia geológica ou petrologia, por exemplo, e a geologia aplicada na qual estão enquadrados os estudos de hidrogeologia e de controle estrutural no dimensionamento e otimização da exploração de rochas ornamentais. A equipa de investigadores da área de Geologia passou por duas etapas distintas: partindo de um estádio inicial com dois Doutorados e vários estudantes de Doutoramento passou a incorporar essencialmente Doutorados a partir de 2007/2008; aos quais se foram associando vários bolseiros e alunos tanto de Mestrado como de Doutoramento. A transição entre a primeira e a segunda etapa assinala a mudança, mais profunda, de um período em que a maior parte da equipa se apoiava quase exclusivamente no financiamento plurianual para o desenvolvimento das suas atividades, para um período em que os investigadores se vão posicionando para se tornarem cada vez mais independentes desse financiamento, iniciando o processo de candidaturas aos seus financiamentos próprios, tanto como membros de equipa em projetos europeus, investigadores principais ou membros de equipa em projetos FCT, proponentes e membros de equipa em projetos de colaboração bilateral, prestações de serviços, entre outros.

2 Desafios do Futuro

Apesar de relevante para a história da investigação em Geologia no CGE, o primeiro período é aquele que menos contribui para a compreensão do momento presente, caracterizado por uma tendência cada vez mais acentuada de *abertura para o exterior*. Neste contexto a expressão à *abertura para o exterior* podem ser atribuídos dois significados distintos: ampliação das equipas de trabalho em que os membros se encontram envolvidos, quer a nível nacional, quer a nível internacional e; alargamento do âmbito geográfico da investigação em áreas dentro e fora do espaço europeu. Por outro lado, o fortalecimento das ligações com o exterior promove a diversificação dos temas de estudo, alinhando-os com o *state of the art* da investigação realizada nos países mais desenvolvidos.

A *abertura para o exterior* nem sempre foi acompanhada pela consolidação interna da equipa com o consequente aproveitamento de sinergias. Mais motivado por uma declarada falta de disponibilidade física do que por alguma eventual incapacidade de relacionamento interpessoal, a ausência de consolidação, trouxe-nos até ao presente momento que corresponde igualmente a um momento de transição para a próxima etapa de crescimento.

Na atual conjuntura, de incerteza sobre o financiamento nacional para a ciência, assiste-se a um crescente estrangulamento das verbas disponibilizadas pela FCT, para os programas plurianuais, cujo modelo de financiamento ainda não é conhecido pela comunidade científica à data deste manuscrito, para os projetos de investigação e para a formação avançada. O estrangulamento do financiamento interno em ciência obriga, em alinhamento com o previsto nas políticas europeias de ciência, à inclusão crescente das equipas portuguesas em projetos internacionais, como líderes de projeto ou como participantes. Para potenciar esta participação é necessário que o grupo dedicado à investigação geológica evolua em dois sentidos: a) prosseguir com uma abordagem holística do estudo dos objetos geológicos fortalecendo ligações interdisciplinares já existentes e estabelecendo outras dentro do CGE; b) desenvolver ligações fortes a equipas de outros países do espaço europeu. Este processo deverá ser uma aposta a curto-médio prazo por forma a não permitir que a investigação resvale para o campo da irrelevância. Para o conseguir será necessário que a equipa dedicada aos processos geológicos torne a centrar a sua atenção no seu próprio potencial, por forma a aumentar a sua "massa-crítica", aumentando as suas competências como um conjunto, tornando-se mais atrativa para as equipas internacionais.

Outro percurso que deverá a curto prazo ser percorrido é o da participação em redes de investigação nacionais, presentemente embrionárias, e que têm como objetivos principais a racionalização de recursos existentes no nosso país e o desenvolvimento de massa-crítica relevante no contexto europeu. Com este intuito em mente já se encontra o CGE envolvido na negociação de algumas dessas redes de investigação, alinhado com os objectivos do *roadmap* da FCT para os próximos anos.

Por último, em relação às temáticas geológicas a desenvolver pelos investigadores do Centro de Atividades, elas estão bem enquadradas nos desafios globais e nacionais estando em fase de franco desenvolvimento: a) os trabalhos de geologia de base no nosso território bem como em países fora do espaço europeu como Marrocos ou Timor Leste (inclusive abrindo uma janela de oportunidade de atrair novos potenciais interessados para a formação avançada); b) os trabalhos de caracterização do nosso potencial marítimo através dos estudos de geologia marinha de diversos âmbitos; c) os estudos de otimização de exploração de recursos minerais; d) a investigação relativa à mitigação dos efeitos de produção de gases com efeito de estufa nomeadamente a relativa ao armazenamento geológico de dióxido de carbono; e) os estudos das modificações climáticas globais do passado geológico.

CGE: DA DIVULGAÇÃO À INVESTIGAÇÃO

RUI DIAS
Departamento de Geociências e Centro de Geofísica de Évora,
Laboratório de Investigação de Rochas Industriais e Ornamentais,
Escola de Ciências e Tecnologia, Universidade de Évora
Centro Ciência Viva de Estremoz,
Évora, Portugal, rdias@uevora.pt

BENTO CALDEIRA
Departamento de Física e Centro de Geofísica de Évora,
Escola de Ciências e Tecnologia, Universidade de Évora
Évora, Portugal

ISABEL MACHADO
Laboratório de Investigação de Rochas Industriais e Ornamentais,
Escola de Ciências e Tecnologia, Universidade de Évora
Centro Ciência Viva de Estremoz,
Évora, Portugal

A divulgação da ciência e da tecnologia aparece como uma área fundamental na sociedade actual. Isto não será de estranhar pois os tremendos desafios que se colocam ao futuro de um planeta que a cada 12 a 13 anos tem mais mil milhões de habitantes e onde o consumo aumenta de uma forma exponencial, levanta problemas que eventualmente só o conhecimento científico poderá resolver; é importante que as opções que venham a ser tomadas possam ser compreendidas pela generalidade das pessoas, pois são justamente elas que irão ser mais afectadas por essas decisões. Ciente das responsabilidades sociais que lhe cabe enquanto instituição produtora de saber, desde sempre tem sido estratégia do CGE um forte empenhamento nas actividades de divulgação científica e tecnológica. A par do compromisso com a investigação e sua apresentação à comunidade científica, sem dúvida o primeiro factor de prestígio para qualquer grupo de investigação, acresce a responsabilidade de zelar pela qualidade com que a ciência chega ao grande público. Nesse âmbito o CGE mantém, desde a sua formação, uma dinâmica de incentivo, apoio e valorização a todas as iniciativas de divulgação científica, em particular na área das Ciências da Terra. Este trabalho continuado levou a que o CGE se destaque no panorama nacional, tendo o seu nome ligado a algumas das actividades mais importantes de divulgação que têm sido realizadas em Portugal nos últimos dez anos.

1 Os Públicos

A interacção directa entre os investigadores do CGE e o público tem-se pautado por uma enorme diversidade de acções, o que tem permitido atingir públicos muito variados. Embora privilegiado a comunidade escolar através de uma diversidade de actividades dirigidas a alunos (*e.g.* seminários, conferências, demonstrações experimentais, coordenação de projectos envolvendo escolas), as actividades que tem organizado / participado frequentemente têm frequentemente por objectivo um público muito mais vasto, quer não especializado (aquilo que poderemos chamar o grande público), quer especializado (*e.g.* professores, jornalistas, protecção civil, bombeiros e autarcas).

A estreita colaboração com o Centro Ciência Viva de Estremoz (quer no desenvolvimento de protótipos didácticos e outros materiais auxiliares do ensino, quer no apoio à coordenação científica de actividades diversas), tem justamente permitido um maior contacto com o público (desde a sua abertura em 2005, apenas a exposição permanente do Centro já foi visitada por mais de 57 000 pessoas, a que acresce nas restantes actividades realizadas anualmente por este centro mais cerca de 20 000 a 25 000 participantes).

2 As Parcereias

Não sendo uma unidade que tenha por objectivo fundamental a divulgação científica, a estrutura do CGE não lhe permite uma actividade permanente de divulgação científica, visto a principal actividade dos seus investigadores ser a docência / investigação científica. Esta inexistência de membros dedicados exclusivamente à divulgação tem levado a uma estratégia de parcerias com outras instituições mais vocacionadas para a divulgação e que por isso têm estruturas mais adequadas a este tipo de acções.

Embora ao longo dos 20 anos de actividade do Centro o número de instituições com as quais o CGE tem colaborado a nível da divulgação impeça qualquer tentativa de enumeração exaustiva das mesmas, sob risco de omissões frequentes e graves, não queremos deixar de assinalar algumas das parcerias mais activas:

- *Centro Ciência Viva de Estremoz* (CCVEstremoz) - Integrado na rede nacional de Centros Ciência Viva, o de Estremoz tem por temática principal as Ciências da Terra, o que torna as parcerias inevitáveis, tanto mais que existe uma enorme proximidade entre ambos os Centros. Esta proximidade traduz-se, não só em termos geográficos, mas também institucionais (a Universidade de Évora é não só o local onde está sedeado o CGE e à qual pertence a maioria dos seus membros, mas também uma das parceiras da Associação que gere o CCVEstremoz) e até pessoais (alguns membros do CGE têm desempenhado papéis importantes a nível das actividades do CCVEstremoz inclusive na direcção do mesmo). Esta situação leva a que a generalidade de actividades de divulgação realizadas pelo CCVEstremoz inclua o CGE como entidade parceira.

- *Observatório Astronómico da Ribeira Grande* (Fronteira) - Vocacionado, como não poderia deixar de ser para a Astronomia, este observatório da responsabilidade da Câmara de Fronteira, tem por objectivo inicial a integração entre as actividades de investigação e de divulgação, sendo coordenado cientificamente pelo CGE.

Se nas parcerias referidas anteriormente, o CGE procurava a colaboração com instituições possuidoras de estruturas especialmente dedicadas à divulgação (tanto a nível de pessoal, como de infra-estruturas e de equipamentos), por vezes o Centro estabelece também parcerias procurando a obtenção de competências científicas que não possui para actividades de divulgação; a este nível é de destacar as colaborações com departamentos da Universidade de Évora (em especial os de Física e Geociências), outros centros de investigação (como o Centro de Estudos de História e Filosofia da Ciência), ou laboratórios de investigação (como o Laboratório de Investigação de Rochas Industriais e Ornamentais da Universidade de Évora).

Finalmente, a nível das parcerias é importante referir as estabelecidas tendo em vista o financiamento de actividades de investigação. Também aqui a enumeração total é difícil, o que nos leva a destacar apenas algumas das mais importantes: a Agência Nacional para a Cultura Científica e Tecnológica / Ciência Viva, a Fundação Calouste Gulbenkian e algumas parcerias com autarquias, nomeadamente as Câmaras Municipais de Évora, Estremoz e Fronteira.

3 As Actividades

Não é possível num trabalho desta índole enumerar todas as actividades de divulgação científica do CGE, No entanto, esta impossibilidade não deve impedir o destacar de algumas das principais acções que, a este nível, o CGE tem levado a efeito ou colaborado activamente, embora esta abordagem seja sempre um risco pois inevitavelmente conduz a omissões importantes.

- *Actividades com a Comunidade Escolar* - Sem dúvida que uma parte fundamental das actividades de divulgação do CGE se dirigem para a comunidade escolar, assumindo uma forma extremamente diversificada de tipos de acções (*e.g.* seminários, conferências, demonstrações experimentais ou coordenação de projectos envolvendo escolas). A nível dos projectos, para além da participação de membros seus em inúmeros projectos Ciência Viva nas Escolas, são de destacar:
    - Os projectos Ciência Viva ROSEA (Rede de Observação Sísmica nas Escolas dos Açores) e MOSIRE (Monitorização Sísmica da Região de Évora) que, permitiram dotar 6 escolas dos Açores e 3 da região de Évora de observatórios sismológicos com capacidade para desenvolvimento de actividades de investigação no domínio da Sismologia e partilha de dados com as restantes escolas. A par da instalação do equipamento foi implementado um programa de formação técnica e científica para as actividades de rede e observatório.
    - O projecto EXPER (Sismologia: Experimentar para Conhecer) foi desenhado para proporcionar ambientes de ensino e divulgação facilitadores da compreensão fenomenológica dos mais relevantes e fundamentais aspectos da sismologia.
    - O projecto UM HORIZONTE AQUI TÃO PERTO, que decorre desde 2007 em parceria com a Escola Secundária Severim Faria, foi desenhado para apoiar os alunos de Física do 12º ano nas suas aprendizagens, dando-lhes uma perspectiva objectiva e desmistificadora da ciência. Procura colocar à disposição destes estudantes os melhores recursos que o triângulo institucional ensino secundário, ensino superior e investigação têm para dar, recorrendo a metodologias que ponem em articulação as aprendizagens no âmbito curricular com o desenvolvimento de competências complementares. São várias as iniciativas que se desenvolveram a partir deste projeto, na escola e na universidade envolvendo alunos, pais, docentes das duas instituições e comunidade em geral.
- *Ciência na Rua* - Festival anual de ciência iniciado em 2007, no qual durante 2 noites dezenas de cientistas e artistas invadem o centro da cidade de Estremoz recriando e experimentando 7 grandes momentos científicos. Ao longo de 7 horas o teatro, a música, a dança e dezenas de experiências científicas interactivas esperam o visitante ajudando-o a compreender o funcionamento do Mundo em que vive. Este evento foi considerado em

2009 pelo então Ministro da Ciência, Tecnologia e Ensino superior, Professor Doutor Mariano Gago, em declarações à Lusa como "uma das iniciativas mais importantes que se faz em Portugal de divulgação da Ciência no espaço público" e "uma das marcas mais importantes do Ciência Viva em Portugal" (colaboração com o Centro Ciência Viva de Estremoz).
- *Sistema Solar à Escala do Concelho de Estremoz* - As dimensões do Sistema Solar, em especial as diferenças entre as dimensões dos planetas e das suas órbitas, leva a que seja extremamente difícil a sua representação à escala; isto só é possível quando estas representações ocupam extensões quilométricas. Esta situação leva a que os modelos verdadeiramente à escala do Sistema Solar sejam extremamente raros, existindo menos de 50 em todo o Mundo. Em 2007 foi instalado no concelho de Estremoz o único sistema solar à escala da Península Ibérica; com um Sol com 336 cm de diâmetro localizado no centro da cidade de Estremoz e Plutão com 0,56 cm localizado junto ao castelo de Évoramonte, este sistema tem uma escala de 1/414 000 0000. Desde a sua inauguração este original Sistema Solar já foi visitado por milhares de pessoas, em visitas escolares organizadas ou não (colaboração com o Centro Ciência Viva de Estremoz)
- *Sol-Duatlo de Estremoz* - A existência do Sistema Solar à escala no concelho de Estremoz levou ao estabelecimento de uma parceria com a Federação Portuguesa de Triatlo e à implementação a partir de 2012 de uma prova federada anual de duatlo destinada a todos os escalões. Esta prova constitui uma actividade única devido à mistura num mesmo evento das componentes desportivas e científicas (colaboração com o Centro ciência Viva de Estremoz)
- *Geologia no Verão* - Desde 1998 que todos os anos membros do CGE têm vindo a desenvolver ou acolaborar activamente em centenas de actividades de divulgação científica (essencialmente saídas de campo) integradas no programa Ciência no Verão da Agência Nacional para a Cultura Científica e Tecnológica / Ciência Viva (colaboração com o Centro Ciência Viva de Estremoz e o Departamento de Geociências da Universidade de Évora)
- *Curso de Riscos Naturais e Tecnológicos* - A constatação da frequente falta de rigor com que frequentemente se difundem conteúdos das Ciências da Terra, tanto ao nível dos livros didácticos, como nas notícias e artigos de divulgação veiculados por órgãos da comunicação, levou a que o CGE organizasse este curso (que contou já com duas edições) especialmente dirigido a alguns grupos profissionais (*e.g.* professores, jornalistas, protecção civil, bombeiros e autarcas).
- *Congresso Nacional "Cientistas em Acção"* - Com este congresso anual dirigido a todos os níveis de ensino pré-Universitário, pretende-se promover o espírito científico dos jovens, através da realização e desenvolvimento de projectos científicos nos quais o ensino experimental das ciências é uma prioridade.

4 Os "Materiais" produzidos

O CGE tem vindo a dedicar uma parte significativa do seu esforço ao desenvolvimento e produção de materiais de divulgação científica inéditos que têm desempenhado um importante papel na divulgação das Ciências da Terra em Portugal. Embora seja difícil fazer uma abordagem exaustiva da diversidade dos "materiais" produzidos, iremos destacar apenas algumas das que consideramos mais importantes tendo em vista a sua visibilidade.

- *Desenvolvimento de Exposições / Museus* - O CGE tem vindo a colaborar activamente com o Centro Ciência Viva de Estremoz na preparação de diversas exposições por ele produzidas, das quais destacamos:

  - "*Terra; um planeta dinâmico*" – patente de Janeiro a Outubro de 2002 no Pavilhão do Conhecimento / Centro Ciência Viva de Lisboa; uma organização conjunta dos Centros Ciência Viva de Lisboa e de Estremoz.
  - "*Evolução; resposta a um planeta em mudança*" – concebida em 2003 esta exposição, actualmente em exibição permanente no Centro Ciência Viva de Estremoz, teve uma ampla divulgação tendo estado patente em diversos locais (nas ilhas de S. Miguel, Terceira, Graciosa e S. Jorge no âmbito de uma colaboração com a Direcção Regional da Ciência e Tecnologia dos Açores, no Centro Cultural de Vila Nova de Foz Côa, na Feira de S. João em Évora e no Museu de Geologia da Universidade de Trás-os-Montes e Alto Douro).
  - "*Evolução; Portugal de antes da História*" – concebida em 2007 esta exposição teve uma ampla divulgação tendo estado patente em diversos locais (no Centro Cultural de Vila Nova de Foz Côa, no Museu de Geologia da Universidade de Trás-os-Montes e Alto Douro e no convento do Espinheiro).
  - "*Evolução; ver o Presente*" – concebida em 2008 esta exposição teve uma ampla divulgação tendo estado patente em diversos locais (no Centro Cultural de Vila Nova de Foz Côa, no Museu de Geologia da Universidade de Trás-os-Montes e Alto Douro, na Feira de S. João em Évora e no convento do Espinheiro).
  - "*Silício; da Pré-História ao Futuro*" – concebida em 2008 esta exposição teve uma ampla divulgação tendo estado patente em diversos locais (no Centro Cultural de Vila Nova de Foz Côa e no Museu de Geologia da Universidade de Trás-os-Montes e Alto Douro).
  - "*Ver o Clima... nos ombros de gigantes*" – concebida em 2008 esta exposição serviu para a inauguração do Observatório de Ciência e Tecnologia da Terceira
  - "*Rovin dos Mares; uma viagem aos fundos oce*ânicos" - concebida em 2011 esta exposição integra a exposição permanente do Centro Ciência Viva de Estremoz.

- *Módulos científicos interactivos* - Para a implementação das diversas actividades de divulgação em que o CGE colabora, alguns dos seus membros desenvolveram e coordenaram a produção de dezenas de módulos científicos interactivos, de que gostaríamos de destacar:

  - "*Máquina dos sismos*" - permite a visualização do conceito do ressalto elástico, a sua relação com a génese dos eventos sísmicos e a exploração de alguns dos parâmetros que os condicionam;
  - "S*imulador de movimentos sísmicos*" - permite experimentar as sensações desses movimentos e mostrar os seus efeitos nas estruturas edificadas.

- "*Túnel de vento*" - permite explorar alguns dos conceitos físicos associados à deslocação do ar.
- "*Câmara de nevoeiro*" - permite analisar o efeito de partículas sub-atómicas.
- "*Canal hidráulico*" - onde se estudam as leis da hidrodinâmica.
- "*Bicicleta Solar*" - Permite explorar os conceitos de energia potencial e cinética, radiação solar e a sua importância no ciclo hidrológico.

- *Publicações* - Os membros do CGE têm escrito alguns livros e artigos de divulgação científica, dos quais destacamos [1][2][3][4][5][6]:
- *Puzzle Pangeia* - Um *puzzle*, com respectivo texto de apoio, de que permite reconstruir a evolução da Pangeia desde a sua formação até à Actualidade com especial destaque para 4 momentos (170 Ma, 100 Ma, 50 Ma e Actualidade). Este puzzle inclui informação diversificada respeitante à idade dos fundos oceânicos, de alguns aspectos paleoambientais e de alguns dos fósseis emblemáticos utilizados por Wegener. A figura incluída neste trabalho, representa este *puzzle* e pode ser utilizada sem qualquer restrição (incluindo a sua duplicação e divulgação) desde que seja indicada a sua origem e não seja utilizado para fins comerciais.

Agradecimentos

Toda a actividade de divulgação desenvolvida pelo CGE não teria sido possível sem o apoio das muitas instituições e personalidasdes que durante os últimos 20 anos acreditaram em nós. A todos agradecemos. Um agradecimento especial à Agência Ciência Viva, ao Ministério da Educação e à FCT pelos multiplos apoios, incentivos e oportunidades que proporcionaram; ao Centro Ciência Viva de Estremoz, parceiro incondicional em todas as aventuras; às escolas da região que, sempre de portas abertas nos estimulam a continuar; às Câmaras municipais em especial as de Évora, de Fronteira e Estremoz, colaboradoras de longa data; à Fundação Callouste Gulbenkian pelo financiamento de vários projetos.

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ATMOSFERA & HIDROSFERA

ATMOSPHERE & HYDROSPHERE

NEARLY 20 YEARS OF SATELLITE REMOTE SENSING AT CGE

MARIA JOÃO COSTA

CGE and Dep. Physics, University of Évora,R. Romão Ramalho Nº 59
Évora, Portugal, mjcosta@uevora.pt

VANDA SALGUEIRO, MIGUEL POTES, FLAVIO COUTO, DINA SANTOS, DANIELE BORTOLI, ANA MARIA SILVA

CGE, University of Évora,R. Romão Ramalho Nº 59
Évora, Portugal

MANUEL ANTÓN

CGE and Dep. Physics, University of Extremadura,
Badajoz, Spain

CARLOS MATEUS

Instituto de Meteorologia Rua C do Aeroporto, Lisboa, Portugal

RUI SALGADO

CGE and Dep. Physics, University of Évora,R. Romão Ramalho Nº 59
Évora, Portugal

MARIA MANUELA MORAIS

CGE, Water laboratory and Dep. Biology, University of Évora,R.Barba Rala Nº 1, P.I.T.E.
Évora, Portugal

The first steps in satellite remote sensing at CGE were made in 1993, in the first years in close cooperation with the Remote Sensing Division of the Institute of Meteorology. The interest in the study of the atmospheric and surface properties using satellite images was first introduced in CGE by Ana Maria Silva and as a first year Master student, the first author here willingly accepted the challenge of developing her Master thesis on this unknown but rather appealing subject. Since then satellite remote sensing has greatly evolved with the launch of satellites with improved capabilities. CGE has taken advantage of these advancements to explore new methodologies applied not only to the atmospheric characterization, but also to land and water surfaces. Since the beginning of the 2000s the research group contributing to the development of satellite remote sensing at CGE has increased, including several eager students.

1 Introduction

The first steps in satellite remote sensing at CGE were made in 1993. The interest in the study of the atmospheric and surface properties using satellite data was first brought to CGE by Ana Maria Silva, head of a recently established Research Centre in Climate Change, which counted with the participation of four Portuguese institutions, under the leadership of the CGE. As a freshly graduated and first year Master student, the first author here willingly accepted the challenge of developing her Master thesis on this unknown but rather appealing subject. At first several difficulties arose, the main being the difficulty by that time of obtaining satellite imagery, which was mainly restricted to the Institute of Meteorology. In this sense, the close cooperation between CGE and the Remote Sensing Division of the Institute of Meteorology was fundamental in those first years, to carry on research in satellite remote sensing. Later on, research stays abroad, the parallel development of internet and also new policies for data distribution by the main satellite agencies worldwide greatly facilitated and granted the access to satellite data of different sources. On the other hand, environmental and also meteorological satellites have also greatly evolved with improved capabilities with respect to the spectral, spatial and temporal resolutions. Nowadays not only environmental and meteorological satellite data are freely provided by most satellite agencies for any interested user, but also satellite derived physical quantities characterizing the Earth's surface and atmosphere are available. CGE team took advantage of the evolution in satellite remote sensing in terms of data quality and accessibility and have come a long way since the early days. The next sections aim at illustrating the evolution of CGE research on satellite remote sensing.

2 Satellite Remote Sensing of Land Surfaces

METEOSAT and NOAA satellite series were used in the first years to evaluate the surface temperature, as well as the land surface albedo, on clear sky days [1, 2]. In spite of the deficient calibration of METEOSAT, its imagery frequency was at the time the only mean of remote sensing available to evaluate both the minimum and the maximum temperatures at the surface of the Earth. On the other hand, although their low temporal resolution, NOAA-AVHRR satellite series presented a good calibration that made it an accurate mean for the evaluation of surface temperatures and albedos.

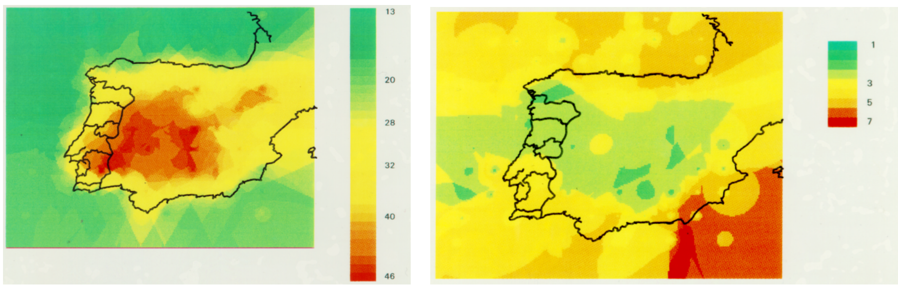


Figure 1. Maximum (left) and minimum (right) surface temperature obtained from Meteosat-5 for 12 July 1996 and 8 February 1996, respectively.

The determination of surface characteristics requires the correction of the atmospheric effects. For this purpose, the physical (radiative transfer) model LOWTRAN 7 was used, together with the vertical profiles of the atmospheric temperature and relative humidity, obtained from the forecasts of the ECMWF at eight atmospheric levels. The effects of absorption / emission and single scattering were taken into account, however multiple scattering in the atmosphere, as well as multiple reflections at the surface of the

Earth and scattering in the thermal infrared spectral region were assumed to be negligible. Figures 1 and 2 shows examples of the maximum and minimum surface temperatures (Fig. 1) and surface albedo (Fig. 2) obtained with the methodologies developed [1, 2].

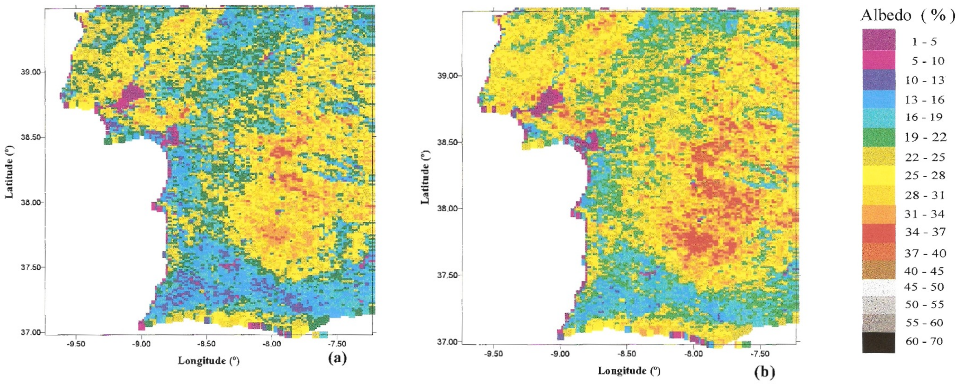


Figure 2. Surface albedo for 9 July 1996 derived from NOAA-AVHRR, assuming: (a) continental aerosols; (b) maritime aerosols.

The validation of the methods proposed for the evaluation of the surface temperature was done by comparison with observations of the land surface temperature available from surface meteorological stations, taken within the area of analysis. As for the surface albedo, the values obtained were compared with literature. Although the first satellite based methodologies derived were devoted to the characterization of land surfaces in terms of their temperature and reflectivity, atmospheric variables were already a concern. Therefore in the next years the attention diverged to atmospheric characterization, at first particularly to the complex problem of aerosol characterization, later on also to gaseous constituents and cloud characterization.

3 Satellite Remote Sensing of the Atmosphere

The synergistic use of low earth orbit (LEO) and geostationary earth orbit (GEO) satellite data for aerosol-type characterization, as well as aerosol optical thickness retrieval and monitoring over the ocean, was explored. These properties are central for the estimation of the direct shortwave aerosol radiative forcing, which in turn is a key variable for climate studies. The synergy serves the purpose of monitoring aerosol events at the GEO time and space scales (15 to 30 minutes; ~3 km) while maintaining the accuracy level achieved with LEO instruments. Aerosol optical properties representative of the atmospheric conditions were obtained from the inversion of high-spectral-resolution measurements from the Global Ozone Monitoring Experiment (GOME). The aerosol optical properties were then input for radiative transfer calculations for the retrieval of the AOT from GEO visible broadband measurements, avoiding the use of fixed aerosol models available in the literature [3, 4]. The retrieved effective aerosol optical properties represent an essential component for the aerosol radiative forcing assessment.

The method was applied to several aerosol events including strong desert dust outbreaks and biomass burning event over the ocean. The retrievals of the aerosol optical properties were checked against retrievals from sun and sky radiance measurements from the ground-based Aerosol Robotic Network (AERONET) as well as from independent aerosol products from different satellites and a considerably good accuracy was found for the AOT [5].

The combination of measurements from satellites in different orbits (LEO and GEO) having different spectral, spatial, and temporal resolutions, with the intention of developing an effective aerosol monitoring tool during strong aerosol events over the ocean was a novelty introduced [3, 4, 5] with respect to other satellite-based algorithms in use at the time. Satellite-based methods were directed either to aerosol monitoring or to a more accurate aerosol characterization, falling short of providing both aspects, which are equally important for climate studies. The method developed is not subject to this shortcoming, presenting as key features the improved accuracy of the aerosol characterization with respect to the methods based on GEO measurements and the stretching of the spatial and temporal coverage of the LEO retrievals to the GEO spatial-temporal scale.

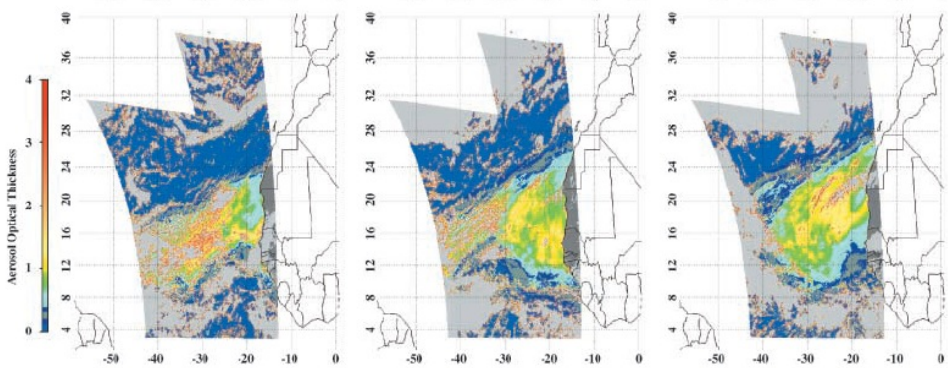


Figure 3. Aerosol optical thickness maps derived from Meteosat-6 full-disk VIS imagery for 6, 7 and 8 June 1997, (1200–1230 UTC), when the dust was blowing off the Sahara Desert and crossing the Atlantic Ocean. Cloudy pixels are assigned light grey and land pixels darker grey (taken from [3]).

In sequence of the methodologies developed to characterize atmospheric aerosols over the ocean, a new challenge appears around 2004 in the form of a contract with the Portuguese Electrical Company (EDP). The study aimed at the identification and characterization of aerosols plumes emitted from some of the EDP Power Plants using satellite measurements, with the purpose of monitoring the emissions of pollutants and of studying their atmospheric dispersion. The novelty with respect to the previous work was the underlying surface, instead of only the relatively dark ocean surface (low reflectance), it was required to deal also with the varying reflectance of land surfaces. A methodology was successfully developed, taking into account the wind speed (intensity and direction) at the power plant tower height and the background aerosol contamination [6, 7], as shown in Fig. 4.

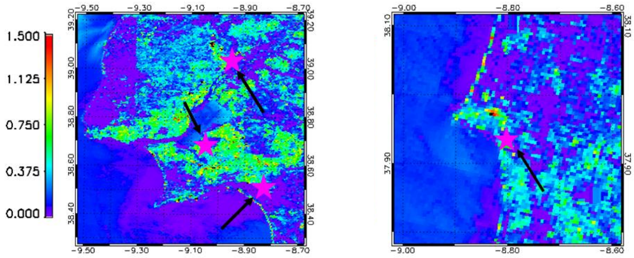
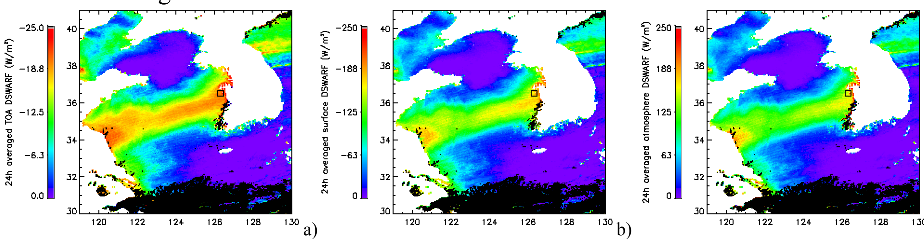


Figure 4. Aerosol optical depth for Carregado, Barreiro, Setúbal (a) and Sines (b) EDP power plants.

Meanwhile the work naturally evolved to extend also to cloud characterization (microphysical and optical) from satellite remote sensing methods, becoming also the effects of aerosols on clouds and radiation a concern [8, 9]. The awareness of the importance of the role that aerosols and clouds play on the climate system, constituted a main motivation to pursue the research in this sense. As an example, the aforementioned developed methodologies [3, 4, 5] were applied to a dust event that occurred between China and Korea. A significant finding was the extremely low single scattering albedo obtained (0.76), much smaller than previous values in literature for Asian dust or Saharan dust, suggesting that Asian dust can become a much more absorbing aerosol during movement when mixed with pollution materials produced over the industrial/urban area of China [8]. This may result in substantial atmospheric heating and surface cooling, as illustrated in Fig. 5.



a) b) c)

Figure 5. 24 hour averaged DSWARF at the TOA (a) surface (b), and of the entire atmosphere (c) for the 7 April 2000. Pixels contaminated by clouds at any time of the day are represented in black.

The development of a methodology to derive cloud properties was encouraged by the existence of a new generation of GEO satellite measurements such as those of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) flying on Meteosat Second Generation (MSG). This innovative sensor opened new perspectives with respect to past GEO systems since it provided the necessary additional spectral measurements, supplied before exclusively by LEO satellite sensors. Fog was also a very interesting and challenging occurrence to study using satellite remote sensing. Being an important phenomenon not only from the point of view of air quality but also for ground and air traffic purposes, the early fog detection and the identification of its extension are therefore essential. Cloud characterization, as well as fog detection and identification were addressed and methodologies developed based on the use of multi-spectral satellite data [9, 10, 11, 12]. The most suitable methods for the detection of fog arose from the difference of brightness temperature between infrared spectral channels at 3.9 and 10.8 μm, and at 8.7 and 10.8 μm. The best solution found for the detection of fog employed the 3.9-10.8 channels during night and daytime, and the 8.7-10.8 during sunrise. An example of the results obtained from the fog detection method developed is shown in the images of Fig. 6.

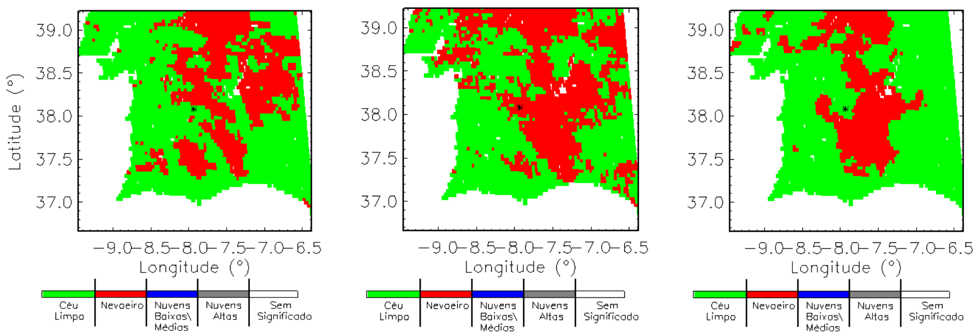
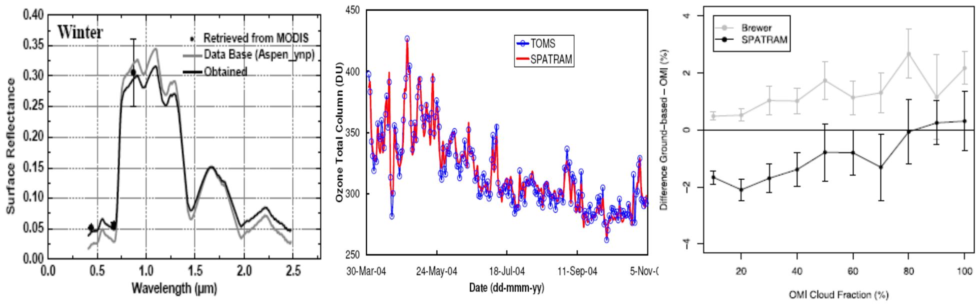


Figure 6. Satellite remote sensing of fog detection (red) around Beja (black *) on 28 July 2006 (at 04:12, 07:12 and 08:57 UTC). Fog was observed in Beja from 04:40 UTC to 08:35 UTC.

After the mid 2000s the Atmospheric Physics Observatory of CGE started to gain importance with reference instrumentation installed, therefore satellite remote sensing was also focused in the region in order to allow for the validation of methodologies by comparison with ground measurements taken at CGE.

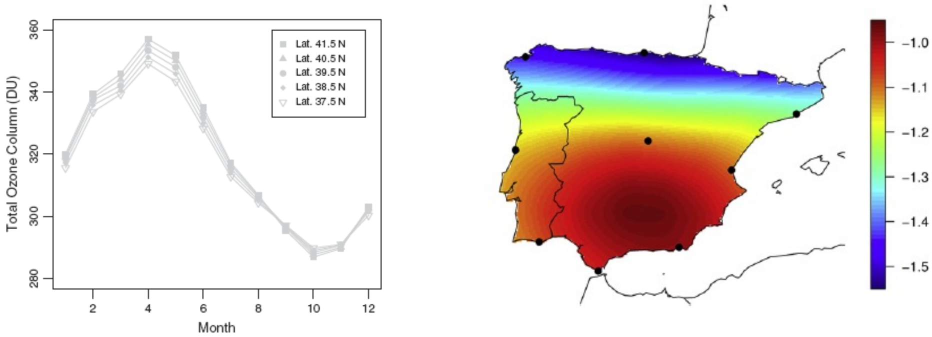
[13, 14, 15] displayed in Fig. 7 are examples of this combination or comparison of data from different atmospheric platforms (satellite and ground-based), aiming at providing increasingly accurate climate-relevant atmospheric quantities, such as the surface spectral reflectances and the ozone total column over Évora.



(a) (b) (c)

Figure 7. (a) Surface spectral reflectance values (taken from [13]); (b) Ozone total column (taken from [14]); (c) Differences between OMI total ozone column and ground-based instruments as a function of OMI cloud fraction (taken from [15].

The spatial–temporal structure of total ozone column over Portugal, as well as its variability and trends over the Iberian Peninsula during the last 30 years were also deeply analyzed [16, 17] and several relevant conclusions could be drawn from the studies, with a moderately strong latitudinal dependence found, as shown in Fig.8.



(a) (b)

Figure 8. (a) Monthly evolution of total ozone column over Portugal for five latitudinal bands (taken from [16]); (b) Spatial distributions of the trends (expressed in percentage) over the Iberian Peninsula for the periods 1979 – 2008 (taken from [17]).

Aerosol effects on clouds and radiation have also been extensively investigated, not only using satellite remote sensing, but also using atmospheric modeling techniques [18, 19], as illustrated by the cloud radiative forcing results shown in Fig. 9.

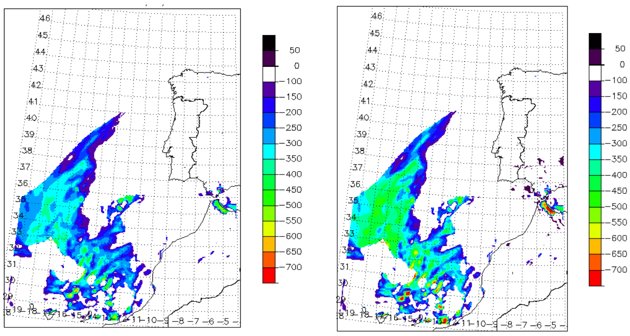


Figure 9. Surface cloud shortwave radiative forcing, in Wm-2, in the absence (left) and in the presence (right) of desert dust aerosols, for 27 May 2006.

Research is also progressing regarding radiative transfer and inversion algorithms, which are fundamental issues in satellite remote sensing [20, 21], aiming at proposing a new improved cloud inversion algorithm. In this regard two new grants were recently funded: a PhD focusing on the problematic of cloud remote sensing and of cloud effects on solar and terrestrial radiation; a Post-Doc exploring the combination of satellite and ground-based measurements to improve the understanding of radiative balance over the Southwestern Iberian Peninsula, especially due to aerosols and water vapour.

Another emerging topic of interest in the last years is the analysis of satellite derived precipitable water to detect the transport of (sub)tropical moisture to higher latitude regions, also known as Atmospheric Rivers. Special attention has been dedicated to atmospheric river structures in the pathway of Madeira Island, which act to increase moisture in the lower atmospheric levels and together with the orographic lifting induce heavy precipitation events [22]. The use of satellite remote sensing for the early detection of these features can be a valuable aid in the prediction and early warning of extreme precipitation events over Madeira.

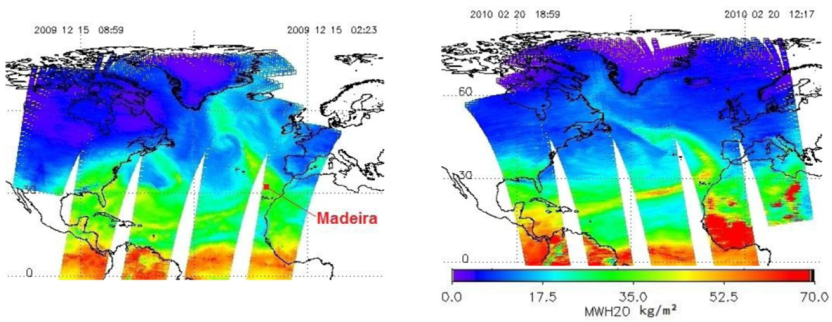


Figure 10. Satellite images of precipitable water obtained from the Atmospheric InfraRed Sounder (Aqua-AIRS) for 15 December 2009 (left) and 20 February 2010 (right).

4 Satellite Remote Sensing of Water Surfaces

At the same time atmospheric remote sensing was developing further at CGE, around 2005 an opportunity of exploring satellite remote sensing applied to the study of water surfaces emerges thanks to the collaboration with José Teixeira da Silva (at the time with the Faculty of Sciences, Univ. of Lisbon) [23]. This work also permitted to establish an enduring collaboration with the water laboratory of the University of Évora.

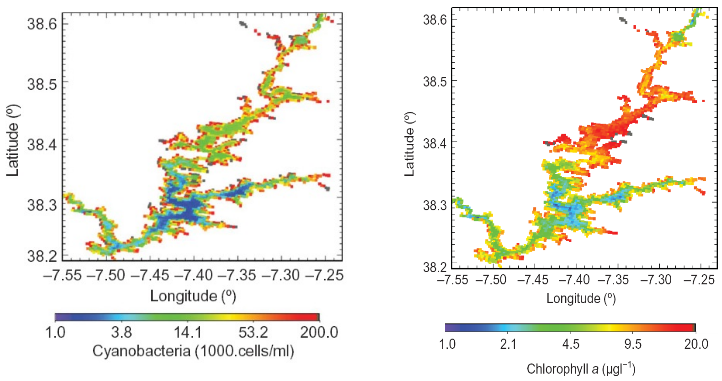


Figure 11. Cyanobacteria density and Chlorophyll a concentration over the whole Alqueva Reservoir surface on 14 November 2007 (taken from [23]).

The potential of the MEdium Resolution Imaging Spectrometer (MERIS) to describe variations of optically active substances over Alqueva artificial lake was investigated. Limnological laboratory analyses of the water samples collected monthly, from 2003 to 2006, by the UE water laboratory were used in combination with MERIS. The water surface spectral reflectance was derived from Level1b MERIS data, using radiative transfer calculations to account for the atmospheric effects. The lake water spectral surface reflectance was then combined with laboratory analyses of cyanobacteria total densities, chlorophyll a concentrations and turbidity, and empirical algorithms for these quantities were derived (Fig. 11). The results obtained were compared with independent laboratory analyses from different years with respect to those used, with good correlation coefficients obtained [24, 25, 26]. The methodology proposed has been developed to inexpensively monitor Alqueva Reservoir water quality in terms of cyanobacteria, chlorophyll a and turbidity, on a regular basis, and to provide useful information to the authorities. On the other hand, turbidity, a measure of the amount of light extinction in the water column, may induce changes in the lake's vertical thermal structure, which in turn plays an important role in autochthonous primary production and in the evolution of the water surface temperature, a key variable in the water-atmosphere transfers. Thus turbidity is deemed an essential parameter towards the improvement of lake parameterization schemes in weather forecast and climate models. The importance of the lake optical characteristics in the evolution of lake surface temperature and heat fluxes was also demonstrated [26].

Work is now ongoing aiming at retrieving the attenuation coefficients of different types of water, not only at the surface but also at different water depths, through the combination of satellite and ground-based remote sensing, as well as laboratory analyses.

5 Summary

CGE team benefited from the developments in satellite technologies and remote sensing as well as radiative transfer techniques in the last two decades and have come a long way since the early days. Nowadays the research is applied to a wide range of domains, mostly dedicating to atmospheric and water quality satellite remote sensing.

Acknowledgments

The first author is deeply grateful to many people that throughout the years significantly contributed, directly or indirectly, to the development of satellite remote sensing activities at CGE and would like especially to mention with no special order: C. Direitinho Tavares, (IM), V. Levizzani (ISAC-CNR), E. Cattani (ISAC-CNR), F. Torricella (ISAC-CNR), A. Arriaga (EUMETSAT), J. Schmetz (Eumetsat), B.J. Sohn (Seoul National Univ.).

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AEROSOL OPTICAL AND MICROPHYSICAL MEASUREMENTS AT CGE SINCE 2004

FRANK WAGNER
University of Évora, Centro de Geofísica de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, frankwagner@uevora.pt

SÉRGIO PEREIRA
University of Évora, Centro de Geofísica de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, sergiopereira@uevora.pt

JANA PREISSLER
University of Évora, Centro de Geofísica de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, jana@uevora.pt

JUAN LUIS GUERREO-RASCADO
University of Évora, Centro de Geofísica de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, jrascado@uevora.pt

ANA MARIA SILVA
University of Évora, Centro de Geofísica de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, asilva@uevora.pt

Properties of the atmospheric aerosols are one of the main research topics carried out at the Geophysics Center of Évora (CGE) since about a decade ago. An overview of aerosol measurements at CGE since 2004 is given. The type of equipments and the period of operation of the instruments are given. Also the measured as well as derived quantities are provided.

1 Introduction

Atmospheric aerosols are one of the most important climate relevant atmospheric constituents, due to their interaction with the radiation field, with the cloud formation and transformation and with air quality.

They have normally short residence times, except the ones in the stratosphere. Due to different origins and mechanisms of formation and transformation during transport form the sources, they have a variety of physical and chemical characteristics, changing with time and space. Consequently their characterization and modeling is very complex and their impacts on the climate and on the environment are quite difficult to quantify.

For all these reasons atmospheric aerosol research has taken the attention of many scientists all over the world in the last 20 years and it is still far from coming to an end (IPCC, 2007).

From the point of view of the interaction of atmospheric aerosols with the climate system the main climate relevant aerosol properties are: spectral aerosol optical depth aerosol phase function**,** and the single scattering albedo. These optical properties must be linked to physical and chemical properties like the size distribution, shape, the complex refractive index, and to the chemical composition. The link between the columnar optical properties and the physical-chemical properties (measured locally) can be made by means of two distinct approaches: the direct one where the aerosol physical-chemical properties are measured at different altitudes and used as input to forward calculations of the optical properties using an adequate scattering theory; the inverse approach where the columnar optical properties are inferred by numerical inversion from one or more complex radiation measurements.

The team of University of Évora has developed some of its aerosol studies by using the inverse approach (Silva et al., 2002), started when CGE participated in the preparation and hosting the continental site of the second International Aerosol Characterization Experiment (ACE-2) in summer 1997 at Sagres. From 2002 onwards CGE devoted itself extensively to the aerosol optical and microphysical *in situ* measurements at the ground surface (Évora); on the vertical profile (Évora) and on the columnar properties at two sites (Évora and Cabo da Roca). These studies have been complemented by the use of air mass back trajectories analysis and other techniques to identify the location of the aerosol sources and the typical paths before reaching the Iberian Peninsula.

2 Instrumentation

2.1 *Measurement site*

Évora, Portugal (38.5N, 7.9W, 300 m a.s.l) is located in the south-western region of the Iberian Peninsula. It's a Portuguese municipality (~1300 km^2) with less than 60000 inhabitants. More than 40000 inhabitants reside in the urban area of Évora city, which is the biggest one within a vast rural and sparsely populated region (Alentejo province) to the south of Tagus River. The distance from the capital, Lisbon, is some 130 km. The regional landscape is of low altitude (average height below 250 m a.s.l.) and it consists primarily of soft rolling hills and wide plains. There are no polluting industries either in the city or in the region. Therefore the local aerosol production should be basically related to traffic circulation, kitchen stoves and civil construction. During the colder periods of winter and fall wood burning is often used for domestic heating.

2.2 *Aerosol in situ instruments*

The nephelometer (Figure 1) started its first measurements in 2002 providing the longest time series of aerosol measurements at CGE. It measures the scattering coefficient at 3 wavelengths (450, 550, 700 nm) and the backscattered coefficient at the same wavelengths. The device is equipped with a PM_{10} inlet and it measures with a temporal resolution of 5 min. The instrument was calibrated regularly assuring a good quality of the data.

The TEOM (Tappered Element Oscillating Microbalance, Fig. 1) was installed at CGE in January 2006. It was used and studied intensively as part of a licenciatura thesis by one of the authors (Pereira). The device is equipped with a PM_{10} inlet and it measures with a temporal resolution of 10 min. It provides the mass concentration of aerosol particles. Due to the heating of 50ºC volatile components are lost. Therefore the instrument was calibrated intensively by comparing the values with the ones obtained by a HiVol sampler.

The Multi Angle Absorption Photometer (MAAP, Fig 2) was installed in April 2007. It provides the particle absorption coefficient at the wavelength 670 nm. It is equipped with a PM10 inlet and provides data with a temporal resolution of 1 min. The absorption coefficient can be transformed into a so-called black carbon mass concentration (BC).

Figure 1, Pictures of the nephelometer (left) and TEOM (right) inside the laboratory

Figure 2. Pictures of the MAAP (left) and APS (right)

The Aerosol Particle Sizer (APS, Fig. 2) measures the particle size distribution between 0.5 and 20 µm aerodynamical diameter. This diameter depends on the particle shape and particle density. Knowing both quantities, the aerodynamical diameter can be transformed into a geometrical diameter.

2.3 *Aerosol remote sensing instruments*

In 2003 two sun photometers were set up at Cabo da Roca and Évora. They determine the aerosol optical depth in the atmospheric column and measure sky radiance in the almucantar and principal plane geometries. Both instruments are part of the AEROSOL ROBOTIC NETWORK (AERONET) and are calibrated by AERONET, recently with support of the FP7 project ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network). The calibration has lead to significant temporal gaps in the data. Therefore – for avoiding these gaps - in 2009 a third sun photometer was purchased.

Since September 2009 a multi-wavelength Raman lidar (Fig. 6) of the type PollyXT is operated at the CGE. The instrument is part of the Spanish and Portuguese Aerosol Lidar Network as well as of the European Aerosol Research Lidar Network (EARLINET), which is integrated in the European project ACTRIS. Lidars enable the direct measurements of the vertical distribution as well as the optical properties of atmospheric particles.

2.4 *Aerosol Measurements with Airplanes*

CGE was successful in acquiring funding for short projects where measurements with airplanes could be performed. In 2006 the experiment CAPEX (Clouds and Aerosols over Portugal Experiment) and the experiment DARPO (Desert Aerosols over Portugal) were conducted over Portugal and lead by CGE members. The aircraft measurements were funded by EUFAR (European Fleet for Airborne Research). Fig. 8 shows the aircraft Falcon used for DARPO and operated by German DLR and the aircraft BAe146 used for CAPEX and operated by the British FAAM together with the Metoffice.

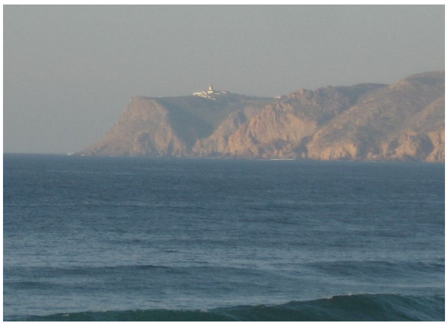

Figure 5. Picture of the Sun photometer (left) and of Cabo da Roca (right)

Figure 6. Picture of the LIDAR instrument

Figure 7. Picture of the aircraft Falcon (left) and BAe146 (right)

3 Data

3.1 *Measured Data*

Fig. 8 shows the time series of the hourly averaged scattering coefficient at the wavelength 550 nm measured with the nephelometer. The gaps are caused by instrumental malfunction. It can be seen that the variability is high ranging from less than 10 up to 600 Mm^{-1}. The long-term average is about 45 Mm^{-1}.

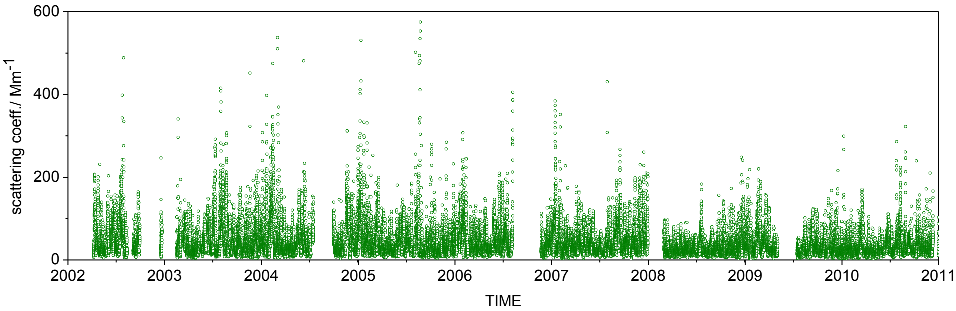

Figure 8. Time series of the hourly scattering coefficient, at 550 nm, between 2002 and 2011.

Fig. 9 shows the time series of the hourly averaged particle mass concentration measured with the TEOM. The gaps are caused by instrumental malfunction. It can be seen that the variability is high ranging from < 5 up to about 250 μgm^{-3}. The long-term average is about 23 μgm^{-3}.

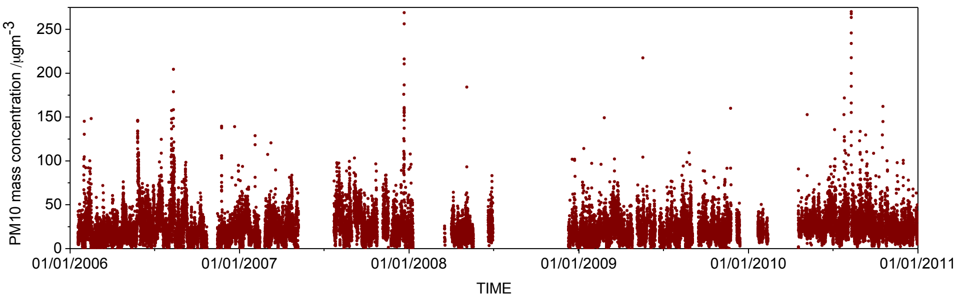

Figure 9. Time series of the hourly aerosol mass concentration between 2006 and 2011.

Fig. 10 shows the time series of the hourly averaged absorption coefficient at the wavelength 670 nm measured with the MAAP. The gaps are caused by instrumental malfunction. The annual cycle is clearly visible. It can also be seen that the variability is high ranging from about 0.5 up to 100 Mm^{-1}. The long-term average is 8.5 Mm^{-1}. And Fig. 11 shows an example of the evolution of the particle volume size distribution over more than one day. The data were measured during the experiment CAPEX.

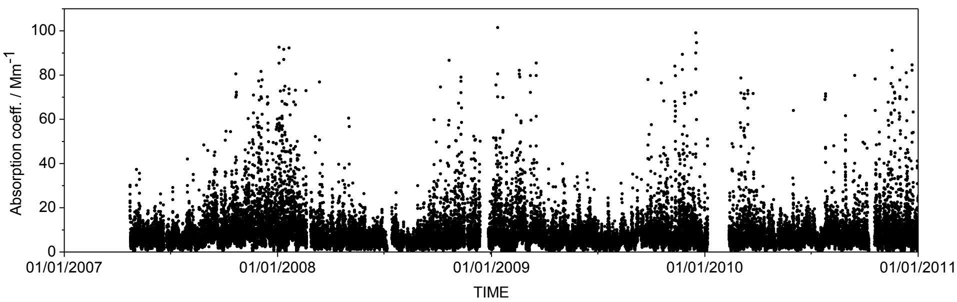

Figure 10. Time series of the hourly absorption coefficient, at 670 nm, between 2007 and 2011.

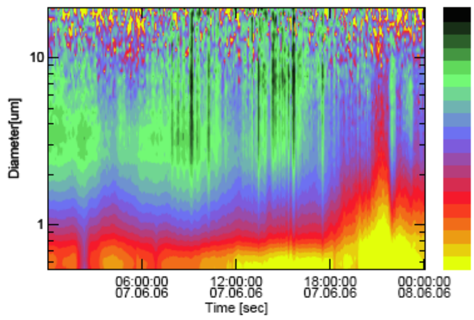

Figure 11. Example of the time evolution of the particle size distribution on 06 and 07 June 2006.

Fig. 12 shows the time series of the daily averaged aerosol optical depth (AOD) at the wavelength 440 nm measured with the sun photometers at Évora and Cabo da Roca. The gaps were caused when the instruments were sent to AERONET for calibration, except for Cabo da Roca in 2008 and 2009 when the instrument was temporally installed at Cabo Raso. It can be seen that the variability is high ranging from about 0.05 up to 1.5. High values were either caused by desert dust particles transported from the African Sahara or by particles created through forest fires.

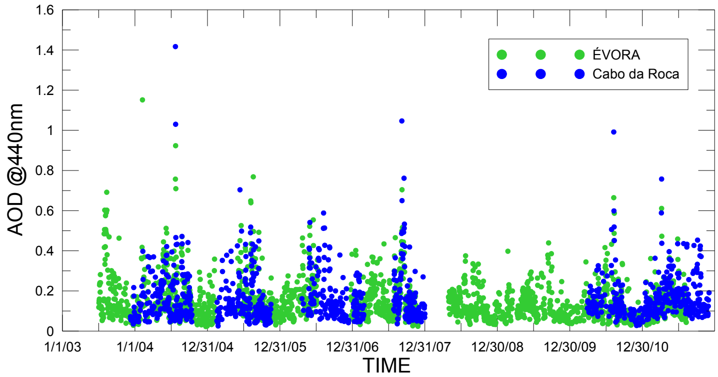

Figure 12. Example of the time evolution of the particle size distribution on 06 and 07 June 2006.

A time series of free tropospheric aerosol layers observed over Évora between September 2009 and October 2011 is presented in Fig. 13. The measurements were performed during three weekly regular measurements, which are scheduled on Mondays at noon and after sunset as well as on Thursdays after sunset. By means of HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) backward trajectories and different aerosol models, the origin of the layers was identified.

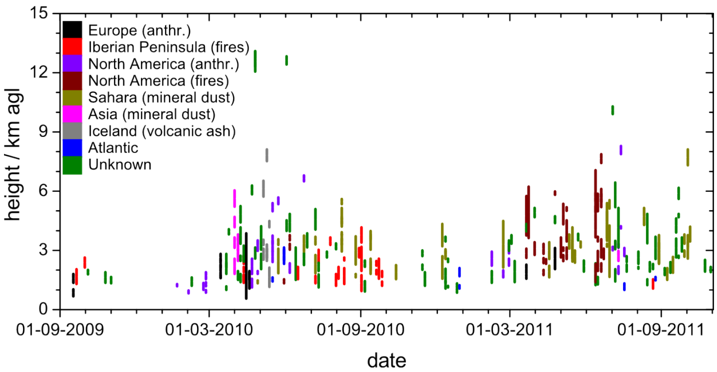

Figure 13. Vertical and temporal distribution of aerosol layers in the free troposphere, colour coded according to their origin.

During summer more and higher layers were detected. However, during winter fewer measurements could be performed due to low clouds or rain. From the months May to October, 87% of the scheduled regular measurements were performed. In total, 247 regular measurements were done between September 2009 and October 2011. During 141 of such measurements, 248 aerosol layers were detected. Of those, 31% could not be assigned unambiguously to any aerosol type.

Another example of the capabilities of the lidar is given in Fig. 14 (see also Preißler et al., 2011, Fig. 3). The vertical profiles of the extinction and backscatter coefficients and the linear particle depolarization ratio are shown.

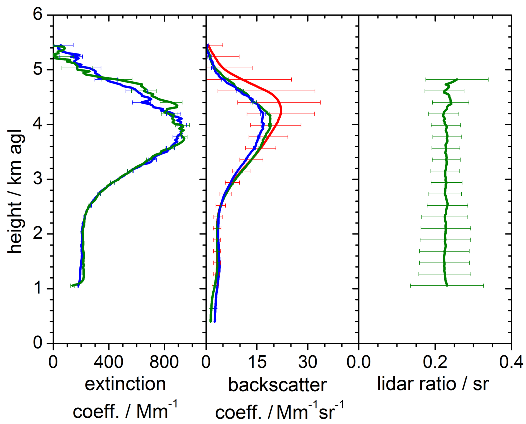

Figure 14. Profiles and absolute errors of the backscatter and extinction coefficients 355 nm (blue) and 532 nm (green), the backscatter coefficient at 1064 nm (red), and the linear particle depolarisation ratio at 532 nm.

This measurement was taken during an exceptionally strong Saharan dust outbreak in the beginning of April 2011. The shown profiles capture the vertical distribution of Saharan dust during the most intense period of the event between 1 and 2 UTC on 6 April 2011.

Fig. 15 shows an example of a CAPEX flight path and corresponding scattering coefficients measured by the airborne nepheleometer. Additionally – for comparison – the scattering coefficients at the ground measured by the nephelometer at Évora and the extinction coefficient at 532 measured by a lidar system which were operated by our colleagues from the University of Granada.

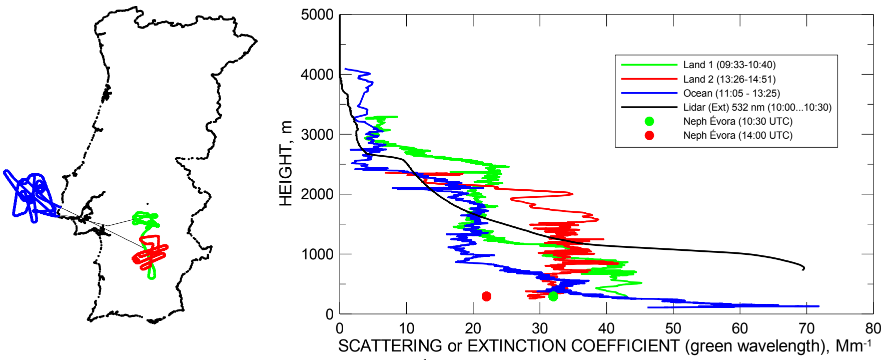

Figure 15. Flight pass of the CAPEX flight on 4th June 2006 and corresponding airborne nephelometer measurements as well as ground-based measurements at Évora (see details in the legend).

In 2011 started the analysis of single particles which were collected on TEM grids and subsequently analyzed using a scanning electron microscope. Fig. 16 shows an example of an image of a large particle together with the corresponding spectrum.

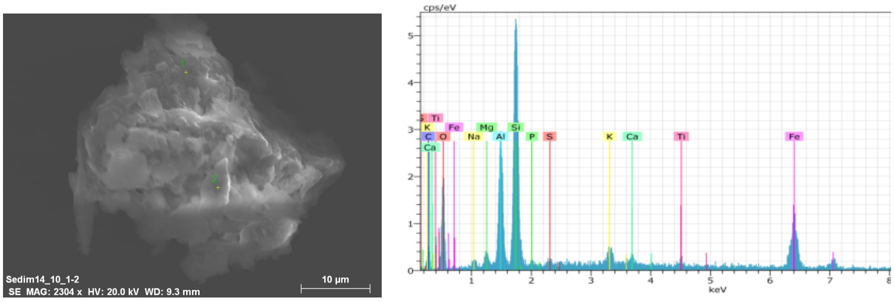

Figure 16. Electron Microscope Image of a large aerosol particle (left). The yellow dots indicate the locations where the elemental composition was determined and the corresponding spectrum for point 1 spectrum is shown on the right.

3.2 ***Derived Quantities***

Fig. 17 shows the time series of hourly values of the Ångström exponent derived from nephelometer measurements at the wavelengths 450 and 700 nm. The most frequent values are about 1.5; but values as low as zero indicating the dominant influence of large particles and as high as 2.5 indicating the dominant influence of very small particles can be observed. Values outside this range are likely caused by large errors of the measurements in conjunction with error propagation.

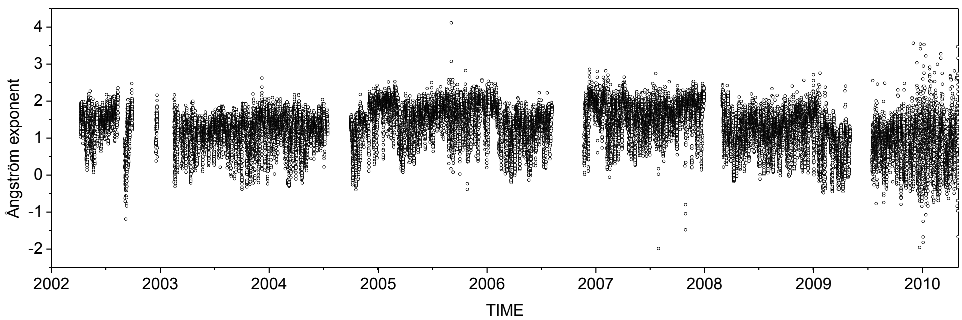

Figure 17. Time series of the hourly Ångström exponent between 2002 and 2011.

Fig. 18 shows the time series of the hourly particle extinction coefficient derived from nephelometer (Fig. 8) and MAAP (Fig. 10) measurements at the wavelength 670 nm. As the scattering coefficient and absorption coefficient the extinction coefficient show a large variability.

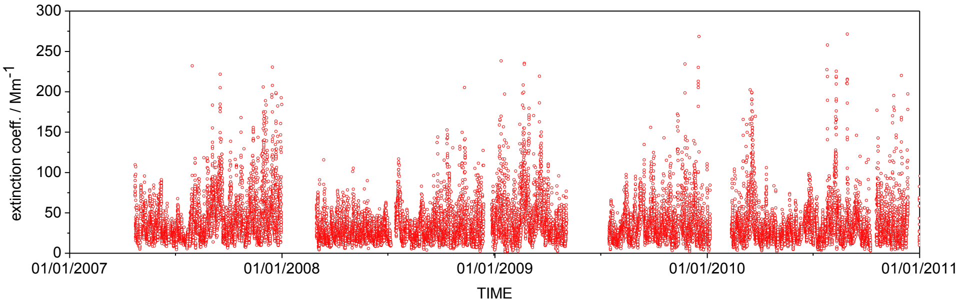

Figure 18. Time series of the hourly extinction coefficient, at 670 nm, between 2007 and 2011.

Fig. 19 shows the time series of the hourly particle mass scattering efficiency derived from nephelometer (Fig. 8) and TEOM (Fig. 9) measurements at the wavelength at 550 nm. Again, the values show a large variability. It should be noted that data gaps are caused either by data gaps in the nephelometer data or by data gaps in the TEOM data.

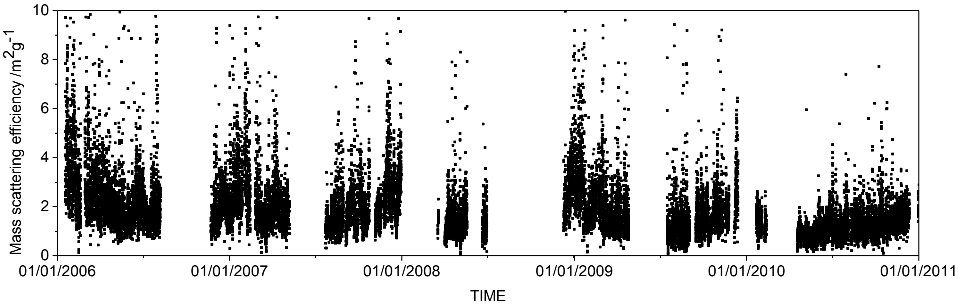

Figure 19. Time series of the hourly mass scattering efficiency, at 550 nm, between 2002 and 2011.

Fig. 20 shows the time series of daily values of the Ångström exponent derived from sun photometer measurements at the wavelengths 440 and 780 nm. The values vary between about 0, indicating large particles probably desert dust or sea salt, and 1.8 indicating small particles probable urban/industrial pollution or particles created by forest fires.

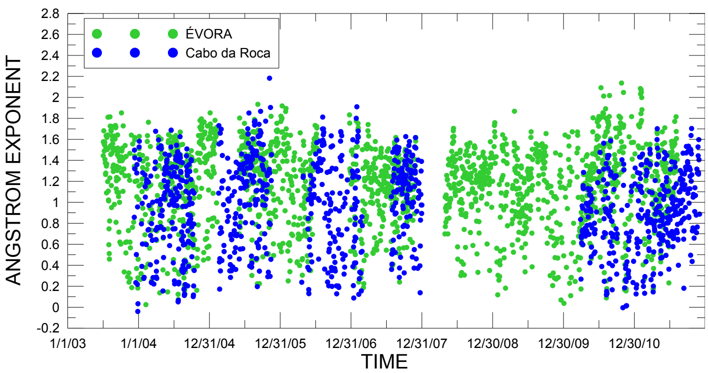

Figure 20. Time series of the daily Ångström exponent obtained from sun photometer measurements.

Fig. 21 shows the lidar ratios and the backscatter and extinction related Ångström exponents at the pair of wavelengths 355 and 532 nm as well as the backscatter related Ångström exponent at the pair of wavelengths 532 and 1064 nm. These values were derived from the ones shown in Fig. 14. The almost constant depolarisation ratio (Fig. 14) and Ångström exponents indicate the observation of the same type of aerosol throughout the shown height range.

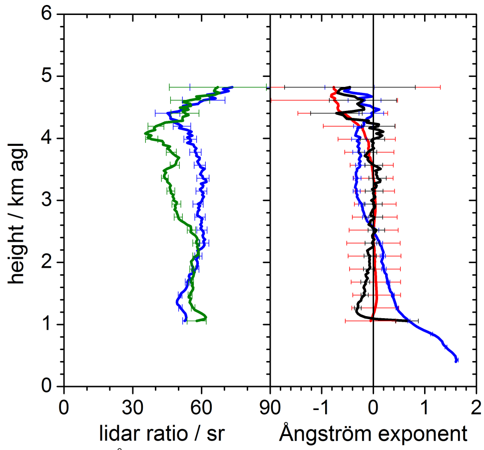

Figure 21. Time series of the daily Ångström exponent obtained from sun photometer measurements.

4 Summary, Conclusions and Challenges

Since many years, CGE is investigating properties of aerosol particles and their impact on climate and air quality. Over the year the park of equipment was extended which leads to a more comprehensive understanding of particles. The biggest challenges for the future is to maintain the high quality of data and to combine all different information to a consistent picture. Here additional data available from satellites and model calculations will play an important role.

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EFFECT OF TWO DESERT DUST EVENTS ON SOLAR ULTRAVIOLET RADIATION OVER ÉVORA

VANDA SALGUEIRO
Évora Geophysics Centre, University of Évora, Rua Romão Ramalho 59
Évora, Portugal, vsalgueiro@uevora.pt

MARIA JOÃO COSTA
Évora Geophysics Centre and Physics Department,University of Évora, Rua Romão Ramalho 59
Évora, Portugal, mjcosta@uevora.pt

The amount of solar ultraviolet radiation reaching the Earth's surface is influenced by several atmospheric constituents, like molecules, in particular ozone, aerosols and clouds, due to absorption and scattering processes of the radiation beam as it crosses the atmosphere. Aerosols can absorb and scatter the UV radiation and thus reduce the UV flux at the surface. The aim of this work is the verification of the influence of Saharan desert dust events on UVA and UVB radiation at surface in Évora. For this purpose, UV irradiance and aerosol optical thickness data are analyzed during two strong Sahara desert dust transports that affected the south of Portugal in April 2011 and March 2012 and the absolute and normalized aerosol UV radiative forcings due to these events are calculated.

1 Introduction

The solar ultraviolet (UV) radiation is part of the solar spectrum covering the wavelength range 100-400 nm. Although UV radiation represents a short range of solar spectrum wavelengths, which covers the wavelengths approximately from 100 nm to 3500 nm at the top of the Earth's atmosphere, it affects important biological and photochemical processes. According to its biological effects, the UV radiation is usually divided in three bands: UVC (100-280 nm), which is completely absorbed by ozone and oxygen before reaching the Earth's surface, UVB (280-315 nm), which is partly absorbed by ozone, and UVA (315-400nm), which is weakly absorbed by the ozone and therefore mostly arrives at the Earth's surface [3]. Thus the quantity of UV radiation that reaches the Earth's surface is essentially UVA and a small part of UVB and besides ozone, the amount of UV radiation that reaches the surface depends on several other factors: altitude, latitude, elevation of the sun above the horizon, reflection from the ground and the absorption and scattering by molecules, clouds and atmospheric aerosols like desert dust. The study of the various atmospheric factors that influence the quantity of UV radiation at surface is of interest mainly due to the potentially harmful effects of this radiation on biological organisms.

The South of Portugal, due to its location relatively to Sahara desert, is sometimes affected by desert dust transports when air masses came from the north of Africa. On the other hand, due to the geographical location, Portugal has high sunshine duration throughout the year. Thus, taking into account the given set of conditions we propose, in this work, to analyze the influence of two Saharan desert dust events, which occurred in April 2011 and March 2012, on UV radiation in the South of Portugal (Évora), using measurements of UV radiation and aerosol optical thickness taken at the surface.

2 Data and Calculations

In this work is used UV irradiance (UVB and UVA) measured at the surface with Kipp&Zonen radiometers, which are installed in observatory of the Geophysics Centre of Évora (CGE), located at 38º34'N, 7º54'W and 300m above mean sea level (a.m.s.l.). The aerosol optical thickness (AOT) data is obtained from the AERONET [6] CIMEL sun-photometer spectral radiance measurements also installed in the CGE observatory. The days corresponding to the desert dust event were selected considering Ängström exponent values below 0.5 and cloud free conditions. The Ängström exponent (AE) is a parameter that provides additional information on the particle size [1]; the smaller are the values of the AE bigger are the particles. The values of AE considered were calculated between the wavelengths of 340 nm and 870 nm, covering part of the UV, visible and near infrared spectral regions, using Eq. (1):

$$AE = \frac{-\log\left(\frac{AOT_{\lambda 1}}{AOT_{\lambda 2}}\right)}{\frac{\lambda 1}{\lambda 2}} \tag{1}$$

The evolution of the AOT and of the calculated Ängström exponent, for April 2011, is shown in Figure 1. The desert dust event occurred in April 2011 is limited by the dashed rectangle in the figure, where an increase in the AOT is accompanied by a decrease in AE with respect to the other days. This was one of the events considered; the other was in March 2012, which is not shown here.

The surface aerosol radiative forcing (ARF) is defined as the instantaneous increase or decrease of the net radiation flux at the surface that is due to an instantaneous change of aerosol atmospheric content. It may be expressed as a function of the downwelling flux and surface albedo as in Eq. (2) [4]:

$$ARF = (1 - \alpha)(F - F^0) \tag{2}$$

Here α represents the surface albedo and it was fixed to 0.035 [7], F is the global measured UV flux and F^0 is the global simulated UV flux, with the 1D radiative transfer model LibRadtran (Library for Radiative transfer) [2], for cloud free conditions, background aerosols and considering the ozone column values measured by satellite. The normalized aerosol radiative forcing (NARF) was calculated as well, with the aim of eliminating the solar zenith angle and surface albedo dependence. NARF is defined according to Eq. (3).

$$NARF = -\frac{(F - F^0)}{F^0} \tag{3}$$

In Eq. (3), the parameters F and F^0 represent the same physical quantities as in Eq. (2).

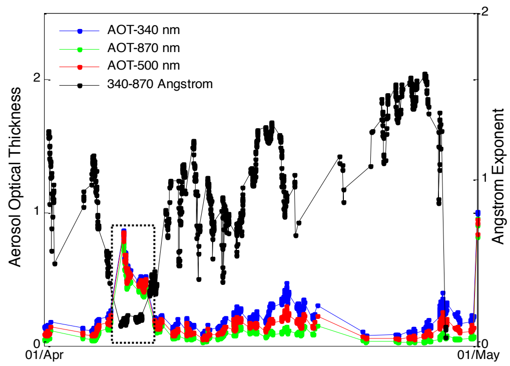

Figure 1. Aerosol optical thickness and Ängström exponent as a function of time, for aerosol events in April 2011. The Ängström exponent was calculated between 340nm and 870nm. The dashed rectangle limits the period of the event considered.

3 Results

In order to investigate the attenuation of UVA and UVB flux in the days of the aerosol dust event, the measured and simulated fluxes are represented as a function of time in figures 2 and 3. The figures show a reduction of the measured UVA and UVB fluxes at the surface compared to the simulated ones. This reduction is proportional to AOT values, see figure 1; when the AOT is larger the reduction of UV fluxes is larger too due to the attenuation of radiation by the aerosol layer.

The normalized UVA and UVB fluxes are presented in figures 4 and 5, respectively, as a function of the AOT, showing the variation of the measured UV fluxes with the AOT without the influence of the solar zenith angle (SZA). Figures 4 and 5 as well as figures hereinafter respect all data, that is, the ARF as well as the AOT (UVA and UVB), are relative to the set of data of April 2011 and the set of March 2012. The normalized values of UV fluxes, obtained through the division of the measured by the simulated fluxes, indicate that in presence of the desert dust, the flux that reaches the surface, F, is smaller than the flux for an atmosphere with background aerosol F^0, which was expected.

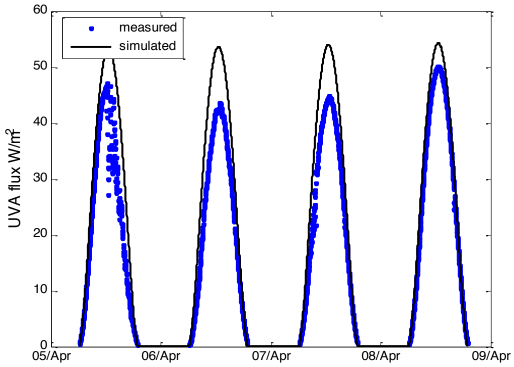

Figure 2. Measured and simulated values of UVA flux for the desert dust event days that occurred in April 2011.

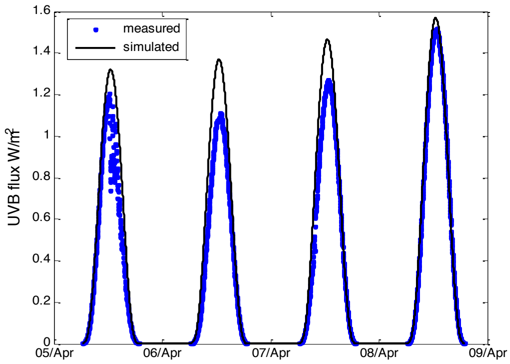

Figure 3. Measured and simulated values of UVB flux for the desert dust event days that occurred in April 2011.

The ARF is presented, in figures 6 and 7, as a function of the AOT and is grouped in three data sets according to the SZA values. The ARF is negative in both cases (UVA and UVB) being more negative as the AOT increases and this relation presents dependence on the SZA. As the SZA value increases, the ARF decreases in absolute value, for a fixed AOT. This relation between UV ARF and AOT and the respective dependence on the SZA has already been analyzed in other studies [4], [5]. According to the authors previously referred, for larger angles the direct beam component of the solar flux crosses a longer path through the atmosphere being more attenuated. This attenuation is mainly through scattering because for short wavelengths, as in the case of UV radiation, scattering process increases more rapidly with decreasing wavelength than absorption. Thus the diffuse component represents an important contribution to the global UV flux, which becomes dominated by this component for high SZA and the global UV flux at the surface becomes less sensitive to changes in the aerosols.

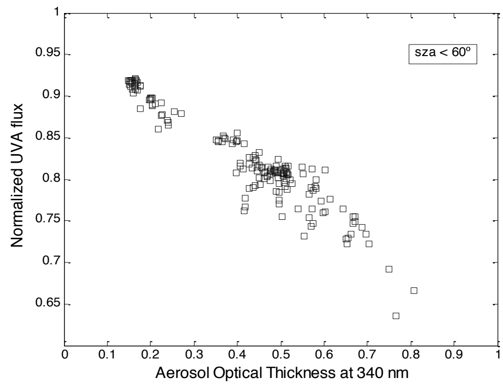

Figure 4. Normalized UVA fluxes (F/F^0) as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012).

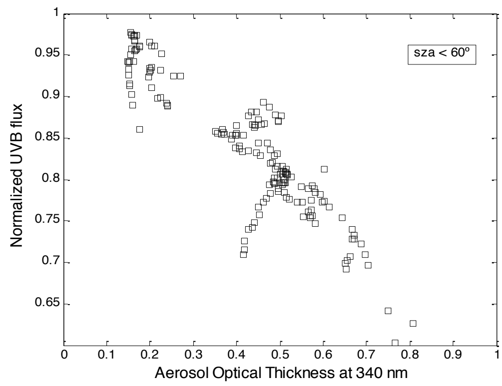

Figure 5. Normalized UVB fluxes (F/F^0) as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012).

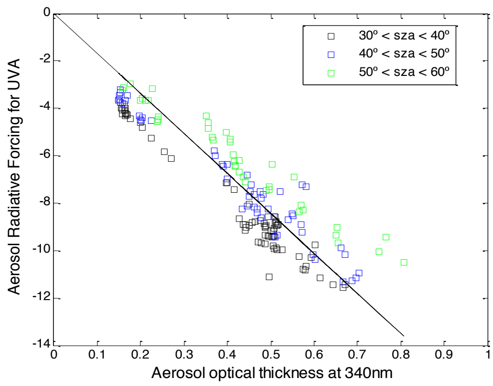

Figure 6. Aerosol radiative forcing for UVA fluxes as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012). The data is grouped according to SZA values, (black squares) 30º to 40º, (blue squares) 40º to 50º and (green squares) 50º to 60º.

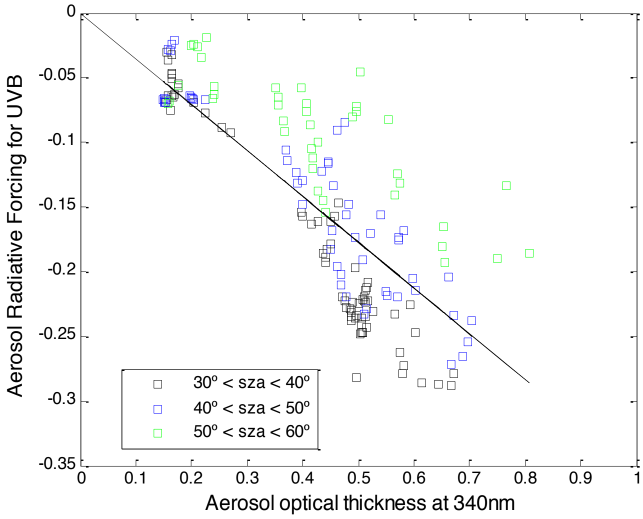

Figure 7. Aerosol radiative forcing for UVB fluxes as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012). The data is grouped according to SZA values, (black squares) 30º to 40º, (blue squares) 40º to 50º and (green squares) 50º to 60º.

To eliminate the dependence of the ARF on the SZA, as previously discussed, the NARF was calculated Eq. 3 and is represented in figures 8 and 9 for UVA and UVB, respectively. The NARF quantifies the fraction of absorbed or reflected radiation by the aerosol layer – effective surface aerosol (desert dust) albedo. As the AOT increases, also the NARF increases, which means that more UV radiation is absorbed or scattered by the aerosol layer.

A method for calculating the ARF efficiency, which is referred by [5] and references therein, is to obtain the slope of the linear regression between the ARF and the AOT. The ARF efficiency is simply the ARF per unit of AOT and in the present work the method was applied to NARF because in this case the SZA effect is not taken into account and thus only one regression line is presented for each case (UVA and UVB). The NARF efficiency values obtained were 0.4076 and 0.3972 for UVA and UVB, respectively.

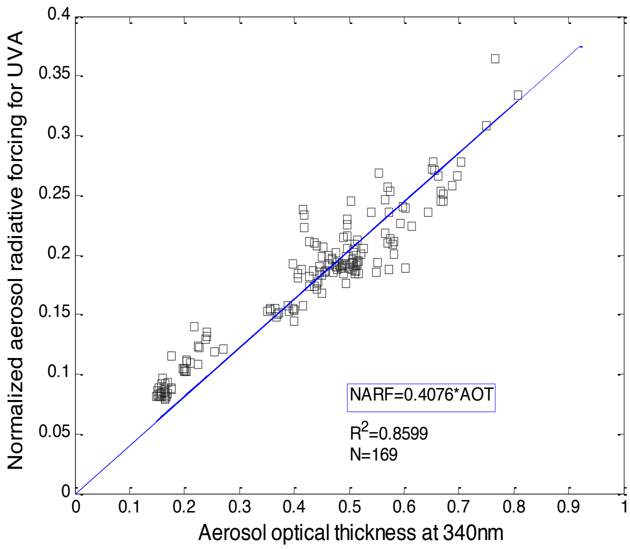

Figure 8. Normalized aerosol radiative forcing for UVA as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012).

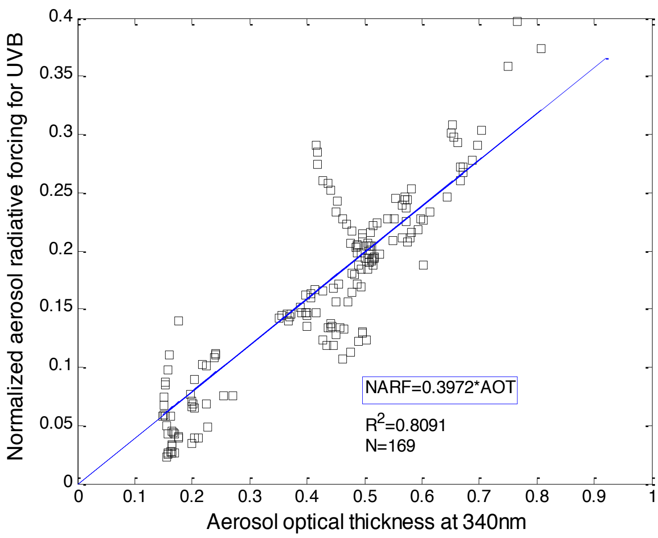

Figure 9. Normalized aerosol radiative forcing for UVA as a function of the aerosol optical thickness at 340nm, for all data (April 2011 and March 2012).

4 Summary

This work allowed verifying the existing dependence between the UV radiation fluxes measured at the surface and the aerosol optical thickness, in conditions of desert dust events. Was also showed the dependence of the aerosol radiative forcing on the solar zenith angle, being more negative as the angle decreases, which is in accordance with other studies. To remove the dependence of the aerosol radiative forcing on the solar zenith angle, the normalized aerosol radiative forcing was calculated. This quantity, which represents an effective surface aerosol (desert dust) albedo as mentioned in text above, showed an increase with the increase in the aerosol optical thickness, which means that more UV radiation is attenuated by the aerosol layer. On the other hand, we applied a method to determine the normalized aerosol radiative forcing efficiency, which allowed for obtaining the values of 0.4076 and 0.3972 for UVA and UVB, respectively, for the study case.

Acknowledgments

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DEVELOPMENT OF OPTICAL REMOTES SENSING EQUIPMENTS AND TECHNIQUES FOR THE MONITORING OF ATMOSPHERIC TRACERS AT THE GEOPHYSICS CENTRE OF EVORA

DANIELE BORTOLI

Évora Geophysics Centre (CGE), University of Évora, Rua Romão Ramalho 59, Évora, Portugal; Institute of Atmospheric Sciences and Climate (ISAC-CNR), Via Gobetti 101, Bologna, Italy;
db@uevora.pt

ANA FILIPA DOMINGUES, PAVAN S. KULKARNI, MARIA JOÃO COSTA, ANA MARIA SILVA

CGE, University of Évora, R. Romão Ramalho Nº 59
Évora, Portugal

MANUEL ANTÓN

CGE and Dep. Physics, University of Extremadura,
Badajoz, Spain

The activities regarding the monitoring of atmospheric tracers (nitrogen dioxide - NO2 and ozone - O3) at the CGE are relatively young. They started in 2000 and in the last 12 years the obtained results are very satisfactory into main field of research: the development of new optical instrumentation for the measurement of scattered radiation and the use advanced algorithms applied to the spectral data measured with the developed equipments. to obtain information on the total columns and vertical distribution of the above mentioned compounds. In addition, the validation/comparison of the ground based data with satellite borne instruments are presented. The Atmospheric Trace Gases (ATG) group is active also in high latitude researches and the main results obtained with the analysis of the measurements carried out at the Italian Antarctic Station are illustrated.

1 Introduction

Since the beginning of the CGE's scientific activities, the main topics of the atmospheric group were atmospheric aerosol and atmospheric electric fields, leading to indubitable excellent works recognized by the international scientific community. Some works were conducted for indoor nitrogen dioxide (NO2) and ozone (O3), using sampling instruments and in-situ analyzers, but any study regarding the physics and chemistry of the stratosphere was conducted. At the beginning of the new millennium, CGE started to develop activities in the field of monitoring and assessment of atmospheric gaseous compounds with new optical remote sensing instrumentation and with spectroscopic techniques. These works began thanks to an informal collaboration, started in '98, of the first author of this text and (at that time) the director of the CGE - Professor Ana Maria Silva. This new field of research, resulted in one PhD (2005), one Master attainment (2007) and the formation of the Atmospheric Trace Gases (ATG) group dealing with physics and chemistry of tracers as well as (recently) with air quality evaluation with 'in situ' instruments.

In 2007, CGE, being the only Portuguese research unit working in atmospheric physics at high latitude (namely in Antarctica) participated actively the creation of the Portuguese Polar Program. In 2009 the activities of the ATG group were well established and evolved to the scientific coordination of 7 people (PhD, Master, undergrad. students, fellowships and Post-Docs).

The outcomes of the ATG group in the last years at the CGE have to be split into two main lines of research: the technological and the scientific. The first line can be summarized in: i) a well established equipment for measurements of scattered solar radiation in different zenith and azimuth directions; ii) an equipped optical laboratory for calibration and alignment of optical instrumentation; iv) a thermo controlled container placed at the CGE Observatory accommodating several 'in-situ' instruments for the surface monitoring of NO2, O3 and CO as well as the remote sensing equipments developed at the CGE. The scientific activities, focused on the stratospheric chemistry of NO2 and O3, comparison/validation of ground based/satellite data and O3 climatology in the Iberian peninsula as well as over Portugal, have produced almost 20 articles in peer reviewed international journals and about 30 presentations in national and international conferences. In addition, the new line of research allowed for the introduction into atmospheric chemistry and physics of master and PhD students that actually are experts in the Differential Optical Absorption Spectroscopy (DOAS) methods and analysis of ground based and satellite data in the frame of NO2 and O3 studies.

In the following sections the main products/results obtained from the members of ATG group are briefly presented and discussed.

2 Equipment development

In the last 40 years the monitoring of atmospheric trace gases, in the troposphere as well as in the stratosphere, assumed a great importance from ground based equipments and from satellite borne instruments in the frame of global warming and climate change. Many data used for the assessment of the above mentioned topics are obtained with multiple instruments and analysis techniques, and among these some remote sensing instruments (such as spectrometers with very high spectral resolution) are always improving their capabilities of measuring the spectral radiation in the UV-Visible spectral range. Among them, the GASCOD instrument (Gas Analyzer Spectrometer Correlating Optical Differences) [1,2], was developed during the nineties at the ISAC/CNR – Institute for Atmospheric Sciences and Climate/National Council of the Research - (Italy). Different versions of GASCOD were installed in ground-based stations [3-6]. The technological improvement in the fields of the CCD cameras, of the computer systems and of the data processing suggested the development of a new ground based remote sensing instrument (SPectrometer for Amospheric TRAcers Monitoring – SPATRAM), with the same optic module of the GASCOD, but with new solution in terms of: i) type and number of signal input, ii) thermoregulation system, iii) use of a CCD array detector,

iv) management of the mechanical, optical and electrical components and v) remote control of the equipment and real time data processing. All these new features allow for the retrieval of minor compounds in the atmosphere, with improved temporal resolution, flexible management and enhanced capability of measurements. The development of the SPATRAM took advantage of the experience acquired by the author affiliated with the ISAC Institute, in the setup of the GASCOD/A4p instrument, the airborne version of the ground based GASCOD spectrometers. On board the GEOPHYSICA stratospheric platform [7], GASCOD/A4p took part in several measurement campaigns [8,9], providing very interesting scientific results [10-12]

The development of the SPATRAM instrument is the result of the collaboration between the CGE-UE), the ISAC Institute, and the National Agency for New Technologies, Energy and the Environment (ENEA), Italy.

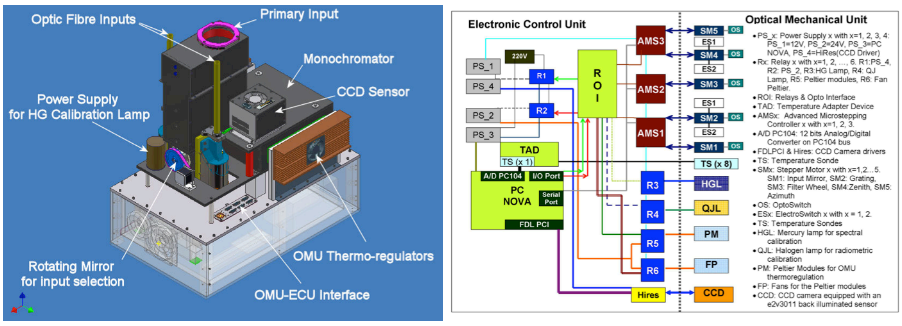


Figure 1 - (Left Panel) Schematic view of the SPATRAM instrument installed at CGE Observatory since April 2004. The Optical Mechanical Unit (OMU), the Electronic Control Unit (ECU) and the main modules in the OMU are highlighted.;(Right Panel) Schematic view of the Optical Mechanical Unit/Electronic Control Unit connections and components

In the SPATRAM, (Fig. 1) the spectrometer is installed inside a thermostatic box able to keep the internal temperature within the working range of the instrument (typically 15°C for the Optical Mechanical Unit - OMU). The Electronic Control Unit (ECU), equipped with 1GHz CPU, drives the spectrometer both in an automatic way and in an unattended mode according to predefined measurement cycles. The SPATRAM instrument is fully described in the paper of Bortoli et al. [13].

The SPATRAM equipment was not designed to work outdoor, so to carry out spectral measurements in safe mode and in order to extend the capabilities to measure the scattered and direct solar radiation, it was necessary to develop other devices to be coupled with the SPATRAM. The outcomes of this work were the VELOD (VErtical LOoking Devices) for the measurements of zenith-sky scattered radiation and the MIGE (Multiple Input Geometry Equipment) [14] able to measure along any direction in the 2p hemisphere (Fig. 2).

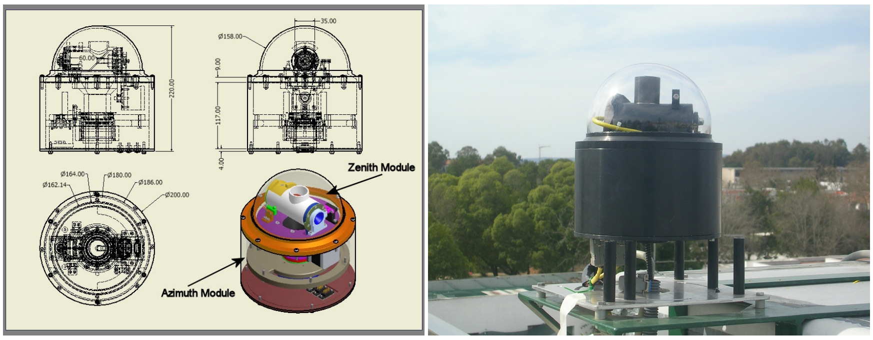


Figure 2. (Left Panel) Executive design for the MIGE device. (Right Panel) MIGE installed outside the container where the SPATRAM instrument is placed.

The developed equipment are managed with the Data Acquisition System (DAS) program completely developed by the first author. The DAS is implemented in ANSI C standard with the support of the multi-platform MGUI (Morello Graphic User Interface) library. The multiplatform features, allow the program to run on computers equipped with Win9x, Win2000, WinXp and in the future also on Linux OS. Moreover the DCL (DTA Camera Library) allows for the control of the operations over the CCD sensor. Other libraries are adopted for the management of the serial port used by the drivers of the stepper motors (AMS) as well as for the execution of several built-in algorithms.

The main features of the DAS is the possibility to carry out measurements in unattended and automatic mode by means of an ASCII file containing the key-words and the parameters for pre-defined measurements cycles. The measurements are stored in binary or ASCII format, in daily folders, on the personal computer embedded in the Electronic Control Unit of the SPATRAM instrument.

3 Stratospheric chemistry of NO2 and O3

The application of DOAS algorithms to the data obtained with the SPATRAM equipment allows for the monitoring of the NO2 and O3 diurnal and seasonal variations as highlighted in references [15-16]. Examples of these works are shown in Figure 3 and Figure 4.

The use of sophisticated inversion algorithms with the output of the DOAS methods consents to determine the vertical distribution of the above mentioned compounds. The inversion model make use of some measurement points, between 83° and 93° of Solar Zenith Angle, for the calculation of the real solution from the a priori profile and the complete set is instead used to check the consistency of the solution using a least squares fit. This reasonableness makes the calculation very stable with respect to oscillation in measurements and on the other hand tends to give more weight to the shape of the measured slant column, which contains the real physical information on the NO2 vertical distribution. Figure 5 illustrates the obtained results for the SPATRAM observations [17, 18].

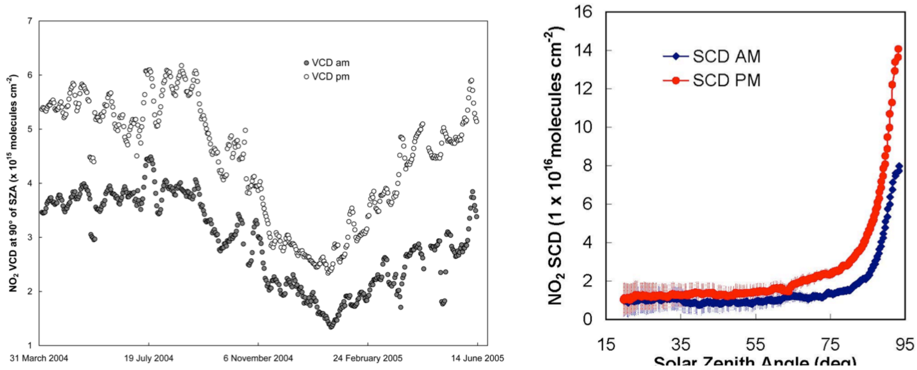


Figure 3. (Left Panel) Suasonal variation of NO2 as observed with SPATRAM. (Right Panel) Diurnal Variation of NO2.

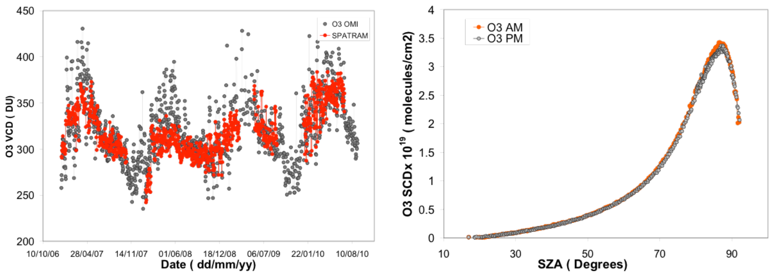


Figure 4. (Left Panel) Seasonal variation of O3 as observed with SPATRAM. (Right Panel) Diurnal Variation of O3

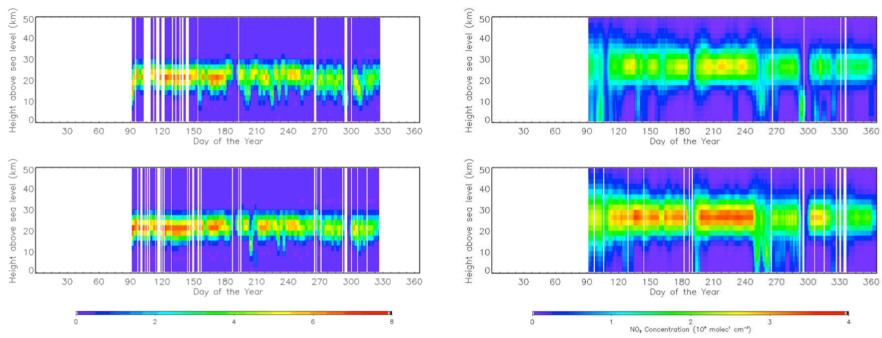


Figure 5. (Left Panel) Seasonal variation of O3vertical distribution over Évora. (Right Panel) Seasonal variation of NO2vertical distribution over Évora

4 Satellite/ground based validation

As a consequence of the performed works, a validation of the obtained results with independent measurements is strongly requested. Mainly for this reason, the ground based observations for NO2 and O3 were compared with other data from satellite and ground based instruments. The SPATRAM data were analyzed with the OMI (Ozone Monitoring Instrument) and the GOME (Global Ozone Monitoring Experiment) satellite instrument, and with the results of a Brewer spectrometer (the reference instrument for ozone measurements). The correlation of the results is very satisfactory as evidenced in figure 6 and Figure 7

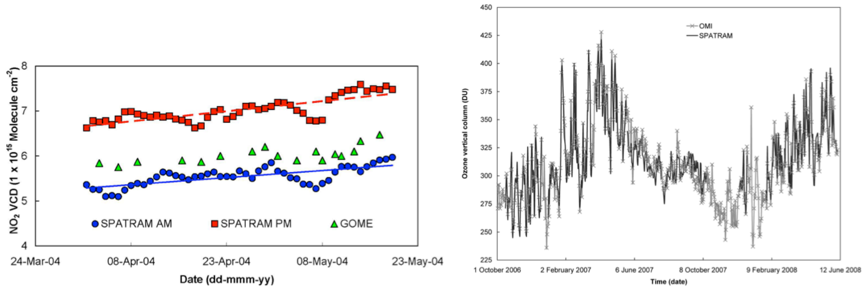
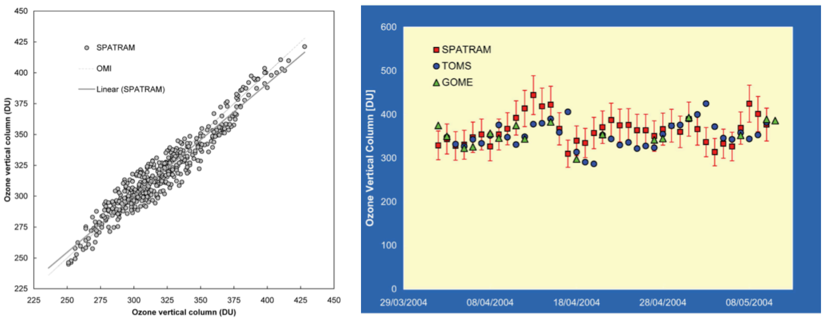


Figure 6. (Left Panel) NO2 vertical column densities over Evora with the data from the GOME satellite instrument. (Right Panel) O3 from SPATRAM and O3 from OMI



satellite instrument

Figure 7. (Left Panel) OMI vs SPATRAM scatter plot . (Right Panel) SPATRAM, TOMS and GOME time series for the first period of the SPATRAM operation at the CGE Observatory.

5 Antarctic results

The studies focused on the tracers at high latitudes, specifically in Antarctica, allowed for the identification of the occurrences of the "Ozone Hole" phenomena during the Austral spring.. The seasonal variation of O3 is evident from figure 8b. The highest values of the ozone column (TOC >350 DU) are mainly imputable to an artifact introduced by the calculation of the O3 AMF that amplify the retrieved values for the beginning and the end of Antarctic Summer season (with 24h of sunlight).

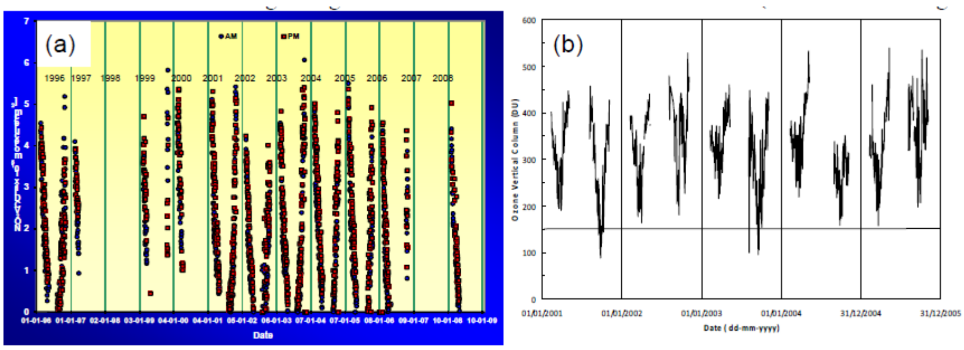


Figure 8. (a) NO2 vertical column density (VCD) time series for the period 1996-2008 (b)Time series of Total Ozone Column (TOC) during the period 2001-2005 at the "Mario Zucchelli" Station

Beside O3, the stratospheric NO2, was monitored and the presence of the GASCOD spectrometer at the Italian Antarctic Station since 1995, allowed for the filling of a 15 year dataset as shown in Figure 9a. From the figure it can be seen that No measurements were carried out in '98 and 2007 due to equipment's problems solved in the following summer campaigns. It can be also noted that for some years ('97, 2000 and 2008) the results are obtained only for the period February – April mainly due to severe conditions of the Antarctic winter preventing the equipment to operate normally at the end of the polar night. For problems to the main power supply no data were obtained in 2009 and for 2010 and 2011, the measurements suffered of an irregular pattern making almost impossible to obtain trustful data. GASCOD restarted the normal operation in 2012.

A full statistical analysis has been conducted for the NO2 observation towards the data obtained with satellite instrumentation. Figure 9 reports the obtained scatter plots for different datasets and different sensors.

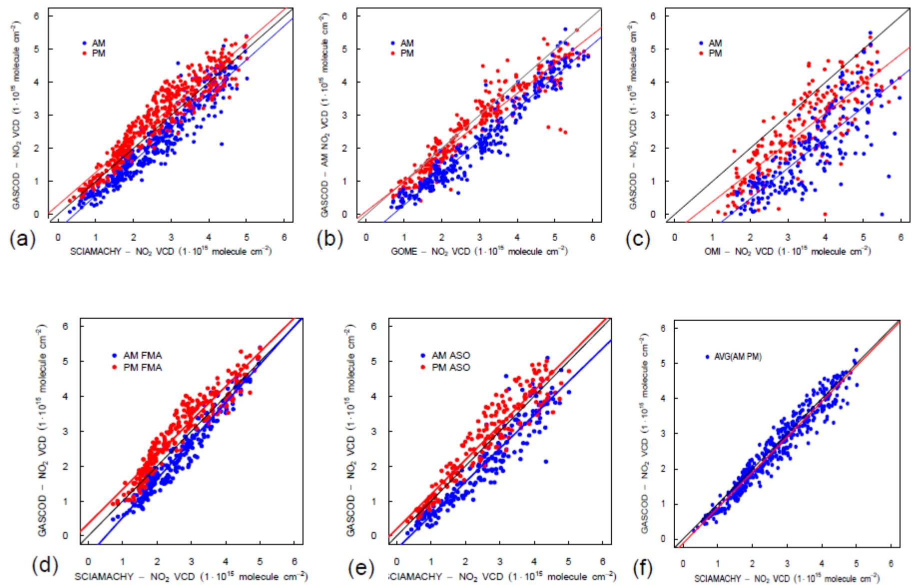


Figure 9. . (a), (b), (c) Scatter plots of NO2 VCD retrieved with GASCOD at MZS during sunrise (AM - red points) and sunset (PM - blue points) versus SCIAMACHY, GOME and OMI data, respectively; (d) AM and PM ground based measurements of NO2 VCD versus SCIAMACHY data for austral fall season (February/March/April - FMA); (e) the same as (d) but for austral spring season (August/September/October - ASO); (f) mean values of AM and PM ground based measurements versus SCIAMACHY data.

6 Automatic Station for Air Quality Assessment

One of the main results of the ATG group is also the setup, started in 2010, and maintenance of an automatic station for the air quality evaluation equipped with: ozone, nitrogen oxides and carbon dioxide oxides.

Surface ozone is a secondary air pollutant, highly reactive, an important trace gas and greenhouse house gas. Moderate to high concentration of surface ozone is harmful for flora and fauna. During clear sky days with strong solar radiation, in the presence of volatile organic compounds (VOCs) and nitrogen dioxides, ozone is photochemically produced and can accumulate to hazardous levels during certain meteorological conditions. However, the distribution is highly variable with transport and photochemistry and is determined by air chemistry, turbulent diffusion, and deposition to the earth surface.

Air pollution due to high surface ozone arising from photochemical formation and accumulation is now a major problem of many regions of the world, and is of environmental concern. Ozone is an oxidizing agent, an increasing concentration of which can modulate the oxidizing capacity of the atmosphere and in turn can affect climate. The diurnal variation in ozone concentration in urban areas exhibits marked diurnal variability, with high concentrations during the day and low concentrations at night but, at the same time sub-urban and rural sites show less pronounced diurnal variation. The characteristics of these temporal patterns of ozone are determined by the complex interaction between precursor emissions, chemistry, depositional processes and meteorological controls on dispersion.

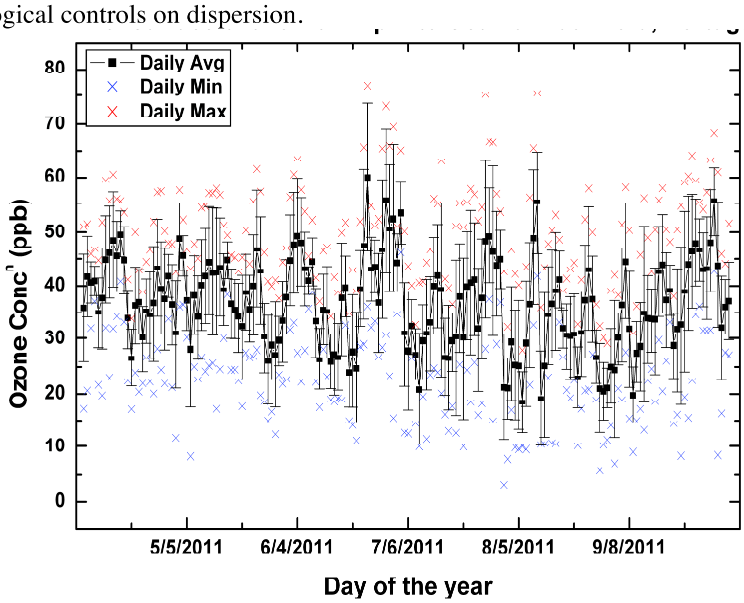


Figure 10. Daily averaged concentration of surface ozone measured at the CGE observatory.

Monitoring of suface ozone over CGE, Evora is carried out with O342 UV photometric ozone analyzer from Environment S.A. UV Light at 253.7 nm is passed through a sample cell that alternately contains the measurement sample and then a reference sample that is selectively scrubbed of ozone. The difference in UV light attenuation between the sample and reference gas streams provides the measurement of ozone present in the gas sample. The minimum detection limit of the analyzer is about 1 ppbv. Figure 10 shows the first preliminary results of surface ozone observations at the observatory of the CGE. Discussions about the ozone chemistry and dynamics can be done only after studying it in relation with NOx and other meteorological observations with at least one year time series [19].

Acknowledgments

The activities at the CGE regarding the Atmospheric tracers monitoring have grown-up in the last 10 years and a special thanks to Giorgio Giovanelli (ISAC-CNR), that believed in the Centre giving support as a scientific consultant, to Adriano Gabellini (COM snc) that always gave the right suggestions in the mechanical development of the equipments and to Manuele Turini (DTA) that always follows the applications of the CCD cameras at the CGE.

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DETERMINATION OF THE OZONE COLUMNAR CONTENT FROM SPECTRAL IRRADIANCES MEASURED AT THE SURFACE

MARTA MELGÃO
Geophysics Centre of Évora, University of Évora, Rua Romão Ramalho, 59 Évora, Portugal, martamel@uevora.pt

MARIA JOÃO COSTA
Geophysics Centre of Évora and Physics Department, University of Évora, Rua Romão Ramalho, 59, Évora, Portugal,mjcosta@uevora.pt

ANA MARIA SILVA
Geophysics Centre of Évora, University of Évora, Rua Romão Ramalho, 59, Évora, Portugal, asilva@uevora.pt

DANIELE BORTOLI
Geophysics Centre of Évora, University of Évora, Rua Romão Ramalho, 59, Évora, Portugal, db@uevora.pt

The purpose of the study is to determine the ozone columnar content over Évora, from spectral irradiances measured at the surface. The instrument used was a spectral radiometer, (Multi-Filter Rotating Shadow Band Radiometer YES MFR-7), installed at the Observatory of the Évora Geophysics Centre. This study was carried out for four years, 2005 to 2008. Satellite data (once a day) from the Ozone Monitoring Instrument (OMI) on board AURA satellite, was used too and compared with the daily means calculated from the surface instrument. A strong linear correlation between the two data set (O_3OMI and O_3MFR-7) was found, with a correlation coefficient R=0.8. The seasonal and inter-annual ozone (from OMI and from MFR-7) variability was analyzed, showing similar patterns, although OMI ozone values are normally greater than those obtained from the MFR-7 radiometer.

1 Introduction

Ozone, O_3, is one of the gaseous constituents of the atmosphere, being a molecule composed by three oxygen atoms it can also be dissociated by radiation between 200 and 300 nm. At the surface ozone is considered a threat to human life, and in fact, even in reduced concentration it is a toxic gas. This gas can be found in the stratosphere, where its concentration is maximum between roughly 20 and 25 km of altitude, and in lower and variable concentrations in the troposphere that close to the surface are may be strongly related to human activity. Ozone plays an important role in the radiative balance of the atmosphere, absorbing selectively, either thermal or ultraviolet radiation (Ramanathan et al., 1976; Ramanathan and Dickinson, 1979; Fishman et all., 1979a, Wang et al., 1980; Logan, 1994). The ozone thus contributes to the greenhouse effect, mainly due to the existence of the absorption band located in the 9.6μm region and plays an important role at regional and global scale (Anton et al., 2010). Stratospheric ozone performs a fundamental role for the existence of life on Earth, being responsible for the absorption of ultraviolet radiation, thus ozone variability highly influences the values of ultraviolet radiation measured at the surface. Ozone is highly variable daily and seasonally (Dobson, 1930; Angstrom, 1972; Byrne and King, 1976), through an annual and seasonal ozone cycle, due to various factors, including geographical and meteorological. In this work, measurements of the irradiance at the surface were done using a spectral radiometer YES MFR-7 Shadow band, which measures simultaneously the spectral irradiance in six spectral channels and a broadband channel. In this study we use the MFR-7 measurements in spectral regions located in some of the ozone absorption bands aiming at determining the ozone columnar content. In cloud-free situations, these measurements allow for the determination of the amount of columnar ozone and simultaneously the optical thickness of aerosols through the correction of Rayleigh scattering and nitrogen absorption effects.

2 Methodology

The purpose of this study was to determine the total ozone content over Évora, from spectral irradiances measured at the surface. The data was collected with a spectral radiometer (Multifilter Rotating Shadow band Radiometer YES MFR-7), installed at the Observatory of the Évora Geophysics Centre. This study was carried out for 4 years, 2005 to 2008, in some distinct periods each year, due to the lack of data in the rest of the time. The ozone monitoring was made for Évora (38.57°N, 7.9°W) in the period considered. The position of the instrument is important due to the spatial and temporal variation of the O_3 profiles, with latitude, height and atmospheric conditions.

The MFR-7 measures the spectral solar irradiance, the horizontal global component and the diffuse horizontal component. An estimation of the direct horizontal spectral irradiance is obtained by the difference of the two. It measures the spectral irradiance in 7 channels, 413.8nm, 496nm, 612.3nm, 672.1nm, 868.3nm e 937nm, and a broad band channel (300nm to 1100nm).

The instrument software, based on certain conditions, executes the Langley Method in order to obtain the spectral irradiance at the top of the atmosphere (TOA) Ioλ,.

Langley method is based on the Bouguer-Lambert law, equation 1, and could be applied at the surface of the globe, under some restricted conditions: atmospheric stable conditions, low aerosol concentration and clear sky (cloud absence). In thisway constant values of optical depths are assured. Based on the mentioned conditions, it is possible to obtain the solar spectral irradiance measured ate TOA, Ioλ, that is, the value that the instrument would measure if it wouldbe installed at the TOA.

$$\mathrm{In}\,(\mathrm{I}\lambda) = \mathrm{In}\,(\mathrm{Io}\lambda) - (\tau\lambda\mathrm{m}) = \ln(\mathrm{S}\lambda\left[\frac{a}{R}\right]) - (\tau\lambda.\,\mathrm{m}) \qquad (1)$$

Here I_λ is the spectral direct irradiance measured at the surface; Io_λ spectral irradiance inferred at the TOA when the distance to the Sun is R and S_λ is the solar irradiance at the TOA (solar spectral constant) for an Earth-Sun mean distance a. This mean Earth-Sun distance represents the Astronomical Unit (1 AU), R assumes different values for each day (superior or inferior to 1AU) according to season; τ_λ represents the atmospheric optical depth and m the air mass. Using the Langley method, the atmospheric optical depth τ_λ and the spectral irradiance at the TOA, Io_λ could be obtained graphically. This method is computed using equation 1, for the required atmospheric conditions, yielding the plot of direct spectral irradiance measured at the surface vs air mass, betweenair mass values of 2,8 and 4,8. Equation 2 shows all the extinction components that contribute to the total optical depth, τ_λ, $\tau_{\lambda rayleigh}$, $\tau_{\lambda aerosol}$, $\tau_{\lambda O3}$ e $\tau_{\lambda NO2}$, Rayleigh, aerosol, ozone, and nitrogen optical depths, respectively.

$$\tau = \tau_{rayleigh} + \tau_{aerosol} + \tau_{O3} + \tau_{NO2} \quad (2)$$

The aim of this study was the retrieval of the total ozone content using spectral irradiances measured at the surface, with a spectral radiometer MFR-7 and the comparison with satellite data from the instrument OMI on board of AURA satellite. In this study the total ozone content was determined, by the correction of the contributions of Rayleigh and nitrogen, changing iteratively the ozone content through the adjustment of a 2nd order polynomial to the aerosol optical depth, $\tau_{\lambda aerosol}$, according to the procedure described by [1] and illustrated in figure 1.

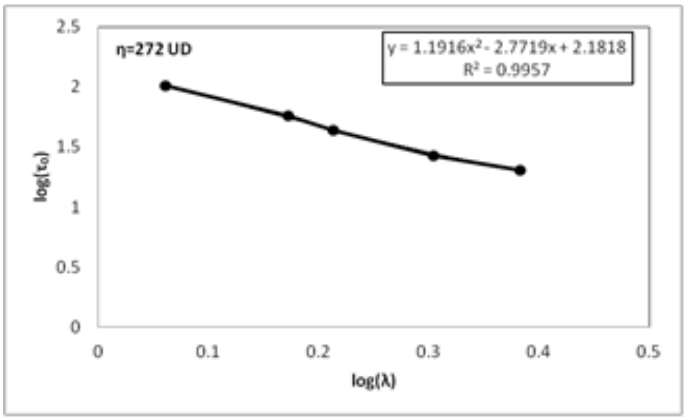

Figure 1. Graphic representation of the procedure followed to determine the ozone total column.

Based on figure 1, for any given results of $\tau_{\lambda aerosols}$ and η_{O_3} a curve is obtained, from the fitting of equation 3, and the optimum content of ozone was chosen when X^2 (statistical distribution) was a minimum. That was the value that we compare with the one from OMI instrument.

$$\log(\tau_a) = a_0 + a_1 \log(\lambda) + a_2 [\log(\lambda)]^2 \quad (3)$$

3 Results and Discussion

This study was carried out for 4 years of data, although, the data was not collected continuously. In 2005 we use data from October, November and December (45 days), in 2006 we use data from January to September (199 days), in 2007 we use data from August to December (116 days) and in 2008 we use data from January to July (167 days). The results obtained were based on the chosen data with the described methodology. One of the purposes of the study was the determination of the ozone column in Évora and in figure 2 it is possible to see the ozone column daily evolution during 6 July 2008. It is found that during one day, the O_3 content is approximately constant under the described conditions in the methodology section (section 2).

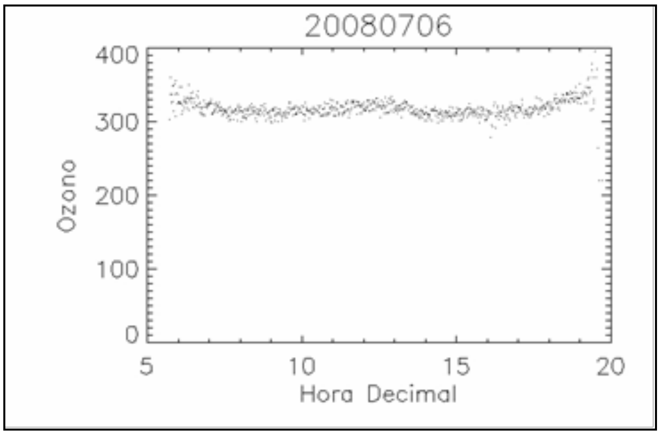

Figure 2. Graphic representation of the total ozone content (expressed in Dobson Unit (DU)) obtained with MFR-7 instrument, for 6 July of 2008.

Next in Figure 3, we present the results of the total content of ozone in Évora obtained with the MFR-7 and the comparison with the values obtained from OMI instrument. A linear correlation test, r, is also done with the goal of understanding whether there was sufficient statistical evidence to prove that the linear correlation between the sample data obtained by OMI instrument and sample data obtained by Ozone MFR-7 instrument is significant. The above test was carried out to a level of significance of 0.05 ($\alpha = 0.05$). Considering the number of samples, n, if the correlation coefficient exceeds the value of the critical correlation coefficient for this test, then there is a significant linear correlation between variables.

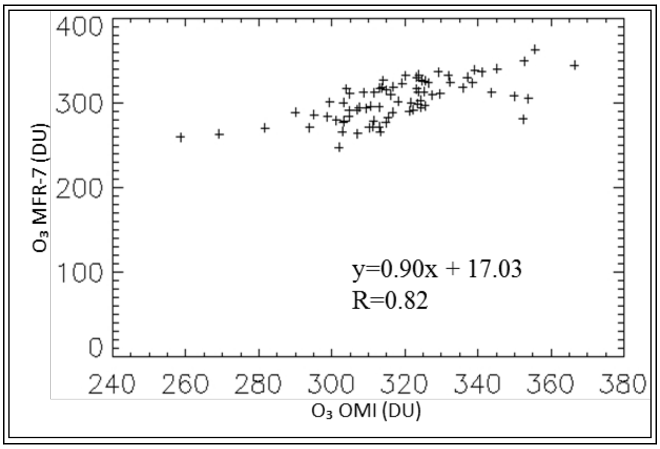

Figure 3. Scatter plot of the two data series and corresponding correlation coefficient for the complete period.

In Figure 4 is represented the distribution of the relative errors obtained from the difference between the two series (O_3OMI and O_3MFR-7). Its analysis reveals that the relative error lies between 3 and 8% for about 70% of the values, and that less than 10% of the values present relative errors greater than 15%.

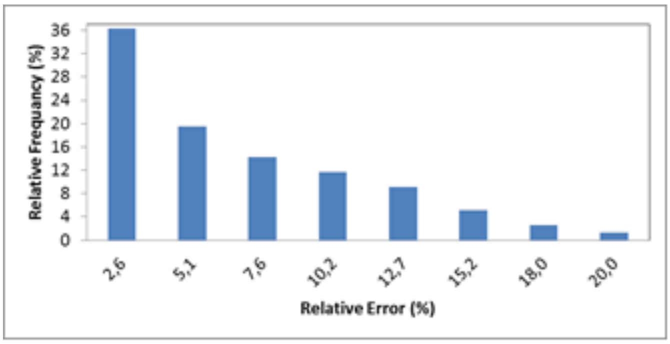

Figure 4. Distribution of the relative errors obtained from the differences between O_3OMI and O_3MFR-7 values.

We performed a seasonal and annual analysis in order to understand the total ozone columnar content variation. In conclusion it was found that in both analysis (seasonal and annual) the highest value was recorded during Spring and the smallest value registered in the Summer season. Furthermore, it can be said that the satellite values are for most of the days, greater than those calculated using the surface instrument.
We also performed a statistical test – r statistical test- to all of our data, in order to check if there is enough statistical evidence to say that there is a significant linear correlation between both series (O_3OMI and O_3MFR-7). The data was tested by season and by year. Table 1, show the results that we obtained. It was concluded that, for a significance of

0.05, there is not enough statistical evidence to say that on the spring season O_3OMI and $O_3MFR\text{-}7$ have a significant linear correlation. For the rest of the samples, it is concluded that there was sufficient statistical evidence to say that the linear correlation between both series are significant.

Table 1. Correlation Coefficients (R) between the O_3OMI and $O_3MFR\text{-}7$ series, per year and per season.

Season	Correlation Coefficient (R)	Year	Correlation Coefficient (R)
Spring	0.260	2005	0.890
Summer	0.692	2006	0.577
Autumn	0.968	2007	0.653
Winter	0.980	2008	0.670

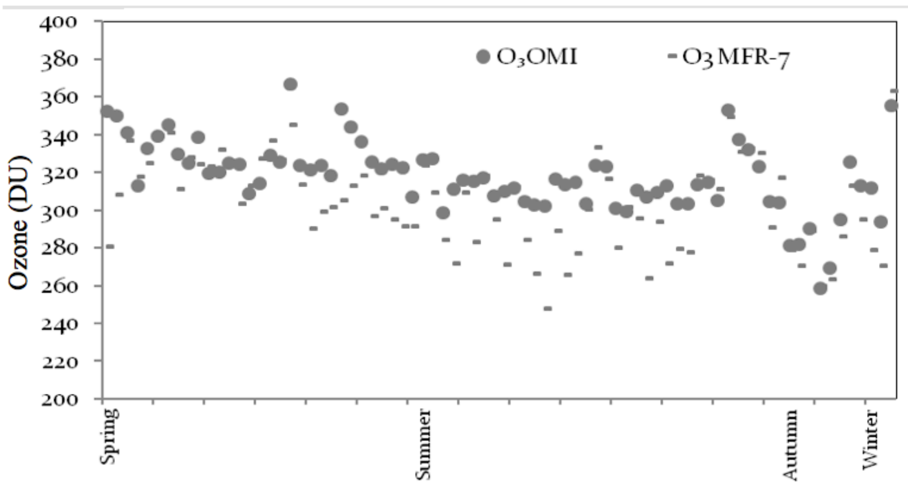

Figure 5. Seasonal evolution of the daily mean columnar content of ozone (DU).

Based on figure 5, we see that most of the O_3_OMI values are greater than the $O_3MFR\text{-}7$ values. So, analyzing the data, it was verified that for 73% of the total values O_3OMI are superior to $O_3MFR\text{-}7$, figure 6.a) and that corresponds to different percentage in each season, figure 6.b).

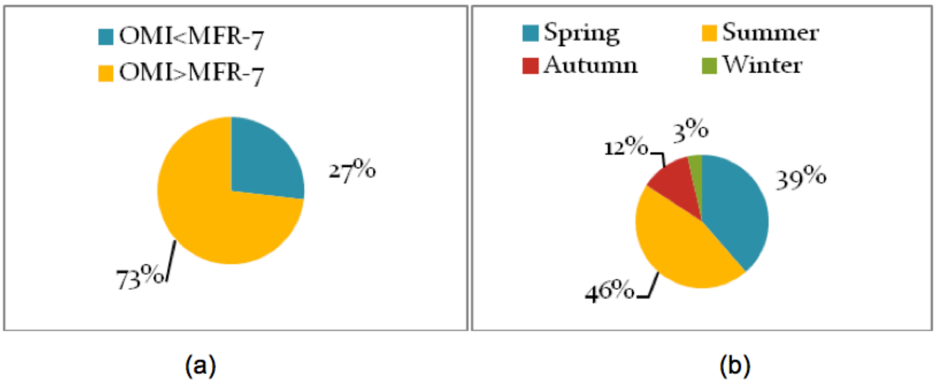

Figure 6. Illustration of the percentage of values where O_3OMI>O_3MFR-7. Complete period (a) and per season (b).

4 Conclusions

The main goal of this study was the retrieval of the total ozone content obtained using spectral irradiances measured at the surface, by a MFR-7 spectral radiometer, and its comparison with satellite data from OMI instrument onboard AURA satellite. Concerning the results obtained for the columnar content of ozone, we can conclude that for 73% of the days (57 of 78 days) the satellite values, obtained from OMI instrument, were higher that the values calculated using the spectral irradiances measured at the surface with the MFR-7. We calculate the relative error and the correlation coefficient between the two series. The results show a high correlation, R=0.8 and a relative error within 3% and 8%, for most of the values. It is also to note that there are few values with errors superior to 8%. In conclusion, the obtained columnar content of ozone was according to the expected values for our geographical position.

Acknowledgements

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STUDY OF SIGNIFICANT WINTERTIME PRECIPITATION EVENTS IN MADEIRA ISLAND

FLAVIO TIAGO DO COUTO
Évora Geophysics Centre, University of Évora
Évora, Portugal, couto.ft@gmail.com

RUI SALGADO
Évora Geophysics Centre, University of Évora
Physics Department, University of Évora
Évora, Portugal, rsal@uevora.pt

MARIA JOÃO COSTA
Évora Geophysics Centre, University of Évora
Physics Department, University of Évora
Évora, Portugal, mjcosta@uevora.pt

The purpose of this paper is to show the main features of the atmosphere related to seven significant precipitation events in the Madeira Island occurred during the 2009/2010 winter. In this study, the MESOscale Non-Hydrostatic model (MESO-NH) is used, as well as measurements of precipitable water obtained from the Atmospheric InfraRed Sounder (AIRS) and in situ measurements of precipitation. In accordance with the data analyzed, it was concluded that the orography of the island is the dominant factor both in the formation and intensification of precipitation. However, this work also identified the presence of atmospheric rivers in six of the seven cases, which transport water vapor from the tropics towards higher latitudes favoring the development of dense clouds and the events of high precipitation, even in marginally unstable conditions.

1 Introduction

Situated in the Subtropical Atlantic Ocean (32º 75' N and 17º 00'W), Figure 1, the Madeira Island is the largest island of the Madeira Archipelago, with surface area of 737 km^2. The island is formed by volcanic materials with an approximately East-West elongated form (58 km long and 23 km width) being able to block and deviate the wind around and above, presenting favorable conditions for generation or intensification of orographic precipitation. Sometimes this characteristic is responsible by high records and several social-economical damages. Evidences of heavy precipitation during the winter 2009/2010, for example, the disaster occurred on 20^{th} February 2010, when the Madeira Island was hit by intense precipitation, causing more than 40 deaths and huge economic losses, were the main motivation for the development of this study.

The mechanisms responsible for orographic precipitation development or enhancement are reported in several studies, e.g. [3], [4], [7]. The different mechanisms of orographic precipitation can be associated with stable and convective precipitation or amplification of an existing precipitation (also known as Seeder-Feeder [1], [2]), depending on some factors, for example, size/shape of the mountain, moisture content, stability of the airmass, and large scale disturbances.

Figure 1. Location of Madeira Island. Source: Google Earth.

The precipitation regime over the Madeira is not only affected by local circulation, but also by synoptic systems typical of mid-latitudes, as fronts and extra-tropical cyclones, and the Açores Anticyclone in the summer season. Recent studies have confirmed the important role played by the meridional water flux, also known as Atmospheric Rivers (ARs) that favors the intensification of orographic precipitation. Atmospheric rivers are long (>~2000 km), narrow (<~1000 km wide) bands of enhanced water vapor flux (e.g., [6], [8], [9]), that can produce heavy rainfall when striking the coastal mountains, through orographic lifting. This paper aims to show the main features of the seven significant precipitation events in the Madeira Island occurred during the 2009/2010 winter and its relation with the North-Atlantic Atmospheric Rivers.

2 Methods, data and case studies

The first step of the methodology consisted of the analysis of rain gauge data in the 2009/2010 winter (i.e., December 2009, January and February 2010). The analysis of these data led to the choice of seven case studies, based on the daily rainfall amounts. Daily amounts were extracted from hourly data from a total of 7 stations distributed over the island (Figure 2b). The case studies identification was based mainly in the data from the Areeiro station, situated near the top of the island. The second step comprises the large scale analysis, carried out using precipitable water maps obtained from the Atmospheric Infrared Sounder (AIRS). The AIRS is one of six instruments on board the Aqua Satellite, part of the NASA Earth Observing System. Finally, the last step consists of numerical simulations of the four most intense cases that occurred during the study period. Besides the high-resolution simulation of precipitation (mm), other variables have been examined such as the atmospheric stability from the Convective Available Potential Energy – CAPE (J/kg), the wind components (m/s), vertical velocity (m/s), cloud fraction, and mixing ratio for rain, cloud water, ice, snow, and graupel (g/kg).

The mesoscale non-hydrostatic model (MESO-NH; [5]), used in this work, was jointly developed by Centre National de Recherches Météorologiques (CNRM) and the Laboratoire d'Aerologie (Meteo-France). The MESO-NH is able to simulate the atmospheric motions, ranging from the large meso-alpha scale down to the micro-scale, using as prognostic variables the three components of the wind, the potential temperature, the turbulent kinetic energy and up to seven classes of mixing ratios (r) for water substances, considering the vapor (r_v), liquid cloud water (r_c), liquid rain (r_r), cloud ice

(r_i), snow (r_s), graupel (r_g) and hail (r_h). In addition to dynamic and thermodynamic equations, which govern the atmospheric motions, the MESO-NH is implemented with a rather complete parameterization package of several physical processes observed in the atmosphere.

The numerical simulations were carried out with 45 vertical stretched levels and three horizontal nested domains, in a two-way interactive mode. The larger domain (D1), was established with 40x40 grid points and a spacing of 9 km, the second domain (D2) with 60x60 grid points and a resolution of 3 km and the third domain (D3), with 90x60 grid points and 1 km resolution. The area corresponding to the horizontal domains is presented in Figure 2.a together with the 1 km resolution orography of the inner domain (Figure 2.b), centered over Madeira island. In diagnostic mode the initial and boundary conditions were updated every 6 hours and obtained from the ECMWF analyses, while in prognostic mode these conditions were updated every 3 hours from the ECMWF forecasts. The MESO-NH was run in diagnostic mode in all selected cases. For the 20 February 2010 catastrophe case the model was also run in prognostic mode in order to test the performance of the MESO-NH forecast.

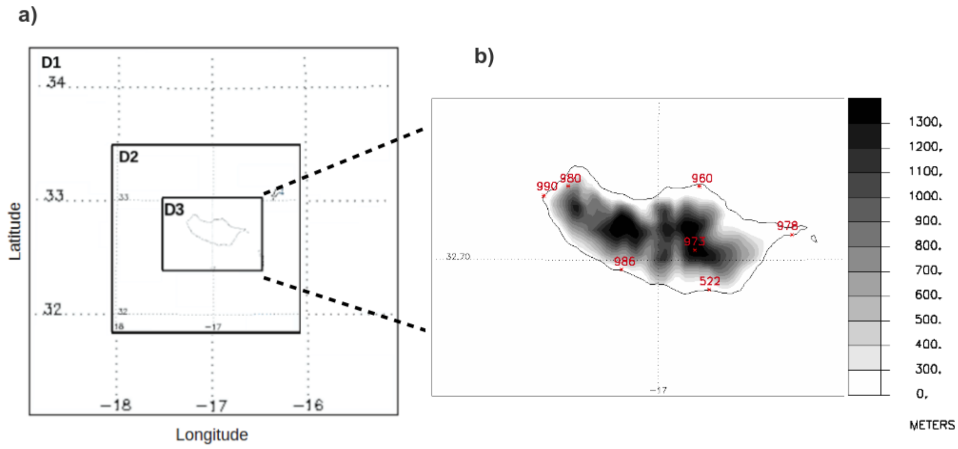


Figure 2. (a) horizontal domains used in the simulations with grid spacing of 9 km (D1), 3 km (D2) and 1 km (D3), (b) The shaded areas represent the 1km orography (m) obtained from the GTOPO30 database. Points (Station): 522 (Funchal), 960 (Santana), 973 (Areeiro), 978 (Caniçal), 980 (Lombo da Terça), 986 (Ponta do Sol), 990 (Calheta). Source: [10]).

3 Results

The analysis of the daily accumulated rainfall distribution for the winter 2009/2010 (DJF) in seven surface stations, indicated that the maximum daily rainfall values are systematically recorded over the Madeira's highlands. From these data, a set of seven cases has been selected to analyze: 15 December 2009; 17 December 2009; 22 December 2009; 28 December 2009; 02 January 2010; 02 February 2010; and 20 February 2010.

According to synoptic charts (not shown here), in 6 (of 7) cases the synoptic conditions over the archipelago were strongly influenced by the passage of a frontal system, with the center of the cyclone located to the North of Madeira. The remaining case was characterized by the development of a low-pressure system over the southern part of the archipelago, being centered between Madeira and the Canary Islands.

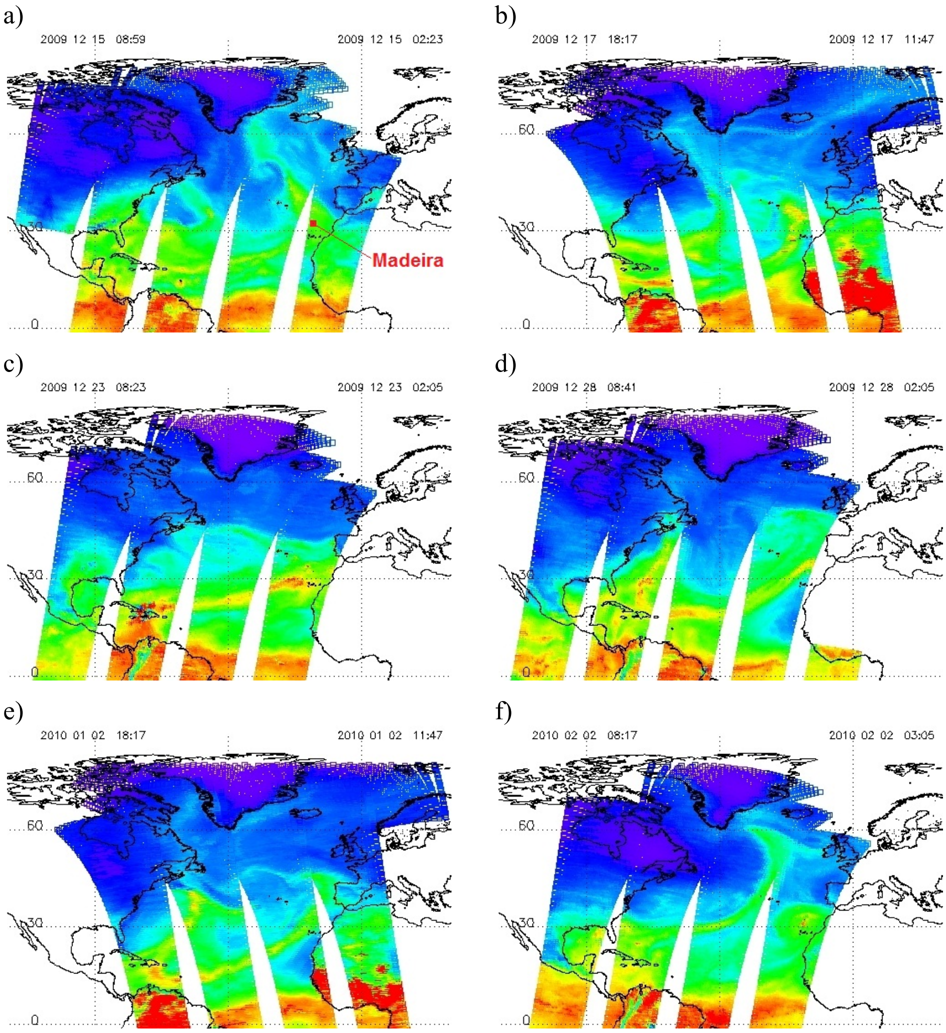
Another factor also associated to the dynamics of the extra-tropical cyclones, related to large-scale circulation, was found in the precipitable water maps: the frequent existence of warm conveyor belts in the warm sector. This is an important structure in tropical–extratropical interaction, which transports heat and moisture from the tropics towards the mid-latitudes. Being coupled to frontal systems, the warm conveyor belts or atmospheric rivers act as low level jets. Comparing the cases where the atmospheric rivers are present (Figures 3.a, 3.b, 3.c, 3.d, 3.e, and 3.g), the satellite observations show that the amounts of precipitable water exceed in most of the cases 40 kg/m^2 (i.e, Figure 3.d). In fact, sometimes the precipitable water reaches values greater than 50 kg/m^2 (Figure 3.g).

In the case of 2 February 2010, the atmospheric river, i.e., the meridional transport of heat and humidity was not present (Figure 3.f), being the synoptic situation characterized by the presence of a low pressure system centered to the South of the island, which contained a large amount of precipitable water, with values greater than 60 kg/m^2 near the island.

Aiming at finding other aspects related to the high precipitation amounts rather than only synoptic similarities, simulations with the MESO-NH were made for the following days: 22 December 2009 (CASE 1), 28 December 2009 (CASE 2), 02 February 2010 (CASE 3), and 20 February 2010 (CASE 4).

Figure 4 shows the horizontal wind vectors at approximately 1 km altitude, for each case when the maximum rainfall was recorded, as well as the daily accumulated precipitation (24 hour) produced by the high-resolution inner model. It is possible to identify from the wind field a southwestern flow in three of the four cases (CASE 1 - Figure 4.a, CASE 2 - 4.b, CASE 4 - 4.d), agreeing with the large-scale analysis, where the presence of atmospheric rivers, flowing from southwest and acting over Madeira, were identified. Figure 4.c illustrates the daily accumulated precipitation over Madeira island obtained in the simulation of CASE 3, with an accumulated precipitation between 260 mm and 300 mm in Madeira's highlands.

In all simulated cases the high-resolution simulations were able to show that the daily accumulated precipitation maxima occurred in the highest regions of the island, indicating the important effect of orography in the intensification of precipitation, given the large differences between the rainfall amounts over the island and over the ocean. On the other hand, the precipitation in the lower regions of the island has a spatial variation depending on the flow direction at low levels and, consequently, of the synoptic pattern observed.



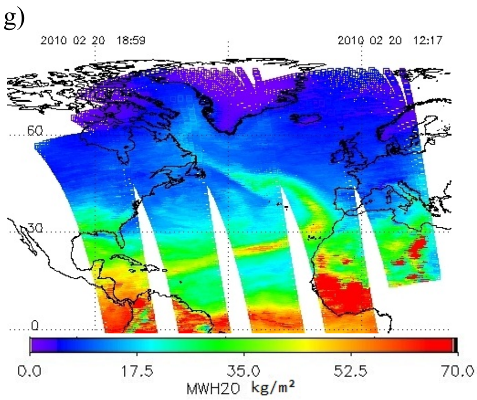


Figure 3. Satellite image of precipitable water obtained from the Atmospheric Infrared Sounder (Aqua-AIRS) for each case study. (a) 15 December 2009, (b) 17 December 2009, (c) 23 December 2009, (d) 28 December 2009, (e) 02 January 2010, (f) 02 February 2010, and (g) 20 February 2010. Source: [10].

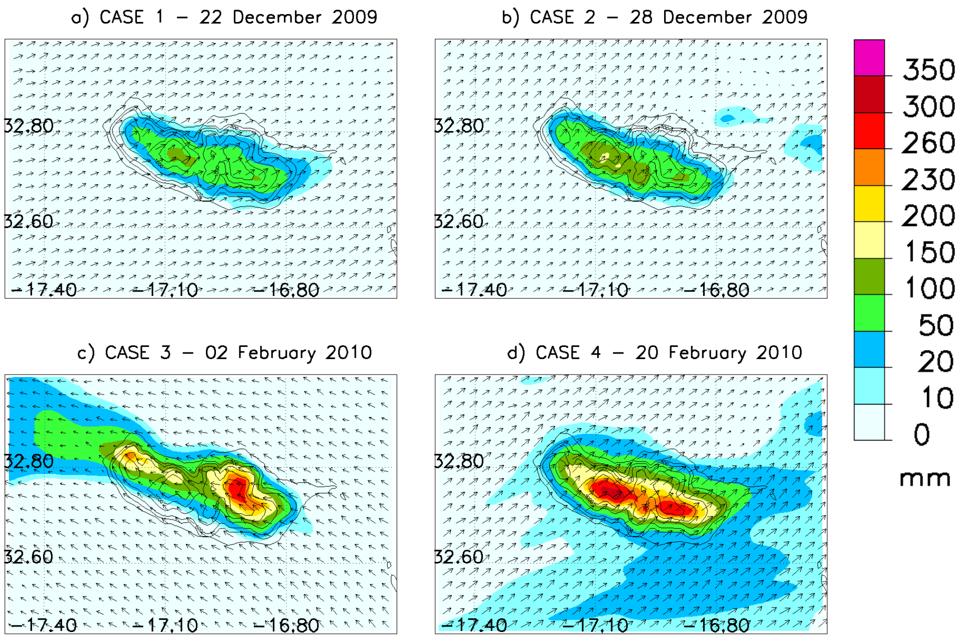


Figure 4. The shaded areas represent the daily accumulated precipitation (mm) simulated with the MESO-NH Model, solid lines the Madeira orography (m) obtained from the GTOPO30 database and horizontal wind vectors at model level 18, approximately 1 km above the surface (a) 22 December 2009 and wind vectors at 20 UTC, (b) 28 December 2009 and wind vectors at 05 UTC, (c) 02 February 2010 and wind vectors at 07 UTC, and (d) 20 February 2010 and wind vectors at 12 UTC. Source: [10].

The accumulated precipitation simulated by the model, running in prognostic mode for 20 February 2010 is presented in Figure 5. The results show that the model simulates well the accumulated rainfall, and the orographic effect on the precipitation enhancement. In general, the results are close to those obtained in diagnostic mode (see Figure 4.d), confirming the ability of MESO-NH model to predict these high precipitation events.

Since one of the goals of this work was the understanding of some of the aspects related to the increase of rainfall amounts in Madeira's highlands, the atmospheric stability evaluated in terms of the simulated Convective Available Potential Energy (CAPE), as well as the vertical motions and the hydrometeor distributions were also analyzed. The complete analysis is not shown here, however, the results revealed the formation of clouds with thicknesses of a few kilometers, which indicates that the anabatic flow created by the presence of the island is sufficient to induce the development of dense clouds and events of high precipitation, even in marginally unstable conditions (CAPE lower than 1000 J/kg), provided that the low-level atmospheric moisture is sufficiently high. Only one of the cases studied showed a moderately unstable atmosphere, while in all other cases the simulated CAPE indicates stable or marginally unstable conditions, which does not favor the triggering of deep convection. Therefore, intense precipitation events in Madeira are not necessarily associated with thermodynamic instability, being the orographic effect allied to high precipitable water values, the crucial factors in the generation of these extreme precipitation events.

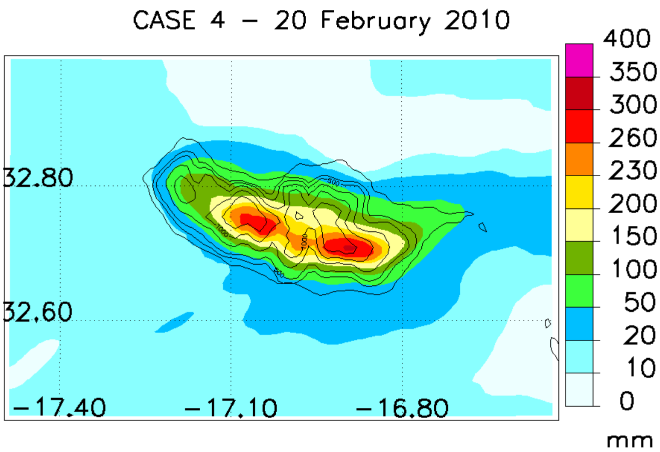


Figure 5. Forecast of accumulated precipitation for 20 February 2010 is represented by the shaded areas, while the solid lines represent Madeira orography (m). The orography is simulated from GTOPO30 database with 1 km resolution. Source: [10].

4 Conclusions

In summary, it was concluded that the high rainfall amounts observed during the winter of 2009/2010 in Madeira Island, were directly related to the orographic forcing. In most of the selected cases, the lifting occurs with the most intense vertical velocities mainly over the island and near the surface. The development of precipitation over the island can be intensified by large-scale patterns, such as the passage of weather systems, as fronts or low pressures. This study also identified the presence of atmospheric river structures, associated to frontal systems that act to provide the necessary moisture conditions for the intensification of orographic precipitation. Southwest winds at low levels favor the transport of moisture to the upper regions of the island, contributing to the formation of denser clouds, although with weak vertical development.

The MESO-NH model has reproduced satisfactorily the main features related to the four simulated cases, taking into account the known difficulties related to the comparison between local precipitation observations and high resolution simulation results, in mountainous regions. The efficiency of MESO-NH in predicting heavy rainfall over Madeira confirms the fact that it is possible to obtain good forecasts of rainfall for the island, based on atmospheric models with high horizontal resolution (~ 1km). A more detailed description of the study is shown in [10].

Acknowledgments

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WATER QUALITY OF INLAND WATERS

MIGUEL POTES
University of Évora, Rua Romão Ramalho, 59, 7000-671
Évora, Portugal, mpotes@uevora.pt

MARIA JOÃO COSTA
Physics Department of University of Évora, Rua Romão Ramalho, 59, 7000-671
Évora, Portugal, mjcosta@uevora.pt

RUI SALGADO
Physics Department of University of Évora, Rua Romão Ramalho, 59, 7000-671
Évora, Portugal, rsal@uevora.pt

Changes in the water surface composition, such as phytoplankton and turbidity, can be detected through satellite remote sensing. Nevertheless, to obtain the surface signal from the top-of-atmosphere data an atmospheric correction has to be performed by a radiative transfer code. Empirical algorithms are used in combination with spectral surface reflectance and limnology data. On other hand, the light penetrating the water body is affected by absorption and scattering processes resulting in spectral intensity changes along its path. The sum of these processes can be measure in terms of water attenuation coefficient of sunlight field.

1 Introduction

The water quality control and monitoring of inland water masses is crucial, since these constitute essential renewable water resources for domestic, agricultural, and industrial purposes, amongst many others. The region of Alentejo, located in the south of Portugal, represents about one third of the mainland country, hosting about 5% of the national population. Alentejo is a region long known by the irregularity of its hydrological resources. This region is characterized by hot dry summers and fairly cold and occasionally rainy winters. In fact, rainfall is usually concentrated in a short period during the year, typically from November to February. Rainfall periods are irregular and the region faces periods of drought that may last more than one consecutive year. Thus, to ensure an essential water reservoir in Alentejo region, Alqueva reservoir was developed, allowing for the water storage and use, even during extensive drought periods. Water quality is monitored by the responsible entities; however, samples regularly collected and analyzed in the laboratory are spatially and temporally limited. In this way the satellite remote sensing it is fundamental technique for full spatial cover and continuous monitoring of key biological parameters which affect the water quality of inland water bodies such as Alqueva. Spectroradiometers aboard satellites, which combines moderately high spatial and temporal resolution with an adequate spectral resolution in the visible and near infra-red, are useful for monitoring the "colour" of these inland water masses. The use of satellite data to evaluate the optical water properties is

steadily increasing, since this kind of data provides undoubtedly the only way to proceed for global characterization of water bodies ([1];[2]). Nevertheless, a crucial issue regarding the optics of the water bodies is the water transparency for light field. One measure of the water transparency is the attenuation coefficient. Results from [3] shown that the two layer bulk lake model, FLake model [4], is very sensitive to different attenuation coefficient values, namely in the lake surface temperature which is a key parameter in heat and moisture transfers between the lake and the atmosphere. Therefore, some authors ([5];[6]) are committed in including the FLake model in operational numerical weather prediction (NWP) models.
The following sections describe the limnology of the Alqueva reservoir; the atmospheric correction performed over Alqueva reservoir; the empirical algorithms developed and their validation; phytoplankton mapping of Alqueva reservoir; measurements of inwater downwelling radiance and attenuation coefficient.

2 Limnology

The optical properties of natural water masses are determined mainly by the organic and inorganic material present in solution or suspended in the water which characterizes the trophic state of the water bodies. Alqueva reservoir is one of the largest artificial lakes in Europe in terms of surface area (250 km^2) and represents a good example of the importance of inland water quality control, due to its importance for the region where it is located ([7]).

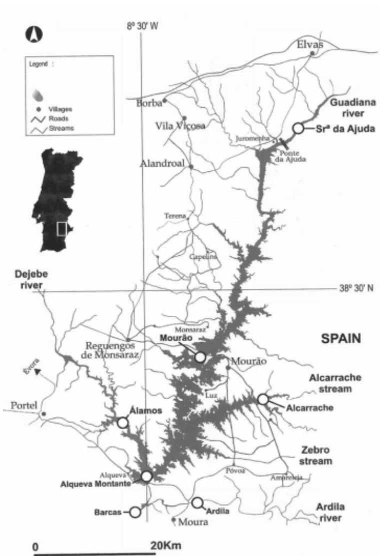


Figure 1. Map of Alqueva reservoir and sampling site locations – Map from [7].

Chlorophyll *a* is the only photosynthetic pigment present in all plants being consequently a good indicator of biomass and photosynthetic activity. This pigment exhibits a unique spectral absorption signature with marked peaks in the blue and red region.
The cyanobacteria, also known as blue-green algae, are unicellular photosynthetic organisms that are able to group together in colonies of a dimension perceivable to the naked eye. Sometimes, great densities may be developed resulting in algal blooms (> 2000 cells ml^{-1}) and surface scum. The most serious effects of cyanobacteria blooms is the production of toxins that constitutes a serious risk for public health and the damage of water purification systems, therefore the interest in developing methodologies dedicated to their identification from space is steadily increasing ([8]).
Turbidity is an optical property of the water body - a measure of the amount of light scattered and absorbed by particles in the water column. Turbidity may induce changes in the lake's vertical thermal structure, which in turn plays an important role in autochthonous primary production ([9]) and in the evolution of the water surface temperature, which is a key variable in the water-atmosphere transfers.

3 Atmospheric Correction

The study of surface water properties from satellite remote sensing techniques requires the correction for the effects of the atmosphere. Accordingly, the spectral radiance measured at the Top-of-Atmosphere (TOA) must be corrected with respect to the atmospheric effects, to obtain the surface spectral reflectance, which can in turn be related with the limnological data. The Second Simulation of the Satellite Signal in the Solar Spectrum (6S) [10] is the radiative transfer code used to correct the satellite measured signal for the atmospheric contribution. This code can simulate satellite radiation measurements in cloudless atmospheres, between 0.25 and 4.0 μm, for a wide range of atmospheric and surface conditions. The 6S takes into account the atmospheric compounds considering 34 atmospheric levels distributed from the ground up to 100km altitude, which is considered the TOA level. Since the atmospheric correction parameters are known (ozone, water vapour and aerosol characterization), as well as the geometry and the satellite measured spectral radiance, the water spectral reflectance can be determined with 6S radiative transfer code. Some field campaigns were conducted with a portable fieldspec in order to validate the water spectral reflectance obtained with the 6S code. Figure 2 shows a comparison between the 6S simulated reflectance and the field measurements.

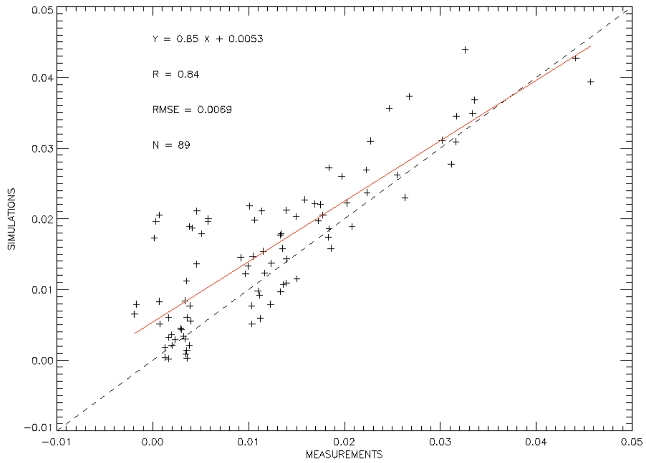


Figure 2. Comparison between the 6S simulated reflectance and the field reflectance measurement.

4 Empirical Algorithms

The reservoir surface spectral reflectance retrieved from satellite data is combined with limnological laboratory analyses. ([11]). The algorithms obtained are then used to estimate the chlorophyll *a* concentration, cyanobacteria density and turbidity, over the whole Alqueva surface area and the results compared with laboratory. A ratio between green and blue bands is investigated and related to values of chlorophyll *a* concentration ([12]). Following [13] the best fit is of power type, a correlation coefficient of 0.88 was obtained. The relation is given by Eq. 1:

$$Chl - a\left[\mu g.l^{-1}\right] = 4.93 * \left(\frac{560nm}{442nm}\right)^{3.90} \quad (1)$$

Cyanobacteria can be retrieved using the absorption feature of pigment phycocyanin (PC) ([1]) which it is present in all cyanobacteria (at least a low concentration), with higher expression in high concentrations, and presents a strong peak around 615 nm ([14]). The combination of the 490, 560 and 620 nm bands was investigated and related with the cyanobacteria laboratory analyses. The fit obtained is again of power type and presents a correlation coefficient of 0.83. The best grouping found is given by Eq. 2:

$$Cya\left[10^3 cells.ml^{-1}\right] = 4.2x10^5 * \left(\frac{560nm * 620nm}{490nm}\right)^{2.84} \quad (2)$$

The ratio between 560 nm and 412.5 nm revealed to be the best fit for retrieving the water turbidity. With a correlation coefficient of 0.96 and a linear type has shown in Eq. 3:

$$Turb[NTU] = -6.39 + 8.93 * \left(\frac{560nm}{412nm} \right) \quad (3)$$

5 Results

5.1. *Validation of the empirical algorithms*

The algorithms presented are applied to a box of four pixels, centred in the geographical coordinates of the sites where the water samples are collected. The mean concentration value corresponding to the four selected pixels is computed and used for comparison with the limnological data. Only values lower than 300×10^3 cells ml^{-1} (for cyanobacteria) and 30 μg l^{-1} (for chlorophyll *a*), to ensure that the validation series is within the range of values used to derive the empirical algorithms: cyanobacteria density [0 , 333×10^3 cells ml^{-1}] and chlorophyll *a* [0 , 50 μg l^{-1}]. The range of values considered to derive the algorithm is limited to data availability (both laboratory analyses and satellite measurements).

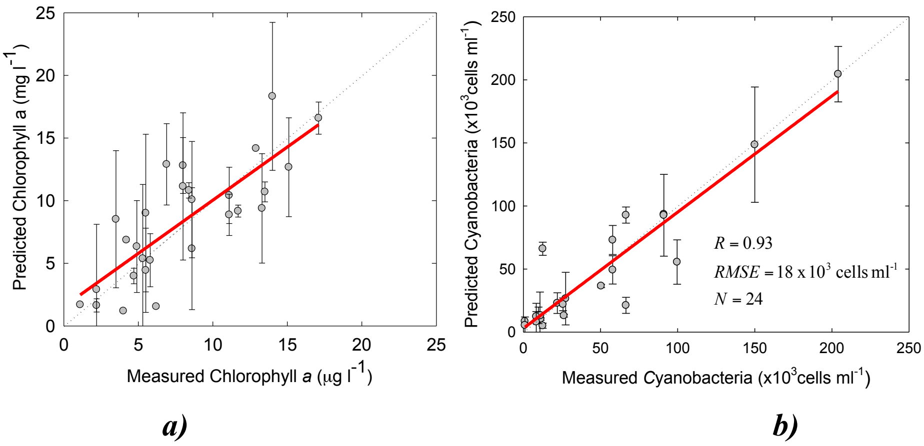


Figure 3. Scatter plot of predicted *versus* measured chlorophyll *a* concentration (a) and cyanobacteria density (b).

Figure 3(a) shows the scatter plot of the satellite derived chlorophyll *a* concentration *versus* the corresponding analyses, in a total of 28 data points. The vertical error bars represent once more the standard deviations corresponding to the four pixels selected. A correlation coefficient of 0.80 was obtained between measurements and retrievals, with

MERIS derived values revealing in general a good agreement with the laboratory analysis. A RMSE of 2.7 μg l^{-1} is found, indicating a small spread of the data, as well.

In Figure 3(b) the relationship between satellite derived cyanobacteria densities and the corresponding analyses, in a total of 24 data points, is illustrated. The vertical error bars represent the standard deviations corresponding to the four selected pixels. A good correlation coefficient of 0.93 is found for cyanobacteria with better results to high densities, when this taxonomic group seems to be the dominant and when PC pigment has higher expression ([15]). A RMSE of 18×10^3 cells ml^{-1} is found, indicating a small spread of the data. These results (Figure 3) demonstrate the capability of MERIS to detect cyanobacteria blooms (densities higher than 2000 cells ml^{-1}). The results above indicate that both cyanobacteria density and chlorophyll *a* concentration can be estimated reasonably well with the present methodology. It is thus possible to systematically monitor the water quality of Alqueva reservoir in terms of these two phytoplanktonic parameters based on satellite image data. Furthermore, our study reveals the potential of satellites to monitor the occurrence of bloom events.

5.2. *Mapping Alqueva reservoir*

Figures 4 and 5 present maps of chlorophyll *a* concentration and cyanobacteria densities obtained by applying the algorithms developed and presented in Section 4 to the whole Alqueva Reservoir area. Close to the shore the pixels are affected by adjacency effects, therefore, in order to mitigate those effects, pixels with NIR radiances greater than 50% with respect to the nearest water pixels (that is, with low NIR radiances and low standard deviation) were discarded. In these maps, values outside the validation interval ($< 200 \times 10^3$ cells ml^{-1} for cyanobacteria and < 20 μgl^{-1} for chlorophyll a) are masked in grey. The first thing we note in both Figures 4 and 5 is that in general higher densities and concentrations are found in tributary streams of the reservoir. This is an expected result since these systems with low depths present higher biological activity. The run-off, mainly by the Guadiana River (Figure 1), usually introduces organic and inorganic matter leading to an increase of the biological activity.

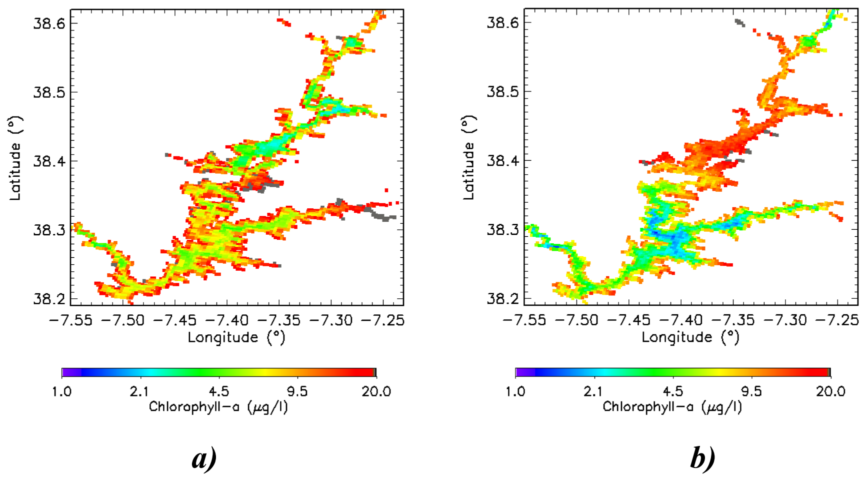
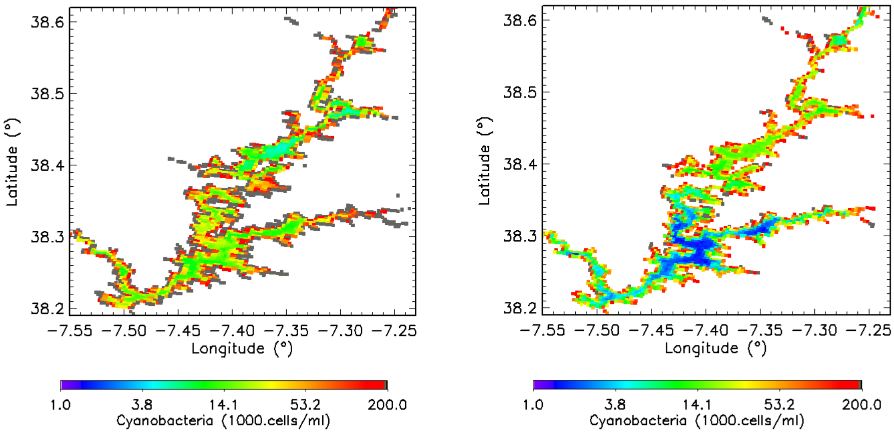


Figure 4. Chlorophyll *a* concentration maps over the whole Alqueva reservoir surface for one day in June (*a*) and another in November (*b*).

Chlorophyll *a* concentrations retrieved from satellite data for Alqueva reservoir are shown in Figure 4, where the results obtained for one day in June (Figure 4(*a*)) and one day in November (Figure 4(*b*)) are presented. Note that in the June case, the southern part of Alqueva Reservoir presents higher chlorophyll *a* concentrations, whereas in the November case the opposite is observed. This is in accordance with the chlorophyll *a* laboratory analyses, where Montante area (located in the south of the reservoir – Figure 1) presents the highest values in April and June (22.8 and 30.2 μg l^{-1}, respectively). On the other hand, from July onwards, Mourão (located in the centre of the reservoir – Figure 1) presents the highest values (between 11 and 17 μg l^{-1}) that are significantly higher than the values of Alcarrache and Montante (between 1 and 8 μg l^{-1}) till the end of the year.

Cyanobacteria densities obtained from satellite data for Alqueva reservoir is represented for the same days than chlorophyll *a*. It is noticeable that the map of June (Figure 5(*a*)) presents higher values of cyanobacteria than the map of November (Figure 5(*b*)), where high densities are present only near the margins and in some tributaries. Although not shown here, the same general pattern can be observed on the spring / summer months (June, July, August and September). These satellite maps present high values over the whole Alqueva Reservoir in spring and summer relatively to the rest of the year. This is probably associated with the normal cyanobacteria activity, which tend to be higher in warm conditions, depending on the water chemical composition. These results are in accordance with the laboratory analyses, which present in general higher cyanobacteria densities for the same spring / summer months, in the three sampling sites, varying between roughly 150×10^3 cells ml^{-1} and 550×10^3 cells ml^{-1}, from June to September.



a) ***b)***

Figure 5. Cyanobacteria density map over the whole Alqueva reservoir surface for one day in June (*a*) and another in November (*b*).

5.3. Inwater downwelling radiance measurements and attenuation coefficient calculations

Measurements of inwater downwelling radiance were performed with a device composed with one portable spectroradiometer, one optical fiber and one frame to hold the optical fiber and keep the tip pointing to the zenith in underwater environment. A portable FieldSpec UV/VNIR Spectroradiometer from Analytical Spectral Devices Inc. (Boulder, CO, USA) was used to record the spectral downwelling radiance measured across the spectral range 325-1075 nm with 1 to 3 nm spectral resolution and an integration time from 17 ms^{-1} to several minutes. An optical fiber was used coupled to the spectroradiometer to operate in underwater environment. Measurements were acquired using the bare tip of the optical fiber with a field-of-view (FOV) of 25º. A frame was developed to guaranty the verticality and horizontality of the bare tip of the optical fiber which has to point upwards to the zenith, in order to collect the downwelling radiance at several levels below the water surface.

The length of the optical fiber allows for measurements to a maximum depth of 3 m and the levels chosen for the profiles were: 0.01, 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50 and 3.00 meter. It is assumed that the spectral downwelling radiance, $L_d(\lambda,z)$, has a exponential profile as described by Bouguer-Lambert Law:

$$L_d(\lambda,z) = L_d(\lambda,0^-) exp\{-K_d(\lambda)z\} \quad (4)$$

The symbol 0^- indicates that the sensor is just beneath the water surface. $K_d(\lambda)$ is the spectral attenuation coefficient of the water column for the downwelling radiance between the depths 0^- and z. Therefore, the spectral downwelling radiance measurements ($L_d(\lambda,z)$) collected at the water column are used, through Equation 4, to retrieved spectral attenuation coefficient ($K_d(\lambda)$) of the water column.

Figure 6 shows one profile of spectral downwelling radiance performed at Alqueva reservoir for one day in August and the consequently spectral attenuation coefficient. It is notice an increase of radiance from the sub-surface (0.01m) level to the second level (0.25m) in the range 500-700 nm. Despite this particular intensification an exponential decrease of downwelling radiance was recorded with depth and through Equation 4 the spectral attenuation coefficient of the water column it is possible to retrieve. The first level intensification must be associated with the direct component of the downwelling light field reaching the water surface (not flat) composed with gravity waves that focus the sunlight within the first meters of the water column, since the sun zenith angles for this case was relatively low (37º). Since the optical fiber has a FOV of 25º the refracted solar beam in water may be recorded directly. This focusing effect was studied in the past ([16];[17]). Recently, [18] shows a system of high sampling rate (1 kHz) capable to measure wave-induced fluctuations in near-surface downwelling radiance and irradiance field. He shows that the brightest flashes of radiance relative to the time-average radiance occur at zenith angles of observation close to the direction of refracted solar beam in water. In extreme case, the flashes can reach nearly 40-fold at a zenith angle of 30º, at 532 nm. In our case it is not possible to record the flashes but only the effect caused by them in the average of integration time of the spectroradiometer used.

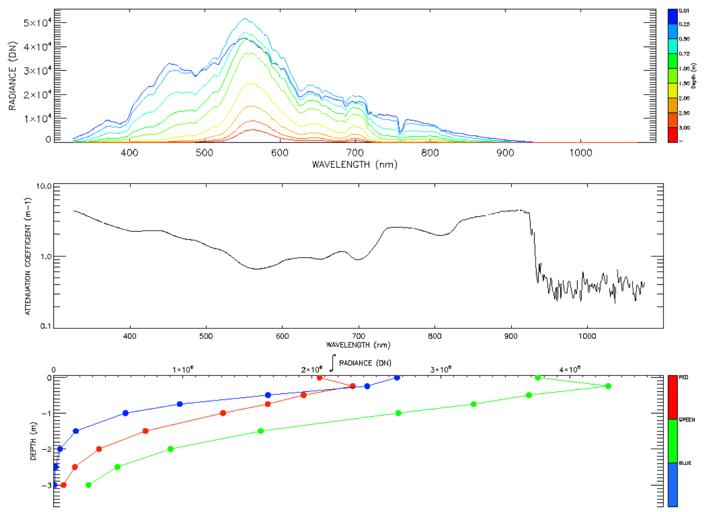


Figure 6. Measurements of spectral downwelling radiance at several levels deep on Alqueva reservoir for one day in August. On the middle panel the spectral attenuation coefficient of the water column. On the lower panel the respective profiles for the blue (400-500 nm), green (500-600 nm) and red (600-700 nm).

Acknowledgments

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The Évora Geophysics Center (CGE) celebrates 20 years of activity in 2012. 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.

The Workshop "TWO DECADES OF EARTH SCIENCE RESEARCH" (Évora, November 23, 2012) with the participation of prestigious national and international figures as keynote speakers provided a forum for debate on the evolution of Solid Earth, Atmosphere and Hydrosphere Sciences, as well as the national and european science system in these two decades, and the future perspectives.

The Editors

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