Jornadas de Física por ocasião da jubilação do
Professor Rui Namorado Rosa

Edited by

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Prefácio

Este livro é uma homenagem ao Professor Rui Manuel Vassalo Namorado Rosa no final da sua carreira como distinto professor de Física da Universidade de Évora. Embora a actividade principal do Professor Rui Rosa se tenha centrado na investigação e nas actividades académicas, em particular como Vice-Reitor e Presidente do Conselho Científico da Universidade de Évora, o seu rico *curriculum vitae* engloba muitas outras actividades que incluem intervenções sociais e de cidadania, de divulgação científica e participações em debates de importância internacional. A sua reconhecida simpatia e disponibilidade granjearam-lhe muitos amigos que sempre beneficiaram dos seus sábios conselhos, pontos de vista abrangentes, mente aberta, e opiniões bem fundamentadas. O seu trabalho e o compromisso com a Universidade de Évora muito contribuíram para o desenvolvimento da investigação e do ensino, e para a internacionalização de diferentes áreas desta Universidade. É por tudo isto que o Professor Rui Rosa, que actua e se considera a si próprio como um homem comum, tem o respeito e a estima de muitas pessoas e recebe agora a merecida homenagem com que a Academia decidiu comemorar a sua jubilação.

O Professor Rui Rosa licenciou-se em Física e Química na Universidade de Lisboa (1961) e obteve seu doutoramento em Física de Plasma na Universidade de Oxford (1969). De 1961 a 1983 fez investigação no Laboratório de Física e Engenharia Nuclear (LFEN / LNETI) em Lisboa. Desde 1983 a Junho de 2010 foi Professor Catedrático de Física da Universidade de Évora. A sua lista de publicações é diversificada e inclui trabalhos sobre física dos plasmas, fontes de energia convencionais e renováveis, e tecnologias associadas, para além de trabalhos recentes sobre a política energética, a que se juntam ensaios sobre os impactos educacionais e sociais da ciência e da tecnologia.

Este livro inclui três ensaios sobre os aspectos organizacionais da ciência, energia nuclear, e pensamento racional, juntamente com os artigos dos autores que participaram no Workshop “Jornadas de Física", realizado na Universidade de Évora, em 15 e 16 de Junho de 2010, como parte da celebração da jubilação do Professor Rui Rosa.

Os Editores

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Foreword

This book is a tribute to Professor Rui Manuel Vassalo Namorado Rosa at the end of his career as a distinguished Professor of Physics of the University of Évora. Although Professor Rui Rosa's main work has focused on research and academic activities, in particular as Vice-Rector and Chairman of the Scientific Council of the University of Évora, his rich *curriculum vitae* encompasses many other activities ranging from social interventions and citizenship, science communication, and participation in debates of international significance. His ever recognized friendliness and helpfulness granted him many friends that have beneficiated much from his wise advice, far-sighted views, open-minded judgment, and well-based opinions. His work and commitment with the University of Évora has much contributed to research, teaching development, and internationalization of different fields of this University. This is why Professor Rui Rosa, who acts and considers himself as an ordinary man, got the respect and esteem of so many people and deserved the tribute that the Academia has decided to celebrate his retirement.

Professor Rui Rosa graduated in Physics and Chemistry in the University of Lisbon (1961), got his PhD in Plasma Physics from the University of Oxford (1969). From 1961 to 1983 he did research at the Physics and Nuclear Engineering Laboratory (LFEN/LNETI) in Lisbon. Since 1983 to June 2010 he was Full Professor of Physics at the University of Évora. His diversified publication list includes the early works on plasma physics, works on conventional energy and renewable energy resources and technologies, as well as recent works on energy policy, together with essays on the educational and social impacts of science and technology.

This book includes three essays, namely on the organizational aspects of science, nuclear energy, and rational thinking, together with the contributed papers by the authors that participated in the *workshop* "Jornadas de Física" held at the University of Évora, on 15-16th June 2010, as a part of the celebration of Professor Rui Rosa's retirement.

The Editors

Ana Maria Silva
António Heitor Reis
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Agradecimentos

A Comissão Organizadora das "Jornadas de Física por ocasião da jubilação do Professor Rui Namorado Rosa" agradece a todos os que contribuíram aos mais diversos níveis para o seu sucesso e, em particular aos oradores convidados que se deslocaram a Évora, bem como a todos os colegas que submeteram os seus ensaios e artigos científicos.

Reconhecimento é igualmente devido ao Reitor da Universidade de Évora, ao Director e ao Presidente do Conselho Científico da Escola de Ciência e Tecnologia pela associação a este evento e pelas facilidades proporcionadas.

À Fundação para a Ciência e Tecnologia pelo apoio material que concedeu para publicação do livro de Actas.

Acknowledgments

The Organizing Committee of the Workshop "Jornadas de Física on the occasion of Prof Rui Namorado Rosa Jubilation" would like to express its gratitude to all that have contributed to its success and in particular to the Invited Speakers who have sent their contributed papers to this Workshop.

The Organizing Committee wants also to express its gratitude to the Chancellor of the University of Évora, to the Director and President of the Scientific Council of the Scholl of Sciences and Technology of the University, who have accept to joint this celebration and given the necessary support. Finally we would like to thank FCT for the funding given for the edition of the Workshop Proceedings.

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Essay in honour of Rui Namorado Rosa From science to innovation

Joao Caraça

Fundação Calouste Gulbenkian

1. Introduction

Should the beginnings of the 21st century seem very different from those of the 20th? Yes and no, for sure. We are not perfect copies of our ancestors; population has grown considerably around the planet --- four times all over; and our conceptions of nature and of ourselves have evolved considerably. And yet, in spite of all these changes, as it happened a hundred years ago, when numerous discoveries of new natural phenomena and of mysterious X-rays, added to cognitive ruptures in philosophy, literature, painting, medicine, engineering and the end of the old regime, we see a similar renewal of superstition and belief in the occult.

Today, we witness complexity, climate change, water and energy concerns, a new understanding of cells and proteins, we are attempting at the disclosure of the most inner secrets of the brain and of consciousness, we experience globalization; but we suffer from social exclusion and new diseases, with new forms of communication spreading over the globe. Increased specialization and advanced training have turned the most rational human being in his (or her) area of expertise into a weak and unprotected individual, prone to emotions and vulnerable to obscurantist thoughts, eager to run after any illusion which claims to bring a seed of hope. After a full century of extraordinary scientific and technological progress, this seems very disconcerting.

Two main factors are driving human evolution: (i) people; and (ii) their talents, or cognitive abilities, taken in the French sense of "savoirs". Given the time horizon of the present exercise, demography is not the main source of incertitude. What about knowledge production and diffusion, in particular, technology?

We know industrialization set a pace of definite structural continuities and transitions, which where labeled "techno-economic paradigm" changes. From early mechanization based on hydraulic power, successive transformations followed, which were characterized by the power of steam, by electrification, and by motorization based on cheap oil. Since the 1980's we seem to be living in an era of "computerization" of the entire economy; non-specialists call it "globalisation" and see it coupled to the emergence of the "information society". Until the 2020's we will continue to perform and operate in this global framework of economic activities. What are the drifts, problems or discontinuities looming in the near future?

To understand what the main issues are, we must recall that in the course of the 20th century the mechanisms of technological creation were drastically transformed, and enhanced. Science nowadays is the source of powerful technologies.

2. Science and technology

The emergence of industries of high technological intensity in the second half of the 20th century, such as nuclear power, aerospace, semiconductors and computers, and more recently the pharmaceutical and biotechnological ones, reveals the critical importance of science applications in the societies of the industrialized world. Business and societal practices now strongly depend on new ideas which have an origin intimately related to the scientific effort, i.e., that do not derive from natural language nor common knowledge. This procedural change was not straightforward; it implied a thorough transformation and a deep institutional reorganization in the societies that assumed it.

The world, today, would not be possible without its products: airplanes, missiles, satellites, space vehicles, computers, lasers, antennas, electronic networks, genetically modified products… In turn, the products of these sectors diffused to enable the deployment of a full package of new and highly comprehensive services.

The instrumental conception of the scientific endeavour --- the generation of wealth and economic development through science-based technology, gave way in the last decade of the 20th century to a more nuanced (or complex) notion of the "embeddeness" of scientific activities in the social context in which they are conducted. Therefore, the very nature of research policies changed, in order to accommodate more diffusion-oriented goals, stressing the mechanisms of knowledge circulation and transmission, of technology management and exploitation, of science awareness and public engagement in science.

This change has also been motivated by the questioning of the character of public intervention in the economy, namely the role of central government in the conduction of operations too close to the market. Public policy and actions have been directed to the regulation of competition, the building-up of infrastructure (including the development of human resources), the stimulation of networking activities (and hence the concept of mobility), the financing of research programmes in basic "pervasive" technologies and the provision of S&T services, norms and standards.

The new enabling conditions and constraints that society imposed on modern science practice evolved in conjunction with an escalation of global uncertainties and political instabilities in a context of demographic pressures, urban sprawl, climate change and perturbing inequalities.

But why should the creation of a new knowledge-based society, involving strenuous cycles of change and adjustment, be a triumphal promenade towards the future? Rather, we should have been prepared to watch the emergence of conflictual issues, leading to severe and irreversible choices. Contingency rules the world around us: only science, the best available science, can enable humankind to see through the mists of complexity, by engaging in proper collaborations with other relevant non-scientific fields of knowledge, like philosophy, the social sciences, arts and humanities, ethics and behavioral disciplines. Science alone cannot solve the problems of sustainability.

3. Knowledge: tree or network? The archipelago metaphor

The system of classification of knowledge we inherited from late positivism, a pyramid with science at the top, aimed not only at the consecration of science as the model of all other fields of knowledge but also at establishing a corresponding hierarchy, is no longer adequate. The novelty comes from the emergence a new immaterial, information-intensive order, in the realm of the material paradigm of progress and socio-economic development.

Information and knowledge are not regulated by the regimes of cumulative possession or ownership developed for tangible transactions. Communicative "sharing" is a concept that must be introduced to allow for aspects such as assimilation and audience. What this means is that knowledge can no longer be thought of as a fluid, as in a mechanical framework, but has to understood by enhancing its communicative, language-based features.

No classification of knowledge can be envisaged without a reference to the societal context in which it is generated. The present notion of "explosion" of information and of "fragmentation" of knowledge is probably the result of the powerful weakening and fragmenting effects that the forces of economic globalisation provoke in the social order of our nations.

But this is not a singularity of our epoch. Fragmentation of prevailing social order has occurred in the past. For instance, Enlightenment brought the idea of the Encyclopaedia. As the old regime was being shaken, knowledge was envisaged as a tree, with its various fields developing as successive ramifications from the common stem: philosophy. Three main branches of the knowledge tree were assumed: the science of God, the science of Nature, and the science of Man. Then, in the late 19th century, the success of industry and the triumph of mechanics, rail-roads and iron, brought along a new rationale, the positivist's pyramid, with mathematics and the other (hard) sciences in a descending order from the top, presiding over philosophy, the humanities and religion.

The pyramid was the organization of knowledge which was conveyed and taught to us and which reigned undisputed until the 1960's. However, from the standpoint of contemporary society it is impossible to maintain rigid distinctions between different fields of knowledge. The proliferation of disciplines was greatly intensified since the middle of the 20th century along with their internal complexity. And interdisciplinary fields became established.

The hierarchy of the pyramid hides important segments of contemporary knowledge, sometimes with very innovative features, simply because they are unclassifiable in the light of current criteria. Think of marketing, or design, or even software…

The issue is simple: criteria do not have any meaning outside strategies. Therefore, we must reappraise rather than dismiss the disciplinary references, articulating them in a communicative manner, creating a network. In this sense, the metaphor of the archipelago of knowledge is useful and heuristically operative, because it allows us to think about the criteria/strategies of the main areas of relevance today.

The archipelago suggests a reticular situation, a network, with no "natural" hierarchy. Further, it allows the creation of new disciplines.

4. Science and knowledge

The traditional approach to science and knowledge has involved the use of two perspectives ---an epistemological one, interested in the status of theories and laws and their relation to reality, and a sociological one, dealing mainly with the framework of scientific activity in a given society or environment.

These perspectives, which could also be described as internal and external, have been found to be most fruitful in the well know works of Popper and Kuhn, respectively. It is doubtful, however, whether they are sufficient today. Profound changes have marked the transformations occurring in economic activities, i.e. the increase in intellectual investment compared to physical investment, the growing role of complexity in the systemic framework (which until recently was particularly dominated by materiality), the emergence of sharing as the dominant form of communicating and circulating knowledge.

We now have to understand knowledge from three different aspects: (i) the production of theories; (ii) the creation of communities, and (iii) the development of specialized languages; in other words, we see knowledge as a cognitive, communal and rhetorical device.

Thus, we can no longer forget the presence of tacit knowledge in the network. And, due to the different levels of sophistication in language development, the archipelago metaphor suggests that "codified" knowledge be split into two parts: "explicit knowledge" (or "specialized information") and "disciplinary knowledge".

The "tacit" relationship with the world corresponds to common knowledge, which is apprehended or diffused by "exposure". The "explicit" relationship between man and his world corresponds to "specialized information", with "teaching" as its main mechanism of diffusion. Finally, "disciplinary knowledge" corresponds to high-level languages, which diffuse through "research" and its protocols.

The practice of research varies according to the "island" of the archipelago in question, i.e., with the specific cognitive, communal and rhetorical strategies: the criteria of science, based on the amplitude of empirical proof, correspond to the method of "experimentation". But philosophy uses other methods, namely analysis; ethics relies on "revelation"; and aesthetics uses systematic procedures of construction/deconstruction. Sharing assumes different aspects in each grand domain of knowledge.

In this network metaphor the central island of the archipelago corresponds to tacit knowledge (encompassing both technical, political, religious and artistic components). Through a process of explicitation the network progressively extends and complexifies. Other "islands" appear: those of technology, of law, of morality, and of fine arts. And then further away, through a more intensive explicitation or thematization process, corresponding to the emergence of high precision languages, new "islands" of disciplines are seen: science, social sciences, philosophy, aesthetics, ethics...

5. Knowledge and learning

True knowledge is therefore what is inside the "boundary" of the archipelago; and ignorance is the "sea at large" that surrounds it. This sea can be conquered by constructing new islands, or by launching bridges to other islands or even to newly built offshore platforms (marketing, design, ecology... emerge by such processes).

The archipelago is nowadays the locus of an intense circulation of knowledge, in all directions, revealing a true network character.

Of course, pseudo-knowledge creeps at every turn of the landscape, every time we want to swim (individually), or navigate (institutionally), in uncharted waters. Pseudo-knowledge can be thought of as a group of sharks, or pirate submarines, that hunt both along the shores and inside the canals of the archipelago, feeding on the discomfort of the human souls. They disrupt the existing connections and make sure that their assertions cannot be verified.

We also observe a wide proliferation and renovation of pseudo-knowledge in the media. The strategy followed by the practitioners of pseudo-knowledge is that of "certainty" versus methodological "doubt", that of escaping confrontation between subject and object, that of finding refuge in unknown powers. It is based on the detection of flaws in the public system concerning scientific culture, in conjunction with the dysfunctions that exist in teaching the practice of active citizenship. The space of occultation in the so-called knowledge-based societies thrives on ignorance, feeds on intolerance.

Knowledge and learning are the central resources and mechanisms of the new institutions, communities and organisations. So, the implications of the intensified circulation of knowledge will have to be recognized and fostered: disciplinary knowledge can only evolve in the context of a strong communicative framework which enables the attitude of sharing meanings and values to realise its full potential.

The globalised world is made of enlarged networks which create, diffuse, finance, manage and support innovation, based on a group of formidable social, organizational and technological changes which were brought by the new process of producing technology from a science base. But these changes are societal, they are responses to the transformations experienced, involving all aspects of today's reality, concerning all networks of intense and enlarged communication that support our activity.

But we must be aware, though, that the view of the world of globalisation based on "knowledge", does not coincide with the view of the world of modernity, based on "science". The vision brought about by the new paradigm of knowledge and information favours "governance" rather than "government"; promotes what is "global", rather than "universal" values. This apparently innocent change is, however, full of implications.

6. Knowledge-based societies

The movement towards a knowledge-based society, involving new long distance interactive mechanisms implies a whole, i.e., a continuum of education, science and innovation which cannot be separated and must be treated in close articulation. Science is no longer at the end, or at the beginning, of societal processes. But the level of pervasiveness of science is also a measure of the achievement of a knowledge-based society.

However, science will have to learn to co-exist, co-operate and co-evolve with other relevant non-scientific fields of knowledge. This is not necessarily simple for the more established scientific communities. But there is no way back.

And even if until the 2030's we do not foresee the emergence of a new techno-economic paradigm, long-term trends will bound the operations and performance of "globalisation". In general, personnel costs will tend to rise, as will the pressures on enterprises to internalize their costs of production; indexes of taxation by governments will also increase. With respect to innovation in the European area we may fear the effects of ageing in the dynamics of innovation policy, as well as the effects of energy concerns; further, the impact of competitive goods and services from big economies based on low salaries will almost certainly prevent the design of policies directed solely towards national contexts.

The emergence of a multipolar world will probably mean the end of the present pulse of globalisation and the return to imperial demarcation of territories based on the availability of known resources. The levels of conflict in disputed areas and their damages in general will certainly continue to plague the world into the 2020's.

The new world leaders after that will have to differentiate themselves from the multitude --- this will require the invention of new resources, through the application of new (science-based) technology.

We have been watching the emergence of new clusters of S&T areas which can possibly lay the pillars of a new techno-economic paradigm for the future – i.e. in the 2030's – based on the "molecularisation" of the economy. This will be supported by a cohesive core of nanosciences and nanotechnologies, biosciences and biomaterials, new communication and information processing technologies.

No big nation, or concert of nations, can afford to thwart the march of science. But new questions arise: (i) which directions to choose (because it is impossible to be excellent everywhere across the board); (ii) which impetus to allocate in each case (as research structure and resources are highly interdependent); how much monitoring to exert (the level of autonomy) to assure expected returns? Will the nations of Europe be able to ride and lead the new wave?

7. Living with universities

Universities were a European invention. They are an essential element of scientific training, besides housing a large fraction of basic research performed in national S&T systems. In the European strategy, universities are deemed to represent central nodes in knowledge production. We know that the older universities missed the scientific revolution, and only caught-up with science much later. Will the same fate be bestowed upon European universities now, when the surge of information technologies is revolutionizing our behaviour? Can Bologna cope with the diversity of ministerial regulations that divide and quench education/science/innovation interactions in Europe? Scientific productivity is being used as a prime determinant of researcher's careers and of the level of science financing. But can we identify with ease the entities who (globally) control science today?

The US followed a singular strategy: a series of "cold-war" universities (the first and best example being Stanford) were selected by the federal government to ensure a proper environment for the new (then, in the late 1940's) science-based technology production processes. The US were very successful in that not only these universities evolved into a new model of university – the "research university" – but also in that they found their place at the top of the higher-education system and developed as prime interlocutors of powerful hi-tech industries.

The US research universities however are both a by-product and a component of a specific highly developed capitalist economy – they are independent, have their own sources of funding (through endowments) and, above all, are not managed by any central ministry or authority of the sort.

The way to follow in Europe until the 2030's (with its constellation of nations) must be based on the creation of European institutions, such as ERC, EIT, a future Innovation Agency, a platform to articulate existing multinational scientific institutions: CERN, EMBO, ESA, ESO… into an European policy for research and knowledge sharing.

The "ethos" of the European universities of the future will also have to change. The US awoke in 1983 from the impacts of massification of secondary and tertiary education. "A Nation at Risk" was the lemma for a set of actions developed to overcome the malfunctions of the system, not all of them successful. But in Europe, with its concert of nations, no movement of the sort emerged – and we were also suffering from the same illness. The terms coined in the early 1980's – "learning society", "long-life learning"… are still with us: not the action.

The modern university developed during the 19th century has as epistemic objective the transformation of nature. The triumph of science in the 20th century can also be seen as a victory of the modern university. However, a century ago, nature could be looked upon as external to mankind, with their passions, their conflicts, their nastiness and generosity.

But if nature is what we make of it, there is no longer room for being outside. So we are beginning to turn round in circles. Europe should devise, as the core of its now "regionalized" system of higher education, a set of highly attractive new global universities, autonomous from national regulations, aiming at a new epistemic objective, fully in line with the issues of sustainability we are going to be engaged in during the 21st century.

Such objective could be centered in "living together", the crucial problem of keeping communication channels open in a turbulent world, and of dealing adequately with the global commons that will support life in our planet.

8. Living with technoscience

The social impact of science is today associated with the usefulness (or with the problematic effects) of the products which are based in scientific principles.

The potential for wealth creation in advanced societies is strongly rooted in science-driven technological change and artifacts. The social image globally projected by science is therefore no longer that of the scientist who doubts, who questions the frontiers of knowledge, but rather that of the specialist who implements measures to obtain the most efficient responses, or that of the engineer who develops practical solutions to the problems of quality of life.

So the evolving relationship of science with politics cannot be seen in isolation from its context --- public opinion and the quality of public debate. Science is nowadays very important for the sustainability of economic and social mechanisms. It can no longer claim to be neutral. It is a player in the political game.

The current relationship between science and power, in the political, economic and military spheres, does not favour the understanding of the emancipatory role of science and knowledge. On the contrary, it conceals it.

Given all this, will we be able to further democracy and critical thinking? What are the alternatives? We must act deftly now; we have to decide what is to be kept and what is to discard in the road to the future.

A Energia Nuclear e a Paz

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Abstract
Rui Namorado Rosa is introduced as a scientist and a citizen conscious of the good and evil ends of his trade, someone that does not loose sight of the responsibilities involved in the pursuit of knowledge in the context of a global society marked by deep inequalities, where freedom of thought can be at stake and survival of the species itself is threatened. His capacity of honest hard work, independence of mind and consequent pursuit of the goals he has set for himself, is stressed. Rui Namorado Rosa is portrayed as an exemplary scientific worker that has constantly taken advantage of a solid scientific experience in the service of social progress and peace. His writings on the applications of nuclear energy for peaceful purposes but also on the dangers associated with nuclear weapons, intended mainly for non-specialists, are briefly covered. Particular attention is given to his contribution to the peace movement in Portugal as well as in the wider international stage.

1.

Apresento-me aqui perante vós, com alguma emoção, para falar de alguém que tem sido ao longo de quase meio século, fisicamente mais próximo ou mais distante, meu constante companheiro, em uma irmandade do espírito, na qual reconheço, no essencial, os valores com que me identifico, a mesma visão do mundo, e do lugar do homem na natureza e na sociedade.

Recordo o que um dia escreveu um outro irmão, daquela referida irmandade (que por sinal era meu pai) a propósito do grande Paul Langevin: "*A Humanidade só tem que agradecer aos cientistas que vivem de atalaia contra si mesmos e contra o que afirmam; aqueles espíritos privilegiados para quem a atitude de dúvida persistente é a mais segura das certezas*." Tratava-se na ocasião de uma homenagem ao grande físico francês e daí falar-se em "cientista", Aqui, estou seguro de poder dizer, com propriedade, a respeito de Rui Namorado Rosa, que se trata de alguém, cientista também, que igualmente vive de atalaia contra si próprio, cultivando a dúvida persistente como a mais segura das certezas. Não se entenda porém que tal postura deva ser exclusiva do cientista (que nem todos aliás a cultivam igualmente) qual ferrete que marcasse aquele, como elemento singular no seio da comunidade dos seus concidadãos. Antes se entenda que essa deve ser a atitude mental do comum dos homens e das mulheres, esses que acabarão por determinar os caminhos futuros do nosso mundo. Ao falar de Rui Namorado Rosa, falamos de um cidadão cuja razão o conhecimento científico esclarece, acrescentando-lhe uma dimensão que completa e valoriza os que a esse conhecimento podem aceder e que são, infelizmente, poucos.

Assim ele se distingue daqueles de quem o poeta[1] dizia:

Em tua certeza, cadeira de rodas, fazes-te conduzir piedosamente,
e os caminhos passam por ti sem tu passares por eles, e sem os veres."

Em Rui Namorado Rosa vejo a sabedoria, aliada ao trabalho honesto e persistente, a constância e honestidade de carácter, o amor do próximo, a modéstia, e a tenacidade de convicções que não o poderiam levar por caminho diferente daquele que escolheu para si próprio, por onde seguiu, segue e - estou certo - seguirá no futuro.

2.

Ao falar de Energia Nuclear nesta ocasião em que se deseja destacar a figura de Rui Namorado Rosa como empenhado militante da causa da Paz, importa ter presente uma realidade com que a cada momento nos vemos confrontados: a materialização do conhecimento científico fundamental em métodos e dispositivos práticos que alargam a capacidade de interacção do homem com o mundo natural - *the extension of man*, nas palavras de John Bernal - pode ser portadora de desgraça como pode ser fonte de bem-estar.

Nisso estará a meditar a Eva de Paul Gaugin junto à "árvore da Ciência do bem e do mal" cobrindo os ouvidos para ignorar as confidências encantatórias da serpente.

A outra realidade que importa ter presente e a qual, no decurso dos tempos, se mostra amplamente confirmada, é a de que não há obstáculos que possam levantar-se com sucesso para coarctar e muito menos impedir, o desenvolvimento do conhecimento científico em qualquer domínio que seja. Não é possível impedir o ser social de interrogar a natureza e de nisso aplicar todo o seu engenho e arte.

Levanta-se então aqui um verdadeiro "campo minado" que põe à prova o sentido de responsabilidade do investigador.

Deixem-me citar, a propósito, um breve extracto da Introdução ao livro, editado em 1946, pela Federation of American Scientists, sob o título "One World or None - A Report to the Public on the Full Meaning of the Atomic Bomb", introdução escrita por Arthur Compton, que recebeu pelos seus trabalhos no campo da radiação cósmica o Prémio Nobel da Física de 1927, e foi colaborador eminente do chamado Manhattan Project. Diz Compton:

"Era inevitável que a humanidade viesse a possuir o fogo atómico. O desenvolvimento, geral e por toda a parte, da ciência e da tecnologia, é a via principal da rápida evolução do homem para um ser social cuja comunidade é o mundo. A libertação da energia atómica constitui um passo de enorme significado nessa evolução. Insere-se na nossa incessante procura de caminhos que permitam usar as forças da natureza para moldar o mundo à imagem do nosso desejo."

E mais adiante: " O tremendo efeito da explosão sobre Hiroshima revelou a um mundo em choque que, se a guerra não for abolida, se caminha para uma catástrofe. "

As explosões experimentais - permitam-me esta expressão que poderá chocar alguns - de um engenho de urânio lançado sobre Hiroshima e de outro, de plutónio, lançado três dias depois sobre Nagasaki, inauguraram tragicamente a chamada "guerra fria". A favor desta posição trago-vos as palavras de Albert Einstein, no artigo com que contribuiu para o mesmo e já citado livro de 1946, quando diz: "O perigo da guerra no nosso tempo é ainda acrescido por um (…) factor técnico. Os modernos armamentos, em particular a bomba atómica, colocaram em considerável vantagem os meios ofensivos ou de ataque sobre os de defesa. E isto pode bem ter como resultado que, mesmo homens de estado responsáveis, se achem eles próprios, obrigados a desencadear uma guerra preventiva."

Aqui está, subjacente, o germe da corrida aos armamentos que efectivamente se verificou e que, em boa medida, hoje prossegue.

A escassos meses da tragédia de Hiroshima e Nagasaki, a iniciativa de um grupo de cientistas que se havia empenhado no Projecto Manhattan, levou à fundação, em Dezembro de 1945 da Federation of American (Atomic) Scientists. Ainda que com diferentes olhares e perspectivando diferentes caminhos para combater a ameaça comum, animava-os a consciência da responsabilidade social dos cientistas relativamente à utilização dos resultados do seu trabalho, consciência que o poder destruidor das armas nucleares veio agudizar.

"Com a libertação do poder do átomo, tudo mudou, excepto os nossos modos de pensar - dizia Einstein - e, por isso, vamos sendo arrastados para uma catástrofe sem paralelo."

3.

Em 1940, com a França ocupada pelos nazis, o laboratório do professor Joliot-Curie, no Collège de France, em pleno centro de Paris, continuava a funcionar, para espanto de muitos. As portas estavam abertas e os alemães podiam entrar e sair, quando entendessem, e à vontade. O que eles não sabiam nem viriam a saber é que nesse mesmo local se preparava a trinitrocelulose, também conhecida por algodão-pólvora, destinada a fazer ir pelos ares os comboios militares alemães. E não estava só: em mais de uma dezena e meia de outros centros de investigação universitários, em Paris, trabalhava-se no mesmo sentido.

Debaixo das tábuas do soalho escondiam-se granadas, minas e engenhos explosivos artesanais. Joliot construiu pelas suas próprias mãos, receptores e emissores de rádio portáteis para serem utilizados pela resistência francesa ao ocupante nazi. Duas vezes preso pela Gestapo, Joliot acabou por passar à clandestinidade na primavera de 1944 para se dedicar à preparação da insurreição de Paris levada a cabo pela Resistência.

Entretanto, Joliot-Curie foi o primeiro presidente do Conselho Mundial da Paz.

Depois da Libertação foi-lhe confiado o projecto de organização da infra-estrutura científica e técnica que conduziria ao desenvolvimento em França dos centros nucleares integrados no Commissariat à l'énergie atomique — o CEA, que continua a existir nos nossos dias. Joliot, nomeado por De Gaulle, tornou-se no início de 1946, Alto Commissário para a Energia Atómica. Em Abril de 1950, foi destituído. Idêntico procedimento foi seguido para com numerosos dos seus colaboradores. Joliot voltou para os seus alunos e para o seu curso de Física no Collège de France.

Que se passara entretanto? Na origem deste afastamento esteve a oposição consequente de Joliot-Curie ao desenvolvimento de toda e qualquer aplicação militar da energia nuclear; o seu incansável activismo pela paz, contra a guerra. Em 1946 era criada a Federação Mundial dos Trabalhadores Científicos, associação internacional de cientistas, que escolheu Joliot-Curie para seu primeiro presidente, eleito ao lado de destacados companheiros como Pierre Biquard, físico francês[2], e John Desmond Bernal — autor da obra monumental "Science in History" e da já referida "The Extension of Man". As raízes mais fundas da Federação Mundial podem encontrar-se na organização "Cientistas contra a guerra", já activa antes da eclosão do conflito e numa associação sindical pioneira fundada em 1918, representativa dos trabalhadores científicos do Reino Unido[3].

Em Abril de 1949, é criado o Conselho Mundial da Paz, sucessor do Congresso Mundial dos Partidários da Paz; como referido atrás, Joliot-Curie é escolhido para seu Presidente.

Numa altura em que a chamada "guerra fria" marcava o comportamento dos EUA e das principais potências europeias, o afastamento de Joliot das funções de Alto-Comissário para a Energia Atómica era inevitável.

Sessenta e cinco anos passados sobre o fim da Segunda Guerra Mundial, mantém-se a contradição aparentemente insanável, entre as aplicações pacíficas da energia nuclear, e a ameaça que representa a posse e aperfeiçoamento dos armamentos nucleares.

4.

Em Portugal, as movimentações e lutas pela Paz e contra a guerra, vêm de longe e ligaram-se estreitamente à luta pela democracia, durante os longos e penosos anos da ditadura fascista. Manifestaram-se já durante a guerra de Espanha, mantiveram-se e desenvolveram-se nas décadas que precederam a queda da ditadura, e o fim da guerra colonial.

Tenho comigo um livrinho editado pela Seara Nova, com data de 1973, intitulado "A Ciência, a Paz e a Segurança Mundial". É uma colectânea de textos apresentados na Conferência de Berlim, promovida em 1971 pela Federação Mundial dos Trabalhadores Científicos, sobre armas nucleares e outras armas de destruição massiva. O livrinho abre com um texto de José Gaspar Teixeira, que conheci bem e que foi membro activo da Federação Mundial. Nessa sua introdução intitulada "Os Trabalhadores Científicos e a Segurança Mundial". Gaspar Teixeira reproduz um texto de Maria Lamas do qual retiro a seguinte passagem: "Apesar das terríveis dificuldades que era preciso vencer, Portugal esteve sempre representado em todas as reuniões e Congressos do Movimento Mundial da Paz e a voz dos portugueses fez-se ouvir entre todas as outras vozes do Mundo, num apelo vibrante contra as armas nucleares e exigindo a sua absoluta interdição." Derrotada a ditadura, "tornou(-se) possível constituir formalmente o Conselho Português para a Paz e a Cooperação, que logo aderiu ao Conselho Mundial da Paz e que, desde então, tem sido agente de informação e mobilização do povo português nas causas da Paz e da Solidariedade, em franca colaboração com muitas outras organizações portuguesas, e bem assim parceiro activo de mais de uma centena de organizações estrangeiras amigas, em todos os azimutes, que no seio do Conselho Mundial conjugam esforços para a intervenção na causa da Paz em qualquer parte do Mundo." Acabo de citar uma passagem da intervenção de Rui Namorado Rosa, na Sessão Comemorativa do 60º Aniversário da criação do Conselho Mundial da paz, proferida em Lisboa, em 30 de Janeiro do corrente ano.

5.

Em 1960, Rui Namorado Rosa inicia uma carreira científica como investigador no então Laboratório de Física e Engenharia Nucleares, da Junta de Energia Nuclear. O Laboratório, inaugurado em 1961 (completará meio século em Abril do próximo ano) foi, em muitos aspectos, uma escola de quadros científicos e técnicos em domínios científicos importantes - física atómica e nuclear, radioquímica, ciência de materiais - domínios nos quais os meios de que o país dispunha eram nulos ou insignificantes, em especial no que toca a grandes equipamentos e instalações laboratoriais, infraestruturas técnicas ou oficinais especializadas.

Olhado à distância é-se tentado a dizer que o desenvolvimento do "projecto LFEN", desde a concepção, que incluía uma definição adequada de objectivos, à implantação no terreno e ao início do funcionamento, conseguidos num prazo relativamente curto, aparece como uma singularidade digna de atenção, num país em que tantas vezes se afirmam propósitos inconsequentes, mal fundamentados e deficientemente estruturados. É certo que para tal contribuiu o facto de a Junta de Energia Nuclear ter mantido ao longo dos anos, quase até à sua extinção, um estatuto, de algum modo, privilegiado no quadro político então vigente. Entretanto, as bases da importância marcante do Laboratório no panorama nacional, lançadas até meados da década de 70 do século passado, ficaram a dever-se sobretudo à acção invulgarmente inteligente e capaz do seu primeiro e único Director-Geral, Carlos Madeira Cacho, que quero lembrar.

Rui Namorado Rosa, como outros jovens investigadores que de algum modo nasceram para a actividade científica no Laboratório de Sacavém, e puderam depois, com o patrocínio do Laboratório graduar-se em centros e universidades estrangeiras, encontraram no LFEN, uma porta aberta para a investigação fundamental, considerada indispensável, mas também, a par dela, a perspectiva do desenvolvimento de aplicações, que era expressamente apontada nos propósitos da Junta de Energia Nuclear e nos objectivos de trabalho do Laboratório. Sabiam, pelo tempo histórico que se vivia, que a importância atribuída pela ditadura ao domínio da energia nuclear não era alheia ao impacto das suas aplicações militares e não olhava apenas aos benefícios que poderia trazer à sociedade, quer na economia quer nos serviços. A decapitação da Universidade na segunda metade dos anos quarenta, estava presente, e marcava os espíritos de muitos como sinal de perigo e ao mesmo tempo um desafio ao espírito crítico e à livre inquirição da Natureza e da sociedade sem os quais o progresso do conhecimento não é possível.

Quando Rui Namorado Rosa, regressado do estrangeiro, volta ao LFEN, com um doutoramento em Física dos Plasmas, "uma vez mais (porque já o fizera nos primeiros tempos da sua actividade no Laboratório) "uma vez mais (estou a citar o próprio) foi atribuída particular atenção ao desenvolvimento experimental, equiparam-se oficinas e laboratórios em domínios pouco desenvolvidos entre nós, com realce para a óptica e o vácuo. E desenvolveram-se projectos com a preocupação da sua relevância económica e social." (fim de citação).

Eis pois, a mostrar-se, o sinal de responsabilidade que implica, naturalmente, consciência social, do cientista.

O interesse pela Física dos Plasmas, de Rui Namorado Rosa, não o levou, e não teria que levar, nem mesmo por razões científicas, a afastar-se da problemática da energia nuclear. Como se sabe, poucos anos após a tragédia de Hiroshima e Nagasaki, os EUA, logo seguidos pela então URSS, procederam aos primeiros ensaios de fusão nuclear não controlada fazendo explodir na atmosfera os engenhos ditos "termonucleares" capazes de libertar uma energia centenas ou milhares de vezes superior à das bombas lançadas sobre o Japão. Intensificava-se o desvario da corrida aos armamentos nucleares.

6.

De novo se nos deparava na encruzilhada dos caminhos da Humanidade, a antiga "Árvore da Ciência do Bem e do Mal". De um lado a promessa de uma fonte de energia quase inesgotável; do outro o tic-tac do relógio simbólico do apocalipse - o "Doomsday Clock" criado em 1947 pela equipa do "Boletim dos Cientistas Atómicos", na altura publicado na Universidade de Chicago, e que se mantém ainda hoje, em edição digital.

Ao longo dos anos, a par das actividades de investigação sem ligação directa às aplicações nucleares em que se empenhou, Rui Namorado Rosa estudou, aprofundou e publicou abundante material sobre questões ligadas à energia nuclear.

Numa primeira fase, interessou-se sobretudo pelas condições do aproveitamento da energia nuclear para fins pacíficos, como fonte alternativa susceptível de vir a ter importância relevante para o progresso económico e social.

Assim, participou na obra colectiva intitulada "O que é a energia nuclear. Oportunidade em Portugal", editada em 1978 por Moraes Editores, Temas e problemas, Série: Documentos. Trata-se de um trabalho que, como se depreende do título, tinha simultaneamente uma finalidade didáctica e de divulgação, e de intervenção política, em sentido lato, quer dizer, a de contribuir para que entre nós fosse possível fazer-se uma avaliação técnico-económica, assente em bases sérias, à luz dos dados então disponíveis, da viabilidade da introdução de uma central nuclear no sistema electroprodutor nacional, A contribuição de Rui Namorado Rosa debruça-se sobre o ciclo do combustível nuclear, informa sobre os recursos uraníferos existentes em Portugal e defende a necessidade da definição de uma política energética de longo prazo para o país. Numa breve nota curricular refere ser investigador do Laboratório de Física e Engenharia Nucleares "onde tem trabalhado em Física dos Plasmas e em Energética".

Tal como eu próprio defendi em Abril último, em Paris, num debate provido pela Federação Mundial dos Trabalhadores Científicos, diz Namorado Rosa, neste seu trabalho: "É evidente que os programas nucleares a longo prazo só fazem sentido quando baseados na tecnologia dos reactores reprodutores" (fim de citação). É útil recordá-lo hoje quando se assiste, no plano internacional, ao que alguns chamam "o renascimento da opção nuclear".

Refiro ainda, do mesmo texto, a passagem, que vou citar, onde Namorado Rosa chama atenção para "(…) o amplo conjunto de meios científicos, industriais e institucionais que serão exigidos para o pleno aproveitamento da energia nuclear a longo prazo", (fim de citação).

A obra a que me venho a referir vem a público no ano que se seguiu à extinção da Junta de Energia Nuclear, determinada por decreto governamental de 31 de Dezembro de 1977. Neste domínio, como aliás em outros de decisiva importância para o País, a situação tem vindo desde então continuamente a degradar-se no que respeita a capacidade técnica, em recursos humanos e infra-estruturas, de algum modo acompanhando o progressivo empobrecimento e mesmo destruição de sectores produtivos de que depende a capacidade de produção de riqueza e a própria soberania nacional.

Em 1979 foi formalmente criada a OTC-Organização dos Trabalhadores Científicos. Os primeiros passos da associação tinham sido dados já em meados do ano de 1974 e nesse mesmo ano eleitos órgãos dirigentes provisórios. Rui Namorado Rosa fez parte desses órgãos e, depois da legalização estatutária em 1979, integrou as direcções eleitas ao longo da década de 80. No Artigo 4º dos estatutos da OTC é expresso como um dos objectivos da associação "Lutar por uma correcta aplicação da Ciência ao serviço do Povo Português e, à escala mundial, ao serviço da Paz, do progresso e da cooperação entre os povos." A aplicação da Ciência "ao serviço da Paz, do progresso e da cooperação entre os povos" mostra uma preocupação partilhada por muitos, cientistas e cidadãos comuns, reflectida também nos textos fundadores de outras associações congéneres, desde logo nos estatutos da Federação Mundial dos Trabalhadores Científicos a que a OTC decidiu aderir logo na primeira Assembleia Geral de sócios convocada após a sua formalização em 1979.

Rui Namorado Rosa, também no seio da Federação, foi elemento activo, chegando a integrar uma das suas Comissões especializadas; a Comissão de Política Científica.

Em 1982, realizou-se em Lisboa, o Encontro Nacional de Trabalhadores Científicos sobre Armas Nucleares onde um numeroso grupo de especialistas ajudou a desenhar um quadro geral da situação mundial no que toca às armas nucleares e aos seus efeitos. A Comissão Promotora do Encontro, que teve lugar no Laboratório Nacional de Engenharia Civil, era constituída por quase uma centena de elementos, representativos de vários sectores profissionais, incluindo, entre outros, físicos e biólogos, médicos, economistas, pedagogos e educadores, e jornalistas[4]. Rui Namorado Rosa foi autor de uma das comunicações apresentadas ao Encontro, a que deu o título: "Responsabilidade social dos trabalhadores científicos", Permito-me transcrever uma passagem da sua intervenção, na qual ele exprime com exemplar clareza aquela que deve ser a posição do trabalhador científico no seu relacionamento com a sociedade de que faz parte:

"Os trabalhadores científicos são cidadãos como os outros. Pesa, também sobre eles, a ameaça de liquidação numa guerra total, em que seriam utilizados os meios de destruição massiva que muitos deles ajudaram a criar. Os trabalhadores científicos não têm, nem reivindicam, o poder político, económico ou técnico, e não são, eles próprios, responsáveis, nem determinantes, na utilização que é feita, pela sociedade de que fazem parte, dos conhecimentos científicos e técnicos de que são produtores. Mas, pela sua formação, especialização e experiência, os trabalhadores científicos estão mais bem colocados - talvez os melhor colocados - para prever e avaliar as consequências da utilização dos conhecimentos científicos e técnicos. Na luta pela Paz, que deve ser entendida como o pressuposto fundamental para a correcção das injustas desigualdades existentes, para o progresso económico e o desenvolvimento social, os trabalhadores científicos têm o dever de integrar e articular a sua acção com a acção de todos os seus concidadãos e de sintonizar os seus objectivos pelos objectivos dos seus povos. Têm o dever de, ao fazê-lo, dar a sua contribuição específica e original para a luta pela Paz, pela democratização das relações sociais, pela criação de condições que tornem a Ciência num factor de progresso e de bem-estar."

Passava-se isto em 1982. Desde então a actividade de Rui Namorado Rosa, mantém-se e desenvolve-se de forma consequente à luz das ideias - ideais, se preferirem - traduzidos nas palavras anteriores. É justo dizer que a intervenção, pela palavra e pela escrita, do cientista e do cidadão, empenhados na luta geral pela Paz e pelo progresso social, que se confundem na pessoa do Professor Rui Namorado Rosa, hoje presidente do Conselho Português para a Paz e Cooperação, vem de longe.

Em 1984, escrevendo sobre "Economias de Energia", questão então, como hoje, de grande relevância, no contexto da definição de uma política energética para um desenvolvimento sustentável, estigmatiza a acção do governo de então orientada (e passo a citar): "no sentido de destruir os organismos de Estado e de entregar os seus recursos à administração dos interesses privados, sem contribuir de maneira séria para a resolução dos problemas científico - técnicos que o País enfrenta". São palavras que, vinte e seis anos passados, mantêm toda a actualidade.

Mais recentemente, numa exposição amplamente suportada em referências insuspeitas, vinda a lume em 2001, trata de "Armas de urânio empobrecido: sua origem, fabrico, propriedades e efeitos, e suas consequências no Golfo e nos Balcãs"[5]. Novamente, aí, afirma o papel dos trabalhadores científicos no "esclarecimento dos factos e na fundamentação das decisões", salientando entretanto que "o conhecimento e as decisões interessam e cabem a todos" e repudiando a manipulação de dados científicos por altos responsáveis de círculos dirigentes para prosseguir políticas lesivas do interesse geral.

Rui Namorado Rosa revê-se certamente no pensamento que François Rabelais, livre-pensador quinhentista, traduziu nestas palavras: "Science sans conscience n'est que ruine de l'âme": "Ciência sem consciência é a ruína da alma".

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[1] António Gedeão, *Cabeçudos e gigantones,* in "Movimento perpétuo", Coimbra, 1956

[2] Entre 1936 e 1938, Biquard ocupou as funções de chefe de gabinete de Irene Joliot-Curie e depois de Jean Perrin, secretários de Estado da Investigação Científica no governo da Frente Popular presidido por Léon Blum.

[3] A Association of Scientific Workers (AScW) foi uma associação sindical criada no Reino Unido. Foi fundada em 1918 com o nome de National Union of Scientific Workers, mudando a sua designação para Association of Scientific Workers, em 1927. O sindicato representava um grande número de profissionais, incluindo pessoal técnico, das universidades, do Serviço Nacional de Saúde, e dos sectores industriais da química e da metalurgia. Era uma associação de cientistas com consciência social, onde se incluíam vários Prémios Nobel. Em 1969, a associação fundiu-se com a ASSET (Association of Supervisory Staff, Executives and Technicians) dando origem à ASTMS (Association of Scientific, Technical and Managerial Staffs)

[4]"Armas nucleares e seus efeitos", Comunicações apresentadas no Encontro Nacional de Trabalhadores Científicos sobre Armas Nucleares, Lisboa 1983

[5] In "Armas de urânio : destruição sem regresso", Albano Nunes, Rui Namorado Rosa, Jorge Cadima, Ângelo Alves, Editorial "Avante!", Lisboa, 2001

Alternativas racionais no pensamento de Rui N. Rosa

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Abstract
To my knowledge, there are two areas of scientific intervention and reflection where the works published by Professor Rui N. Rosa distinguished by a high level of competence: international energy policy and politics of R&D and training in Portugal and the European Union.
In both cases, these works feature the author as an expert in the foreground, a scientific adviser and a potential officer of state to the service of a political alternative.
The purpose of my speech at his academic jubilee is to try to show striking aspects of the relationship between these characteristics of his activities.

1. Introdução

Partirei, no que se segue, de uma exigência de longa duração, a que posso chamar *o predomínio social da atitude científica*, como processo e como finalidade
– do desenvolvimento social,
– da relação multiforme entre disciplinas do conhecimento e destas com uma concepção do mundo.

Emerge deste início de posicionamento um modo de conceber o enraizamento do conhecimento humano em geral e dos fins do conhecimento científico em particular. Para dizê-lo numa palavra, trata-se aí de um modo de regulação racional respeitante a qualquer sociedade culturalmente evoluída e, segundo creio, respeitante também a qualquer comunidade de investigadores que aceitem e pratiquem a cooperação em escala adequada (por exemplo, cooperação das ciências com a filosofia). Em perspectiva, nada menos do que a regulação das relações sociais segundo fins universalmente humanos, entendida esta, por sua vez, como uma condição da inteligência prática da nossa natureza externa (Marx), a «natureza toda» como «corpo inorgânico» dos seres humanos[1].

[1] Marx, K. 1994 *Manuscritos económico-filosóficos de 1844*, trad. port. de Maria Antónia Pacheco, Lisboa, Edições Avante!, pp. 66 sq. – Com diferenças de contexto ou de análise, Marx retomará esta problemática, por exemplo em *A Ideologia alemã* (com Engels), nos *Manuscritos de 1857-1861* e em *O Capital.*

Formulando assim um grande problema, que não pretendo apresentar desenvolvidamente aqui e agora, desejaria entretanto que ele se articulasse com alguns dos trabalhos publicados de Rui Namorado Rosa, trabalhos em que a escrita científica me parece ilustrativa de uma tríplice característica do seu autor: a de perito de alto nível nos temas aí tratados, a de conselheiro científico em política de ciência, a de governante potencial ao serviço de uma política alternativa. E creio que não é descabido considerar que o percurso de Rui Rosa na Universidade portuguesa tem constituído o traço de união dessas marcas integrantes da sua biografia de cidadão e de trabalhador científico. Observo ainda, além disso, que daqueles escritos ressalta forte tendência para uma racionalidade em acto, próxima, decerto com adaptações, da minha própria concepção de razão como expressão superior da unidade de pensar e agir, – esse bem supremo em tempo de desconserto e regressão como o que vivemos.

Gostaria de poder mostrar alguns aspectos de tal proximidade. Com esse propósito, seja-me permitido retomar aqui abreviadamente, em quatro sub-temas, o programa que teve por título «*Percursos da razão contemporânea*», cujo lugar de origem foi um seminário de filosofia que orientei em 2002-2003 na Faculdade de Letras da Universidade de Lisboa. Com diminutas modificações, reproduzo-o a seguir no seu todo.

2. Convergência

«*O sono da razão produz monstros*»
(Francisco de Goya, 1797)

«I – Quer na amplitude dos seus campos de pesquisa e aplicação, quer na diversidade e complexidade das suas manifestações concretas, a categoria de razão é interdisciplinar, dinâmica e aberta.

II – Requerendo a cooperação sem fronteiras rígidas entre as disciplinas de investigação e conhecimento, promovendo em tudo o livre exame e o espírito crítico que aprendeu a duvidar e a descobrir, a razão (...) apoia-se em instrumentos de emancipação como o pensar informado, o ajuizamento autónomo, a formação de consciência histórica.

III – Alheia a definições redutoras que para sempre lhe fixassem a estrutura e as funções, a razão não deixa de ser norma e critério, princípio e fundamento, enquanto universal concreto. Entende-se pois, embora com discordância, a exigência que nos chega de outras eras : se não governa, a razão tem de governar o mundo, porque o mundo é racional na sua essência.

IV – Na sua forma contemporânea, tal perspectiva pode e deve ser traduzida em prática social de regulação, equilibração e decisão, segundo fins humanos universais. O seu campo de acção é a totalidade do real como processo, isto é: natureza, sociedade, pensamento.»

A epígrafe que encima os quatro tópicos ou subtemas traduz a minha convicção de que a severa advertência do pintor em tempo de obscurantismo é hoje extensiva de outro modo ao presente curso do mundo e adquire, com isso, uma talvez inédita e mais atormentada validade do que a de origem, na Espanha de finais do século XVIII.

No subtema I concentra-se de certo modo uma visão deliberadamente inacabada, cujos caracteres explícitos sinalizam apenas a complexidade das tarefas. Num paralelo evidentemente construído, e não pré-estabelecido, esses caracteres estão em correspondência com não poucos conteúdos de artigos e estudos publicados ao longo de anos por Rui Rosa na revista «Vértice»; textos em que, por vezes, a amplitude de um certo fenómeno, – por exemplo, a energia enquanto «factor de produção (...) determinante para o desenvolvimento sócio-económico»[3] – tornado fenómeno global, permite ao autor evocar respostas como a seguinte, na área da ciência económica dos nossos dias:

«Assim, nas duas últimas décadas, emergiram organizadas duas correntes de pensamento económico sediadas nos EUA mas com expressão mundial – a Economia Ecológica e a Ecologia Industrial – que reflectem essas visões materialistas da esfera de actividades económicas, integrada na Natureza e, à sua semelhança, complexa e dissipativa.»[4]

De assinalar, ainda, que o estudo conclui com uma referência ao papel mundial da produção de petróleo na *composição orgânica do capital*, categoria em que, precisamente, amplitude e complexidade se associam de perto para o estudo da divisão internacional do trabalho na sua variante congénita ao capitalismo industrial contemporâneo.

O subtema II. salienta noutros termos a mencionada exigência de predomínio social da atitude científica como campo imenso de uma racionalidade aberta a necessidades prementes no mundo de hoje. Porém, contrariamente a este motivo condutor, «a política cega dos governos» de países da OPEP ou «a completa miopia» de autoridades da UE[5] reduzem uma força de desenvolvimento e emancipação, na análise de Rui Rosa, a instrumento de agressão armada, de dominação, de pilhagem e de competição interimperialista. Na amplitude mundial deste horizonte de devastação, mostra-se o mundo às avessas a que somos conduzidos, seja através da crise da energia,

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[3] Rosa, R. 2005, Alcance económico do pico do petróleo, Vértice nº 124, pp. 5-14.

[4] Ibid., p.10.

[5] Expressões constantes do artigo de Rosa, R. 2008, A crise da energia e suas implicações político-económicas, Vértice nº 140, pp. 9 sq.

ou da falsa racionalidade do mercado mundial, ou da «guerra ao terrorismo» por parte daqueles mesmos que têm nisso a responsabilidade primeira.

Acrescente-se que este segundo subtema adquire neste quadro uma urgência particularmente crua, a que não é possível renunciar, tão-pouco como abdicar da ciência e da técnica segundo fins orientados não só para a salvaguarda do género humano, mas da biosfera como um todo, se o *todo* aqui ainda tem sentido. É por isso, ao que me parece, que o enunciado do problema, hoje banalizado à escala planetária, não dissimula, todavia, o eventual escândalo para a razão que consistiria em que milhões e milhões de seres humanos não tivessem ainda feito daquela salvaguarda a contra-ofensiva que estivesse ao seu alcance por uma vida humanamente digna. Pelo que assim fica dito, não é difícil imaginar estes escritos de Rui Rosa como leitura de trabalho por participantes em actividades de I&D solidários de uma política energética verdadeiramente racional.

Quanto ao subtema III, considerado também ele à luz da correspondência acima esboçada, há aí um interessante embora difícil problema de articulação entre uma teoria materialista do conhecimento e a estrutura da razão. Começando pela «exigência que nos chega de outras eras...», pergunto: o mundo, racional na sua essência? Mas que é a essência de uma coisa senão o que o nosso pensamento nela discerne de constitutivo? Senão um conjunto de determinações que o nosso pensamento extrai da coisa para restituir-lhas sob a forma de síntese conceptual acerca dela? Por outras palavras, dizer que «o mundo é racional na sua essência» constitui algo como uma projecção antropomórfica da compreensão do mundo. A razão é uma instância do pensamento humano, não do mundo objectivo. Entretanto, se vejo bem o problema, nem essa projecção de nós mesmos sobre o nosso mundo se torna estéril, nem perde com isso beleza e inteligibilidade teóricas. Em filosofia, alguém o lembrou já, um idealismo inteligente é mais fecundo do que um materialismo grosseiro!

E o pouco que sabemos do mundo, de nós mesmos e da reciprocidade multiforme de natureza e sociedade, põe-nos hoje face a face com a que é talvez a mais poderosa contradição que coube em sorte às gerações vivas : a contradição entre a nossa limitada compreensão racional da unidade material do mundo (como totalidade ilimitadamente complexa) e o desgoverno do mundo humano, não tanto na esfera da razão como categoria do pensamento, mas, antes de tudo, no duríssimo terreno das lutas de classes, isto é, da dominação supranacional de classe, bem expressa na insaciável sede de lucro (que na *Eneida* de Virgílio, em contexto próprio do mundo antigo, aparece como «execrável fome de ouro»: *auri sacra fames*).[6] O passado e o presente das sociedades humanas ensinam-nos, contudo, que a sede de riqueza é um fenómeno histórico, não uma característica de natureza.

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[6] Livro III, v. 56 sq.

Daí decorre em assinalável medida a responsabilidade conjugada da ciência económica, da ciência histórica e da ciência política – não alheadas, além disso, do psiquismo humano em geral, e da génese das motivações subjectivas em particular – nos caminhos desta ou daquela região do mundo por onde se descobre ou redescobre a superação, quer gradual, quer brusca, do desgoverno e da dominação. Num estudo notavelmente bem documentado, Rui Rosa aproxima-se deste enfoque em aspectos essenciais. Refira-se aqui apenas a sua conclusão:

«Exploração e guerra são duas faces ou dois momentos da mesma realidade. Mas o imperialismo não é invencível, porque não pode existir sem humanidade, sendo intrinsecamente contrário aos interesses e progressão dessa humanidade.»[7]

De facto. A humanidade, essa, pode existir e existir muito bem sem imperialismo.

Resta o subtema IV. Partindo da tese segundo a qual a prática social «é o fundamento último da racionalidade»[8], chamo *regulação* a uma normatividade exequível, necessária e justa, de amplitude social não previamente estabelecida, mas onde seja aceite ou tenha de ser aceite uma instância material de jurisdição da razão. Chamo *equilibração*, com a psicologia genética de J. Piaget, a actividades humanas tendentes a superar disfunções a um nível mais elaborado de conhecimento da realidade, no seio de um sistema de relações que comporta transformação. E chamo *decisão* (em conformidade, aliás, com a etimologia da palavra) ao corte que exclui umas ou outras entre opções possíveis segundo critérios racionais, decisão cujos conteúdos de consciência, entre outros, são o pensar informado, o ajuizamento que delibera autonomamente, a determinação da vontade e a previsão, em certa medida, das consequências da acção.

Deixando de lado o vastíssimo campo da decisão irracional, – digamo-lo de passagem: irracional não por falha de entendimento, mas por falência da própria razão – fica a perspectiva, exequível, necessária e justa, sem início nem fim de prazo anunciados, de articulação entre as três categorias acabadas de circunscrever e decorrentes do primado da prática social. Ora, no mundo de hoje, a entrada em cena de fins humanos universais como aqueles que, directa ou indirectamente, Rui Rosa identifica nos seus escritos,

– sustentabilidade biológica do planeta,

– cessação de todas as guerras e eliminação das suas causas,

– reabilitação do tempo livre, da educação e do trabalho criador como fontes de realização humana, entre alguns outros desses fins,

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7 Rosa, R. 2004, As guerras no mundo contemporâneo : os meios e os fins do imperialismo, Vértice nº 120, p. 107.

8 Magalhães-Vilhena, V. 1984 *Antigos e Modernos. Estudos de história social das ideias*, Lisboa, Livros Horizonte, p. 338.

a entrada em cena deles (dizia eu) consente a analogia, certamente com reservas, de um tribunal do mundo como Hegel dizia da história mundial, onde as partes em litígio são conhecidas, conhecida a gravidade dos malefícios em julgamento, conhecidos os argumentos, antecipadas com probabilidade as alegações.

Em futuro que não pode ser longínquo, a natureza, os povos do mundo e «a força objectivada do saber» (Marx) terão de dar por concluídos, decerto provisoriamente, os seus depoimentos e reclamar para quanto antes a sentença executória, – já inscrita, de outro modo, no curso do mundo. Levando mais longe a analogia, convém todavia que o acusado não morra de velho nem caia de podre: não seria improvável que nos levasse com ele.

3. Antinomia

Se, numa intervenção pública de Rui Rosa como «Imperialismo: seus limites e alternativas»[9], invertêssemos antinomicamente o conteúdo de cada um dos sete capítulos do documento, cujos subtítulos respectivos dizem:

1. *Sistema financeiro internacional.*
2. *A produção mundial.*
3. *O capital internacional.*
4. *O comércio internacional.*
5. *Os limites do imperialismo.*
6. *A força de trabalho.*
7. *Confrontando o imperialismo,*

e com isso lêssemos total ou parcialmente às avessas o que neles se encontra de tensão aguda contra o declínio e pela subsistência do sistema financeiro (cap. 1); de prenúncio de catástrofe ambiental em grande escala, a ser superado pela reequilibração internacionalmente programada da nossa «pegada ecológica» planetária (cap. 2); de regressão do imperialismo do tempo de Lénine, projectada até à bancarrota, eventualmente sem remissão, das corporações transnacionais de hoje (cap.3); de desproporção inumana no consumo mundial que fosse vencida pela autodefesa, bem sucedida solidariamente, dos países ao mesmo tempo produtores e espoliados dos seus recursos (cap. 4); de apologia de um «capitalismo sustentável» tornado contrasenso lógico, como expressão mal formada e sem suporte material (cap. 5); de desemprego e sub-emprego em crescimento no mundo, como antítese do potencial imenso de riqueza contido no tempo disponível, ou tempo de desenvolvimento de cada personalidade individual (cap. 6); e, finalmente, o

[9] Rosa, R., 2005, Vértice nº 121, pp. 26-64. – A «leitura antinómica» que se segue para cada capítulo não reproduz sempre as formulações de Rui Rosa e apenas compromete, nessa medida, o autor da presente comunicação.

que aí se encontra quanto às formas historicamente diferenciadas de compromisso entre trabalho e capital sob a égide do Estado burguês, a caminho da ruptura numa relação de forças que fosse doravante favorável às soberanias nacionais e à cooperação de longo alcance entre Estados de democracia avançada (cap. 7).

Se, por conseguinte, a inversão de conteúdos não for neste exemplo infrutífera para o fim em vista, poderei então ultimar a analogia que vem de trás e acrescentar: teríamos assim por antecipação a causa julgada e, em larga medida, os seus considerandos em aplicação imaginada, mas não inverosímil. Aplicação tão verosímil, de resto, como os *limites* e as *alternativas* que Rui Rosa pôs em evidência quanto ao imperialismo.

Cabe aqui, precisamente aqui, o sentido dominante que atribuo a uma «*prática social de regulação, equilibração e decisão*», pois que a expressão e o contexto a que pertence (o meu subtema IV) não se dissociam da crítica de hoje ao mundo de hoje. Mas não só isso: tributárias, como assinalei, de uma concepção que se demarca do idealismo da razão (que diz: «*a razão tem de governar o mundo...*»), elas permanecem por isso mesmo vinculadas ao lado não contemplativo mas activo, não ideal mas material do mundo a que pertencem. E este não é racional nem irracional. Basta-lhe, por certo, como mundo objectivo, apresentar-se-nos como totalidade ao mesmo tempo estruturada e em transformação.

4. Fundamentos

A destrinça leva-me a «descer aos fundamentos». Como já o disse noutro lugar:

«Vejo três caracteres distintivos na categoria de razão, de tal modo interdependentes que só com propósito expositivo me parecem separáveis. São eles a historicidade, a universalidade e a humanidade da razão (...) Se aceitarmos que a evolução do suporte biológico do psiquismo humano, ele próprio evolutivo, foi, em sociedade, o contexto filogenético da razão; se aceitarmos que as civilizações são a condição necessária do desenvolvimento e transformação da razão, mas também do seu núcleo de estabilidade adquirida, depois em certa medida invariante, decerto aceitaremos que a universalidade da razão é o resultado não definitivo de uma antiga e sempre nova experiência assimilada. E se a esta actividade, como actividade de síntese, convém o nome de *inteligência*, porque opera a estruturação mental da realidade até aos mais elevados índices de coordenação entre compreender e agir (ou ainda: entre agir e compreender), diremos também que a *razão* é a mais universal filha da inteligência, mas que não se confunde com ela.»[10]

Não se leve a rigor este arremedo de genealogia materno-filial, aparentada, segundo a forma, a algum mito arcaico sobre o *logos* arcaico. É que, como se depreende, não é propriamente mítico o problema que lhe subjaz. E o ensaio de dilucidação prossegue, um pouco adiante:

«(...) natureza e sociedade constituem os "polos" de cuja vasta, diversa e complexa reciprocidade depende, em parte essencial, a vida histórica da razão humana. Aqui entronca o seu carácter universal, se este consistir, como me parece aceitável dizer, na totalização pensada do mundo como construção permanente, consoante o que em cada momento e lugar estiver ao alcance das forças humanas. Segundo o que procuraram mostrar alguns clássicos do modo dialéctico de pensar (idealistas uns, materialistas outros), nisso consiste também a vasta contradição, ela mesma em processo, entre forças humanas finitas e tarefas sempre inacabadas, de certo modo infinitas (...) Não tenho por absurdo admitir que a razão "coincida" com o conjunto das representações mais produtivas que dela nos têm dado as civilizações humanas. Dito noutros termos: a identidade da razão consiste na sua própria história até aos nossos dias.»[11]

Para o leitor vai o pedido de desculpa por tão extensa reprodução de uma parte de outro trabalho, todavia ainda inédito. Ficam por expor e debater, a despeito do seu interesse, alegações inscritas no que precede mas sem cabimento, ao que me parece, nesta comunicação. Explico-me, acrescentando apenas : em primeiro lugar e no que respeita à filiação inteligência / razão, a complexidade lógica, gnoseológica e dialéctica dos problemas remonta, na sua versão moderna, à filosofia alemã clássica (de Kant a Feuerbach), que seria despropositado procurar trazer aqui. Em segundo lugar e principalmente, a diferença e complementaridade entre inteligência e razão é hoje parte integrante de uma vasta obra internacional em estaleiro, onde se cruzam demasiados problemas em aberto: não-linearidade e emergência, determinismo e causalidade, analítica e dialéctica, e outros mais, como aqueles que as neurociências trazem à ordem do dia.

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[10] Chitas, E., 2010, Um modo de ver a razão humana (Parte I), *in* : Razão activa. Boletim da Fundação Internacional Racionalista (no prelo.)

[11] Ibid. – A Manfred Buhr, filósofo e historiador alemão da filosofia, recentemente falecido, devem-se nos nossos dias e tanto quanto sei, os primeiros esforços continuados em torno da tese : «a questão da identidade é a questão da história».

5. Transição

Prosseguindo. Se tivesse tido que buscar um escrito de Rui Rosa situado na transição dos assuntos até agora percorridos a caminho do final da minha intervenção, o artigo «Ciência: entre bem público e produto comercial»[12] teria sido uma escolha acertada. Salvo excepção, pouco importa ao caso a sequência dos textos no «tempo curto», se entre eles houver, como aqui acontece relativamente a outros, ligação por conteúdos e proximidade das áreas em estudo. Bem ao estilo do autor, a segurança expositiva está fundada quer na precisão e na riqueza da informação, quer na consistência da análise, que aos factos e processos examinados confia sem mais a explicitação crítica que eles por si mesmos muitas vezes comportam. E quero dizer que a primeira impressão de leitura me foi trazendo ao espírito a «ciência da ciência» de John Desmond Bernal e o seu clássico *The social function of science* (1939), hoje talvez meio esquecido entre nós.

A análise institucional e comparada em política de ciência, que envolve com pormenor o papel dos Estados e das empresas, as «movimentações» de âmbito internacional a partir das superstruturas de ciência da União Europeia, o lugar das universidades e laboratórios nesse espaço e, até, certa aproximação ao «modelo americano» nestes domínios, sinalizam um itinerário de informação e reflexão que não esgota, aliás, todos os recursos deste estudo. Vejam-se os dois exemplos seguintes, sobre os quais, confesso, espero conhecer algum dia o comentário do autor ou, mais do que isso, a explanação alargada por parte dele.

1) Logo no preâmbulo do artigo (p. 87), escreve Rui Rosa :

«As aplicações concretas de uma teoria ou de uma descoberta muitas vezes são imprevisíveis e verificam-se muito mais tarde».

Temos aí um problema que da história das ciências e das técnicas pode transitar para a epistemologia histórica (ou teoria do conhecimento científico considerada historicamente) e tem por pano de fundo não só o surto de novas necessidades sociais, não só a evolução histórica em geral, mas o desenvolvimento daquelas forças produtivas materiais e intelectuais que mais de perto condicionam a validação ou as aplicações da teoria.

Deixo a interpelação :

– Está de acordo, Professor Rui Rosa?

2) Surgem mais adiante as expressões «sociedade da informação» e «sociedade do conhecimento» (p. 96). As aspas aí postas pelo autor significam alguma coisa, mas não dizem nem podem dizer tudo. Além, sem dúvida, de que não lhe faltava em que pensar com outra urgência. Também eu não digo nem poderei dizer tudo a esse respeito. Mas digo o pouco que se segue :

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12 2005,Vértice, pp. 87-104.

a) julgo que há hoje, em círculos cultivados, uma recepção ingénua, ou sem autonomia crítica, das duas expressões, usuais mas não assepticamente neutras;

b) independentemente da sua proveniência exacta, que não conheço, e sem atribuir propósitos inconfessáveis a quem quer que seja, vejo numa e noutra expressão equívocos algo diferentes mas de certa gravidade e, no mínimo, desnecessários;

c) se as premissas estritamente técnicas de uma pretensa «sociedade da informação» estão, para os dias de hoje, largamente cumpridas, não menos importantes são as premissas por cumprir : económicas, políticas, culturais, ideológicas e, claro está, deontológicas, sem ter sequer de invocar, no caso português, a Constituição da República;

d) parece-me sensivelmente outra a natureza do equívoco quanto à pretensa «sociedade do conhecimento»; em sentido próprio, obviamente, a origem do conhecimento humano não passou a ser de conteúdo informático, nem é de prever que o seja predominantemente alguma vez;

e) em sentido próprio, não há conhecimento sem inumeráveis formas de interacção de sujeito e objecto : agir sobre o real e assimilar as suas retroacções é muito mais e outra coisa do que «conhecer» virtualmente;

f) uma sociedade do conhecimento (sem aspas), só pode ser uma sociedade altamente desenvolvida, de seres humanos globalmente próximos de uma formação integral. Também aqui quereria interpelar :

– Aceita, Professor Rui Rosa, esta última alínea, qualquer que seja a sua margem de concordância quanto às restantes?

6. Bolonha

Há cerca de dois anos que o escrito de Rui Rosa «O processo de Bolonha: uma outra face da integração europeia»[13] estava por mim estudado com anotações à margem. É essa leitura que tento de seguida apresentar organizadamente.

Impossível desarticular ou ler sem mútua ligação, neste estudo, uma política de formação e ensino superior e uma análise política em sentido estrito. Impossível, também, não atender aí à simultaneidade da informação institucional e da crítica objectiva acerca da natureza e alcance do assim chamado processo de Bolonha. O título, desde logo, deixa poucas dúvidas sobre a perspectiva adoptada. Mais: o assunto leva o leitor aos antecedentes mais antigos do processo, no quadro da integração europeia como um todo.

E que vemos nós, na análise desses antecedentes?

[13] 2006, Vértice nº 130, pp. 5-17.

1) Vemos que «a Educação estava na mira da política europeia», declaradamente desde, pelo menos, 1989 (p. 5).

2) Vemos que entre Maastricht (Fevereiro de 1992) e o início da «estratégia de Lisboa» (Março de 2000) decorre uma importante etapa da agenda neoliberal, na qual «explicitamente emergem os conceitos instrumentais de Espaços Europeus da Investigação e do Ensino Superior.» (p. 6).

3) Vemos que a pretendida (pela Comissão Europeia) «concentração de capacidades competitivas de formação avançada e de produção científica num número restrito de universidades ou de redes integradas» com propósito semelhante, caminhava a par de «medidas para captar estudantes talentosos de todo o mundo» (ibid.). Para inverter, prossegue Rui Rosa, «o *brain drain* a favor de um *brain gain* no "mercado" mundial do ensino superior.» (ibid.).

4) E vemos ainda a atenção do autor ao «resultado combinado dos efeitos demográfico e educativo» na União Europeia. Trata-se aí do «ciclo vicioso» e da «ameaça de rotura» resultantes, na Europa, da insuficiente taxa de conclusão do ensino secundário e da taxa de êxito relativamente baixa no ensino superior.

Destes e de outros considerandos ressalta a subjacente perspectiva neoliberal, que desde o conceito duvidoso de «sociedade do conhecimento» até à «urgência de alargamento do mercado de trabalho» trouxe à luz do dia o processo de Bolonha, que o autor caracteriza como «expediente da União Europeia para promover qualificações de curta e média duração» (p.8), «sem prejuízo da formação e fixação de talentos que sirvam as elites do grande capital.» (ibid.).

Julgo apropriado acrescentar que a análise severa, consideravelmente mais complexa do que procurei mostrar, é acompanhada por um conjunto de outras observações, relativas, agora, ao Ensino superior em Portugal e ao que neste decénio tem ocorrido susceptível de antecipar um «para além de Bolonha», a combater se chegar e quando chegar ao nosso horizonte (pp.10-17).

A este respeito parecem-me de particular interesse:

– a periodização ao longo do decénio, o registo do tempo concreto, datável (não forçosamente linear), de toda uma regressão, estratégica primeiro, institucional depois;

– a alta «concentração» de categorias operatórias mediante as quais o autor acentua deliberadamente a contraditoriedade entre, por um lado, o Ensino superior como bem público dotado de autonomia num Estado soberano e, por outro, aquele «para além de Bolonha» sem harmonização voluntária entre Governos nem recusa por estes da «superintendência da Comissão Europeia» (p.14);

– e, como corolário, a denúncia documentada da agenda do capitalismo europeu para o Ensino superior, à margem dos povos europeus.

Ao leitor atento não terá passado despercebida a finalidade principal desta intervenção, sob o diverso dos problemas apresentados. E essa permanece como *o predomínio social da atitude científica*, um motivo condutor da actividade de Rui Rosa.

The peak of peaks or the peak peak

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Abstract
The term *peak oil* was first introduced by Colin Campbell in December 2000, with an article titled «Peak Oil - a Turning Point for Mankind», leading to the founding of ASPO «Association for the Study of Peak Oil and gas». *Peak oil* is often related to the *Hubbert Peak* from his famous 1956 paper forecasting the USL48 oil peak in 1970 for an ultimate of 200 Gb. But in his last paper in 1981 he was convinced that the USL48 oil ultimate was only 170 Gb, based on the extrapolation of discovered oil by exploratory foot. The recent estimate is 230 Gb. The problem is that Hubbert was using the official proved current discovery. Hubbert was too pessimistic about the US offshore and using wrong discovery data. *Gold peak* seems to have passed, *silver peak* and *copper peak* could occur within this decade. My grandchildren will see the peaks of most important commodities, or the *peak peak*

1. Hubbert's US crude forecasts

Peak oil is often related to the *Hubbert Peak* from his famous 1956 paper forecasting the USL48 oil peak in 1970, with for an ultimate of 200 Gb (but also in 1965 for an ultimate of 150 Gb). In 1956 the US had only the 48 states because Alaska only joined in 1959!

In 1956, Hubbert was not the first geologist to forecast such a peak around this date.

The forecast by J.Pogue & K.Hill (Chase Manhattan Bank), which is similar and earlier than Hubbert, should have also been vindicated. Hubbert quotes Pogue& Hill in his 1956 paper.

The Chase Manhattan report titled "Future growth and financial requirements of the world petroleum industry" was published on February 21, 1956 for presentation at the Annual Meeting of the Petroleum Branch of the American Institute of Mining, Metallurgical and Petroleum Engineers and was reported in the New York Times. As shown in the figure below, the

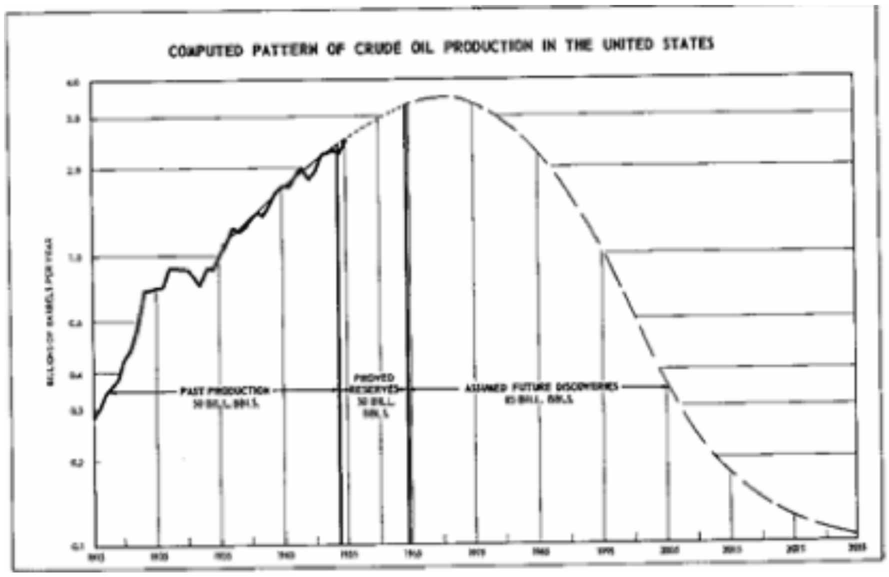

Fig. 1. US oil production forecast by Pogue & Hill 1956 for ultimate 165 Gb

report concluded that the US peak of production would likely occur between 1965 & 1970 based on the assumption that only 85 billion barrels of oil would be discovered in the lower 48 states after 1956.

Pogue & Hill's graph (time scale hard to read: seems to be every 10 years from 1915 to 2025) with a future discovery of 85 Mb plus proved reserves of 30 Gb with a cumulative production of 50 Gb (or an ultimate of 165 Gb) is too pessimistic with an end of production in 2025!

Also, their graph was far from being symmetrical, in contrary to Hubbert's forecast!

But 2P backdated discovery up to 1956 was in fact 150 Gb, so Pogue's ultimate should have been in fact 235 Gb, close to reality.

The US problem for reserves is the poor practice of reporting only proved reserves because of the SEC rules (change in 2010)!

In his 1956 paper, Hubbert forecasted a peak in 1965 for an USL48 ultimate of 150 Gb (his estimate) and a peak in 1970 for an ultimate of 200 Gb (taking the largest estimate (DGMN) from a Delphi enquiry by W.Pratt upon 25 experts).

His curve was drawn by hand and the area below the curve was estimated by counting the square (the unit is shown in the right up corner for 25 Gb).

Hubbert in 1956 was only saying that the production curve starts from zero, goes to a peak and ends at zero, the only equation was that the area below the complete production curve represents the ultimate reserves (reserves

= recoverable resources) and there may be an infinite number of curves corresponding to this ultimate. The main problem is to estimate the ultimate and

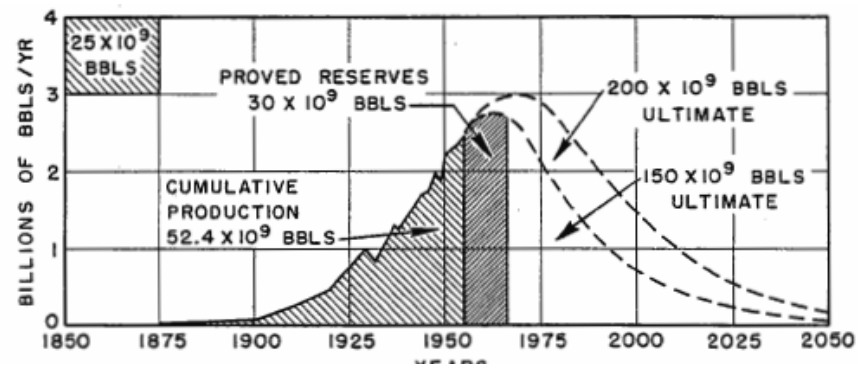

Fig. 2. US oil production forecast by Hubbert 1956 for ultimates 150 & 200 Gb

the so-called Hubbert linearization of production data, introduced by Deffeyes later on, is not the best way. The creaming curve of cumulative backdated mean discoveries is the best way to estimate ultimates.

In reality USL48 crude oil peaked in 1970 at 3.4 Gb and the ultimate is about 230 Gb (maybe 250 Gb with subsalt). With such ultimate ,the production curve is unsymmetrical!

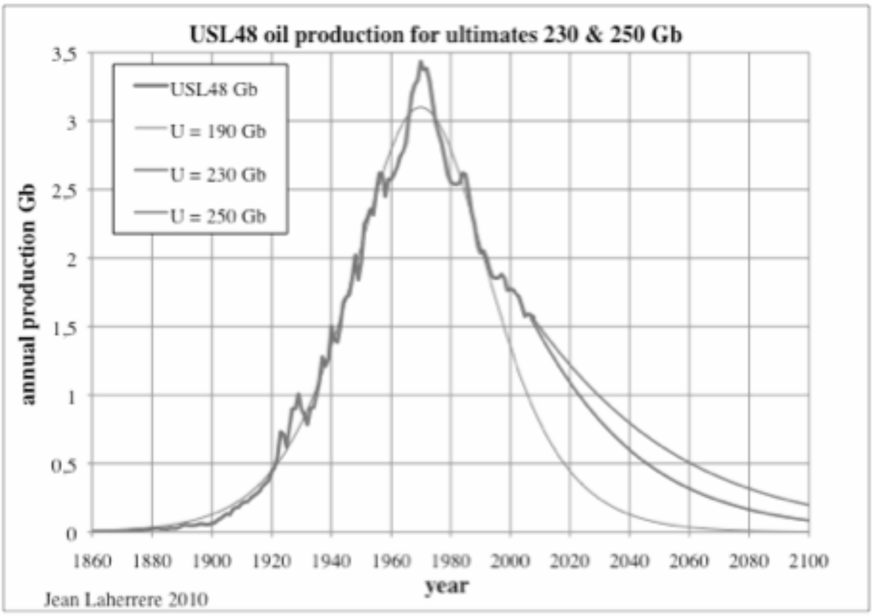

Fig. 3. USL48 oil production forecast for ultimates 230 & 250 Gb

Estimated Ultimate U. S. Crude-Oil Reserves

	Date	Author	Estimate (Barrels)
a	1948	Weeks	110×10^9
b	1956	Dept. of Interior	300×10^9
c	1956	Pogue and Hill	165×10^9
d	1956	Hubbert	150×10^9
e	1956	Pratt	145×10^9*
f	1957	Hill, Hammar and Winger	250×10^9
g	1958	Netschert	372×10^9*
h	1958	Weeks	204×10^9*
i	1958	Davis	165×10^9
j	1959	Weeks	391×10^9*
k	1959	Knebel	173×10^9*
l	1961	Zapp (U.S.G.S.)	590×10^9
m	1961	Averitt (U.S.G.S.)	400×10^9*
n	1962	Moore	364×10^9

Fig. 4. US oil ultimate estimates from 1948 to 1962

The estimates for US oil ultimates up to 1962 (Hubbert 1962) ranged from 110 to 590 Gb. Hill in 1957, with Hammer & Winger, raised the value to 250 Gb when in 1956 with Pogue he had 165 Gb!

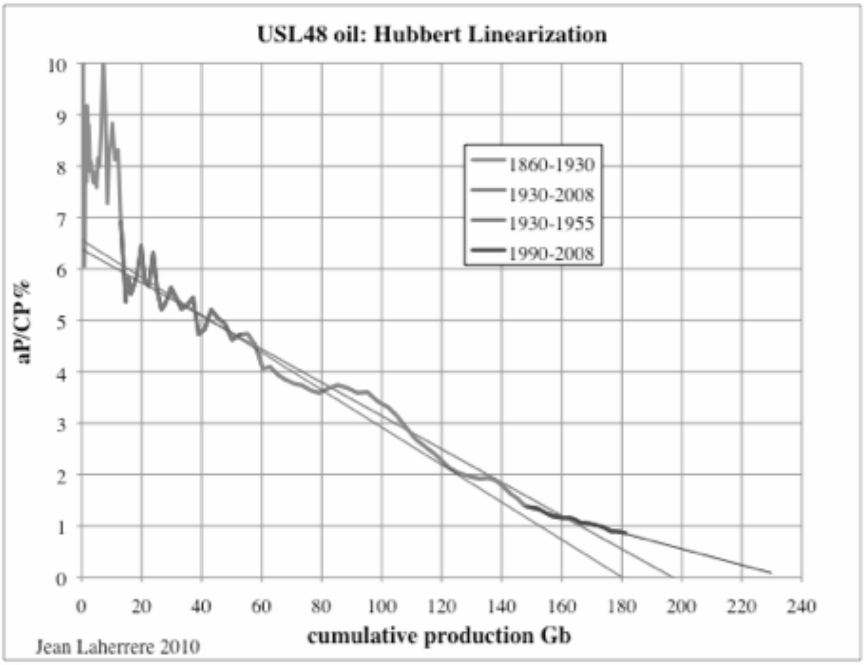

Fig. 5. present USL48 oil production Hubbert linearization 1860-2008

If Hubbert had used the production data to estimate the ultimate by plotting what is now called the Hubbert linearization (by Deffeyes), which is the percentage of annual production over cumulative production versus cumulative production. The plot from 1930 to 1950 is roughly linear and trends towards 180 Gb. But the recent linear trend from 1990 to 2008 (deepwater) trends towards 230 Gb

In 1959 Hubbert started to use different techniques to estimate US oil ultimate, combining cumulative discoveries (but assessed as proved reserves) and production.

In 1962 Hubbert tried to extrapolate the number of large fields (>100 Mb), being 240 large fields at end 1961 and representing in volume 57% of the total discoveries (59 Gb out of 103 Gb). The number of large fields was only around 150 in 1951.

Hubbert extrapolated the number of an ultimate of 460 large fields.

Hubbert acknowledged the difference between date of discovery and date of recognition. He assumed that reserve growth would increase the number of large fields discovered in 1961, from 240 recognized fields to about 400 not yet recognized fields. Hubbert estimated the average size of large fields to be 250 Mb. So the large fields ultimate should be 460 times 250 Mb, or 113

Gb. But L.F. Ivanhoe and G.G. Leckie 1993 reports USDOE field sizes distribution at end 1989 with only 280 oilfields over 100 Mb.

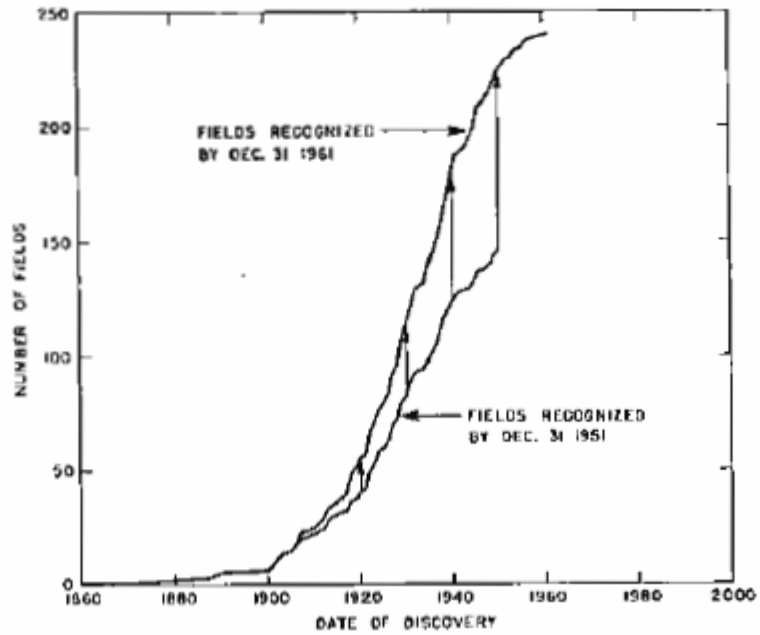

Fig. 6. Hubbert's estimate of large US oilfields

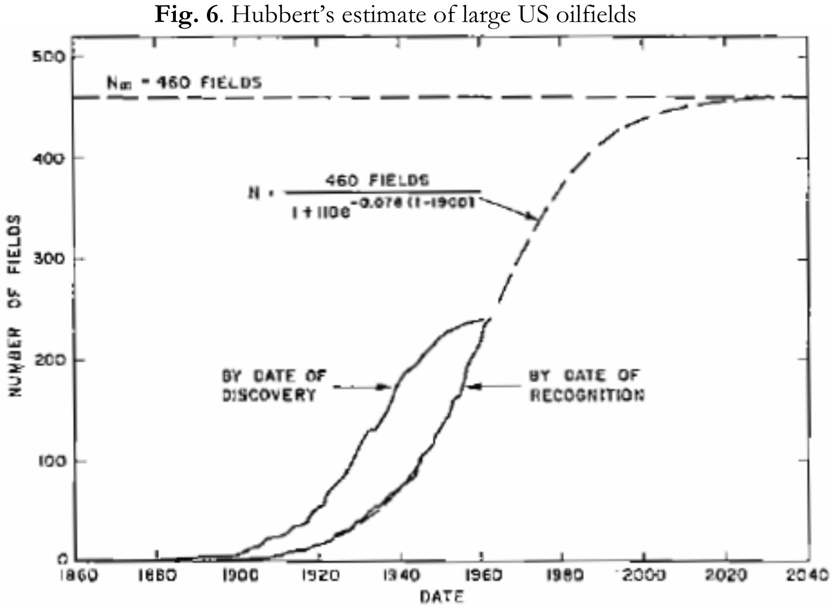

Fig. 7. Hubbert's estimate of large US oilfields by date of discovery & date of recognition & forecast to 460 fields.

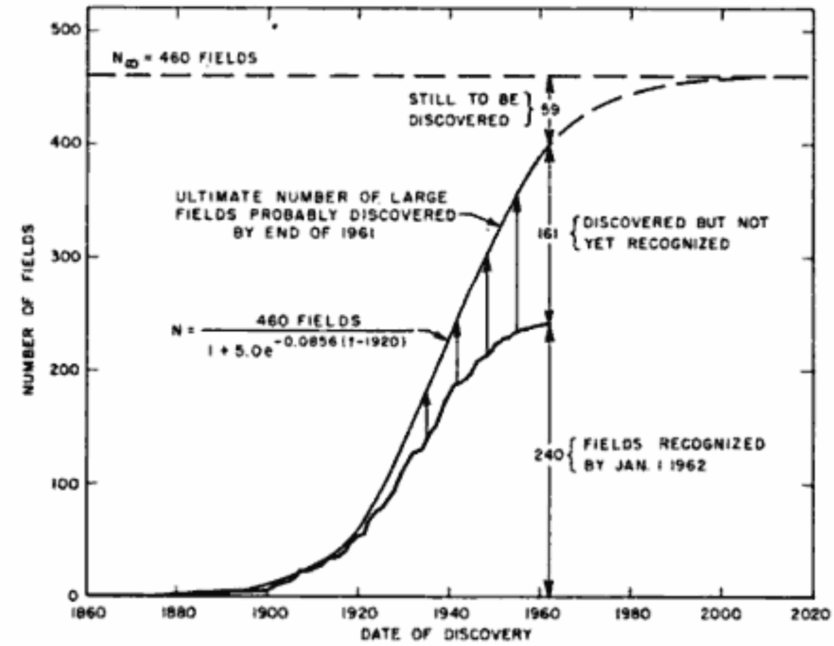

Fig. 8. Hubbert's estimate of large US discovered but not yet recognized oilfields

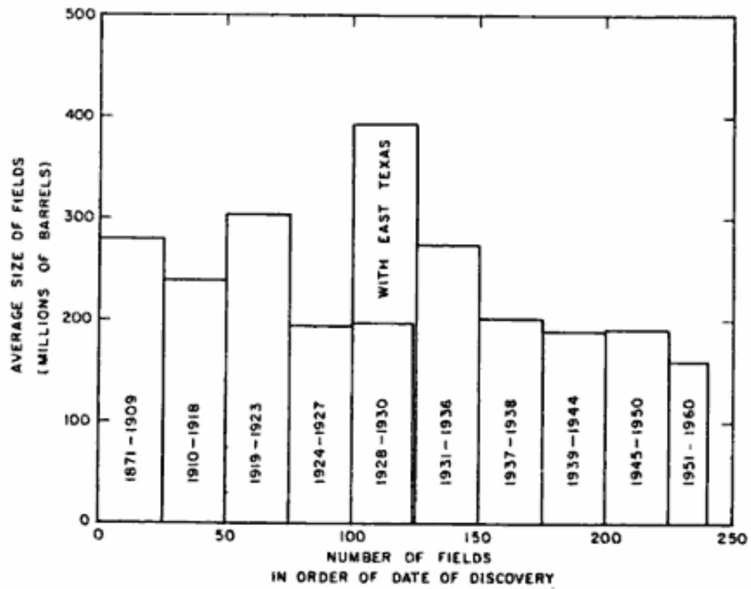

Fig. 9. average size of US large fields by discovery date 1871-1960

It means much less than what Hubbert forecasted (450 in 1990). Hubbert's approach on number of large fields was thus unreliable.

The USDOE report 0557-1992 presents the same data but under a different size classification and allows to plot the field size distribution for US L48 (excluding Appalachian oilfields) at end 1989 in a fractal display.

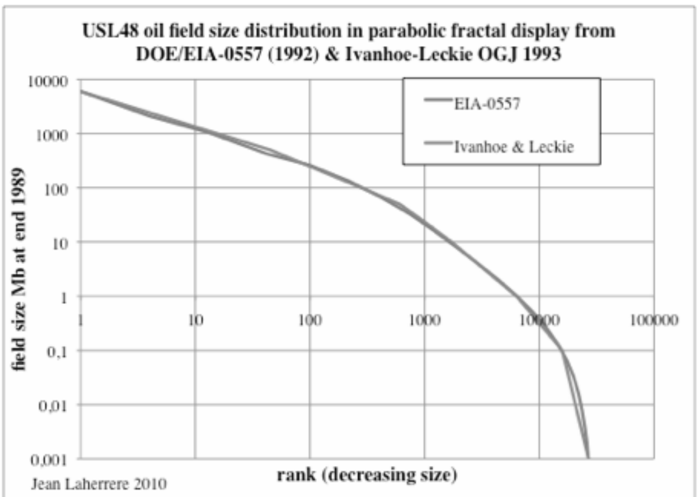

Fig. 10. USL48 oilfield distribution in parabolic fractal display from USDOE/EIA-0557

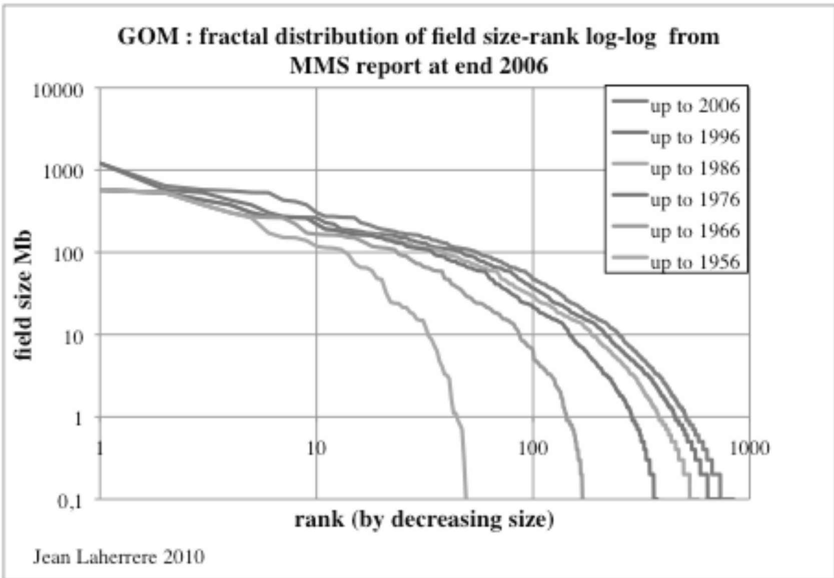

Fig. 11. Gulf of Mexico oilfield distribution in parabolic fractal display from MMS 2006

The 557 reports that cumulative discovery at end 1989 is 183 Gb for the all US and 167 Gb for USL48

The GOM MMS report at end 2006 displays over 1200 fields and the fractal presentation for oilfields is also parabolic

The number of large fields (>100 Mb) in the GOM is plotted every 10 years from 1947 to 2006 and modelled with two logistic curves (second cycle being the deepwater and subsalt) for an ultimate number of large fields of 70 & 80.

This ultimate from curve fitting shows that the number of **undiscovered** large fields in the GOM is about a range of 20 to 30 fields.

Hubbert's ultimate of 460 large fields looks optimistic! Furthermore, Hubbert was considering only conventional oilfields (excluding deep oceans without defining it except lack of technology to develop) and subsalt oilfields look more unconventional than conventional.

In 1967 Hubbert used the discoveries as function of exploratory footage to counter the study of Zapp (USGS) forecasting an ultimate of 590 Gb. He will update the same plot in 1977.

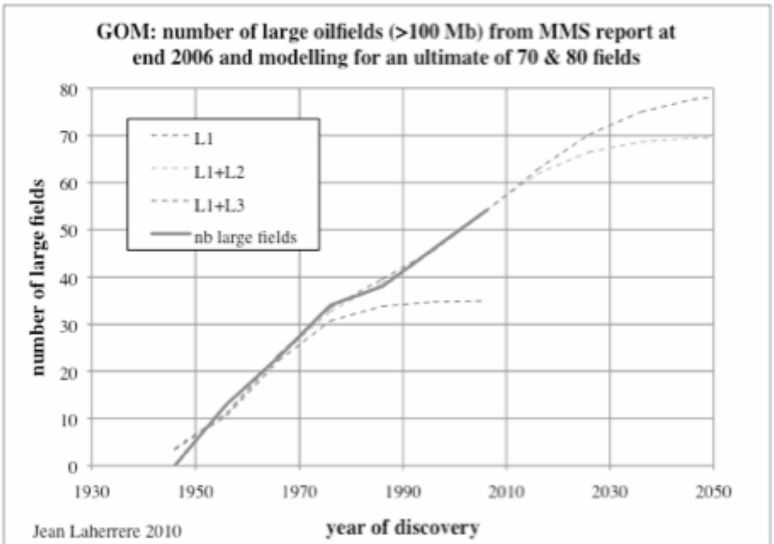

Fig. 12. Golf of Mexico number of large oilfields & forecast to 70-80 fields

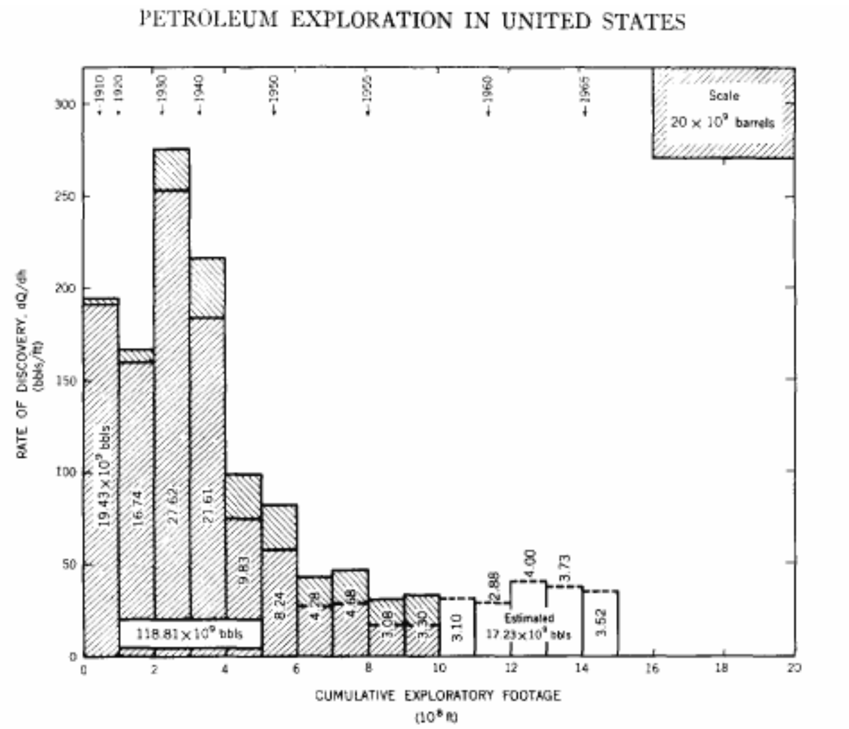

Fig. 13. 1967 Hubbert's discovery per exploratory foot versus cumulative exploratory drilling

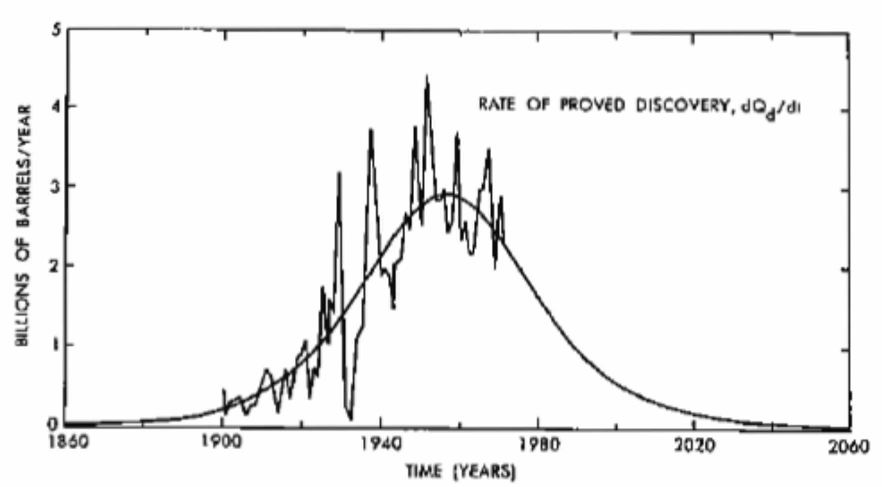

Fig. 14. 1975 Hubbert's annual discovery modelled with a derivative logistic curve

In 1975 Hubbert fitted the annual USL48 proved discoveries with a derivative logistic curve

The oil discovery peak is plotted around 1950 when it is well known that US discovery peak was about 1930 with East Texas, as shown by Hubbert in his 1962 graph for large fields.

Hubbert reported that the National Petroleum Council study used back-dated proved reserves at discovery peak, which confirms the discovery peak around 1930 and contradicts the peak from current proved reserves around 1950.

Another suite of data is provided by successive studies made by the Petroleum Administration for War and by the National Petroleum Council, in which the oil discovered has been allocated to the years of discovery of the producing fields. These, when corrected to an estimated ultimate growth, indicate that by the end of 1966 about 136 billion bbl of producible crude oil had been discovered. The rate of discovery per year, averaged for successive 5-year periods, reached a peak of 3.57 × 109 bbl/yr during the period 1935-1940, and has declined subsequently to a present rate of less than 2 × 109 bbl/yr.

In 1977 Hubbert stated: *In the meantime, successive estimates by the writer, based on analyses of publicly available petroleum-industry data, led consistently to about 165 to 175 billion bbl as the ultimate amount of crude oil, and 1,000 to 1,100 Tcf for natural gas, with the crude oil production peak due to occur during 1967-70, and that of natural gas in the mid-1970s. These estimates were predictions of the future, and that future has now elapsed. The peak of crude oil production was reached in 1970 and that of natural gas in 1973. By the end of 1972, the evidence was consistent with* ***170 billion bbl for the ultimate amount of crude oil*** *and 1,000 to 1,100 Tcf for natural gas.* ***However, since 1972 proved reserves and discovery and production***

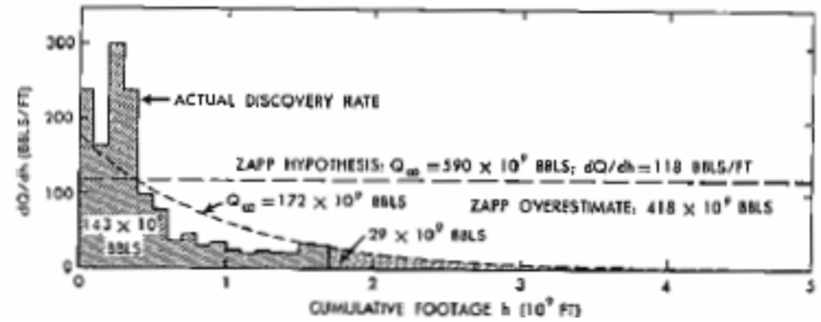

Fig. 15. 1977 Hubbert's oil discovery per foot of exploratory drilling

rates of both oil and gas have been declining more rapidly than originally estimated. Should this continue, the ultimate quantities of oil and gas may be less than those estimated in 1972.

Hubbert failed to anticipate the discovery boom of the Gulf of Mexico!

Hubbert's graph in 1977 (role of geology) of US discovery in b/ft is too pessimistic (updating the 1967 plot of figure 13) unable to foresee deepwater (or thinking that it is unconventional), when Zapp is unrealistic with a constant discovery of 118 b/ft .

But present data on US exploratory drilling shows several cycles and when will be the next?

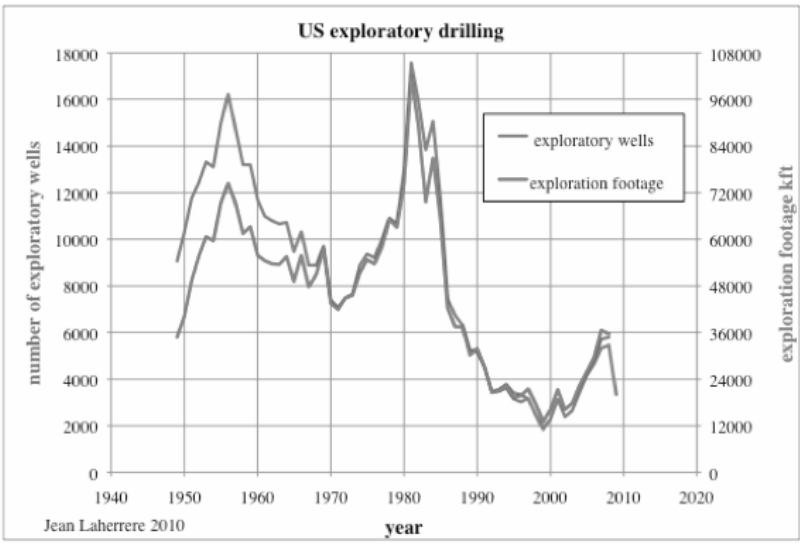

Fig. 16. US exploratory drilling 1949-2009

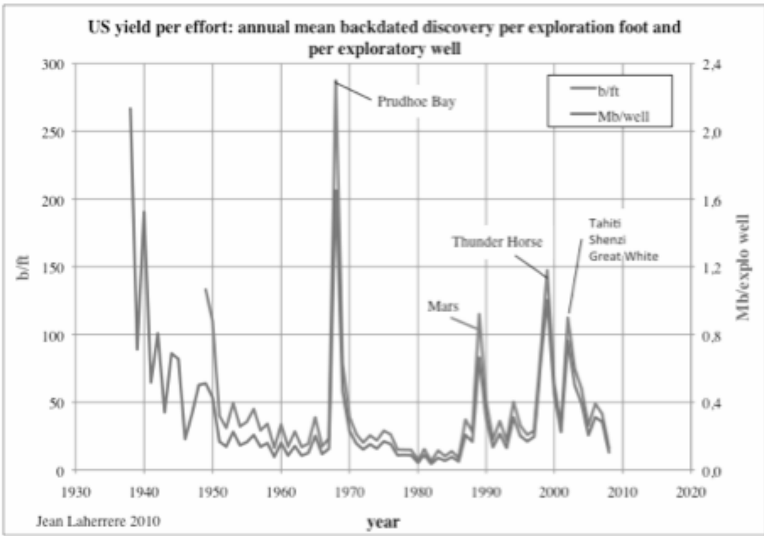

Fig. 17. US annual mean backdated discovery per exploratory foot and per exploratory well

The US yield per effort displays also several cycles difficult to foresee

The data for the USL48 is not available to plot discovery in b/ft, but Alaska discovery is mainly shown with a spike by the Prudhoe Bay discovery of 1968. To compare with Hubbert's plot in figure 15, Prudhoe Bay has to be eliminated. Hubbert did not foresee this starting 1986 offshore success or simply ignored it by deeming it unconventional.

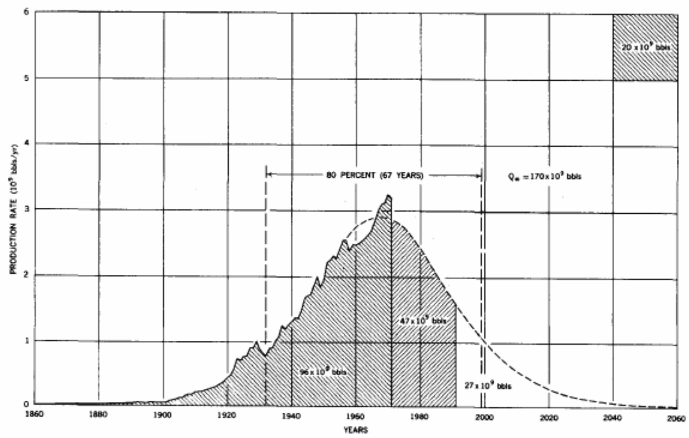

Fig. 26. Estimated complete cycle of crude-oil production from lower-48 states, based upon data to the end of 1971 (Ref. 6, Fig. 51).

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Fig. 18. last Hubbert forecast in 1981 for an USL48 ultimate of 170 Gb

In 1981 Hubbert USL48 ultimate estimate was 170 Gb. It is the last Hubbert graphs on USL48.

After US production peaked in 1970, Hubbert's approach was well recognized, however he kept only one estimate for the USL48 well below 200 Gb (170 Gb in Hubbert's 1981 last paper).

In 1988 Hubbert's interview by Steve Andrews Hubbert read " *In 1978, I got a telephone call from Houston. 'You wrote this report in 1956. How about writing an update report for the API meeting?' I made an oral presentation; I didn't have enough time to submit a paper. I reviewed historically and made a new estimate [for the lower-48 onshore]. My data was 163 BB; the data would allow no exception—it was the best I could do, but I thought it was too low…It will be more than 170, but not a hell of a lot more. It could be 180. I'm going to go back and re-examine the data; I'll try to see if I can find out what went wrong…* "

The last graph from Hubbert was in 1981, using an ultimate of 170 Gb with 96 Gb already produced at end 1971, 47 Gb proved value and 27 Gb (undiscovered or probable).

The US oil peak occurred in 1970 at 3.2 Gb, but the 1956 forecast curve was a peak in 1970 at only 3 Gb (for 200 Gb), when the 1981 forecast was a peak was at 2.8 Gb in 1970 for 170 Gb!

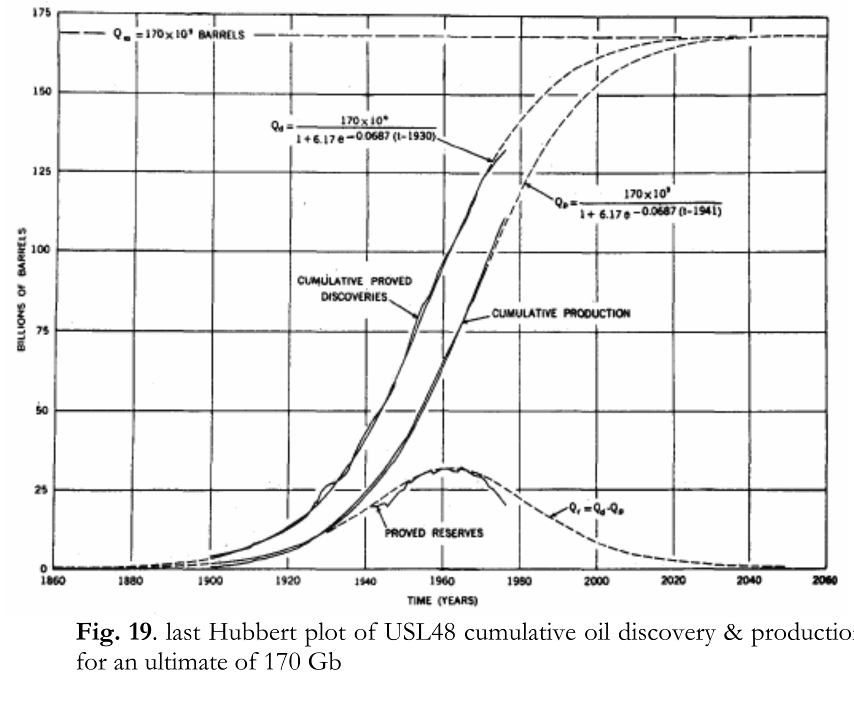

Fig. 19. last Hubbert plot of USL48 cumulative oil discovery & production for an ultimate of 170 Gb

Hubbert was wrongly using proved reserves (because it was the only one available due to SEC rules) despite it being well known that they do not represent the reality, showing discovery peaking in the 1950s when it was in the 1930s!

As shown in figure 5, extrapolation of production data trends towards 230 Gb with recent deepwater discovery and the cumulative oil mean (proven + probable) backdated discovery trends also towards 230 Gb. The mean discovery is completely different from the financial SEC proved remaining reserves (which must be added to cumulative production to get initial reserves). It should be noticed that the so-called proved reserves are close to ten times the annual production, because in Texas this rule of thumb is used to estimate reserves. It is also the way that notaries estimate the value of a building by multiplying the annual rent by ten!

It is strange to see Hubbert believing in 1981 that the USL48 ultimate is 170 Gb when his success of the 1970 peak was based on a 200 Gb ultimate.

In 1981, USDO1/Geological Survey circular 860 " Estimates of undiscovered recoverable conventional resources of oil and gas in the United States " estimated the following:

Gb	produced	remaining	undiscovered		ultimate
US	120.7	54.8	82.6	2	257
USL48	118.9	40.7	63.5		223

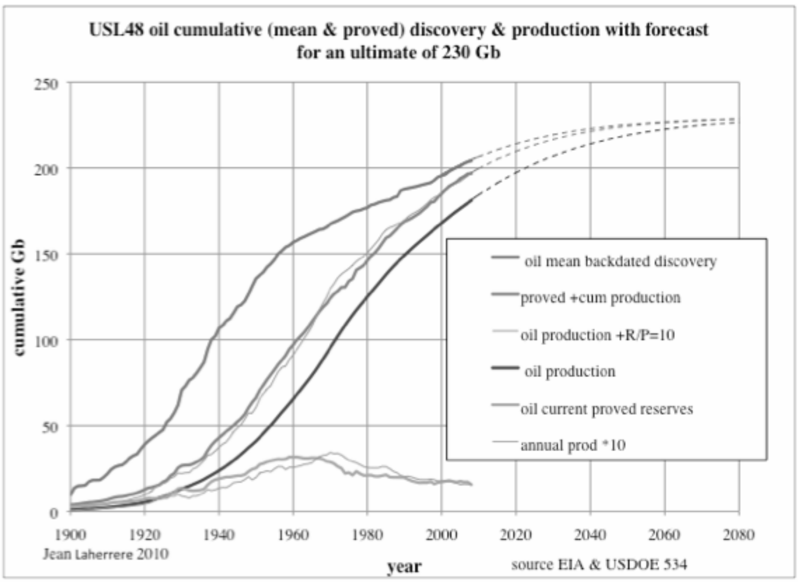

Fig. 20. USL48 cumulative oil discovery & production for an ultimate of 230 Gb

In 1981, USGS was better than Hubbert in USL48 oil ultimate estimate in contrary to 1956 when the USGS ultimate was 590 Gb!

In 1982 Hubbert stated that *the discoveries per foot of exploratory drilling have continuously declined from an initial rate of about 200 barrels per foot to a present rate of only 8 barrels per foot*

Hubbert was too pessimistic about the US offshore potential (over 100 b/ft in 1989 and in 1999 on figure 17), maybe because he was excluding the deepwater!

A good way is to study the range of estimates from several independent studies like Bowden did in 1982 and 1985. The unrealistic estimates of Zapp, at about 600 Gb, were quickly reduced to a more realistic 250 Gb.

My forecast for USL48 is 230 Gb, using the backdated "mean" values (USDOE/EIA-0534 1990 and EIA annual reports) shows that the lag between discovery and production is then about 30 years (only 10 years with Hubbert).The use of proved reserves by Hubbert (only available data because of the SEC rules) has completely disturbed his view on the US ultimate.

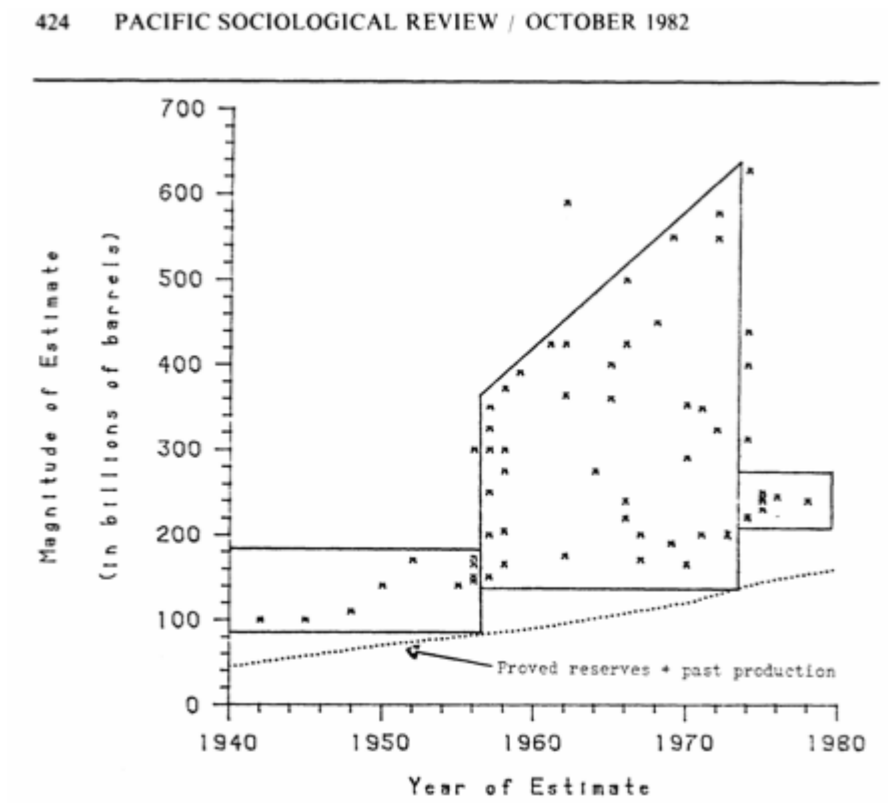

Fig. 21. USL48 ultimate US oil ultimates by Bowden 1985

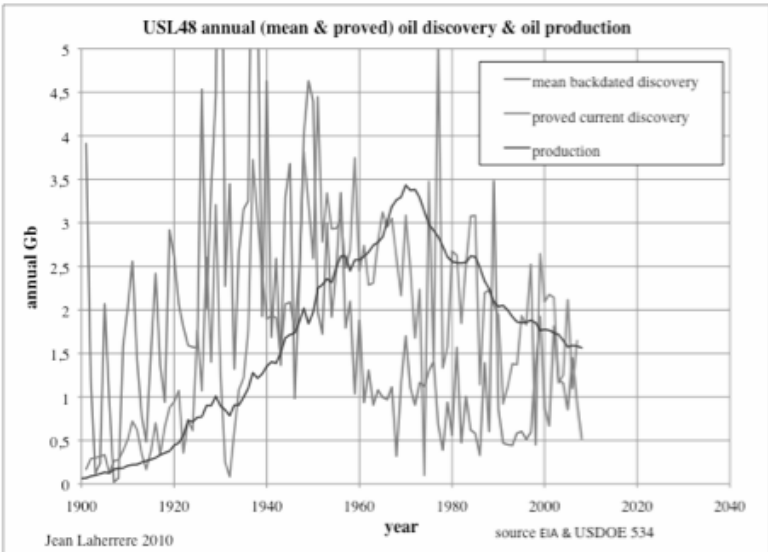

Fig. 22. USL48 annual oil discovery and production 1900-2008

Annual discovery peaks around 1930 using the backdated mean (2P) data and not the financial current proved (1P) reserves.

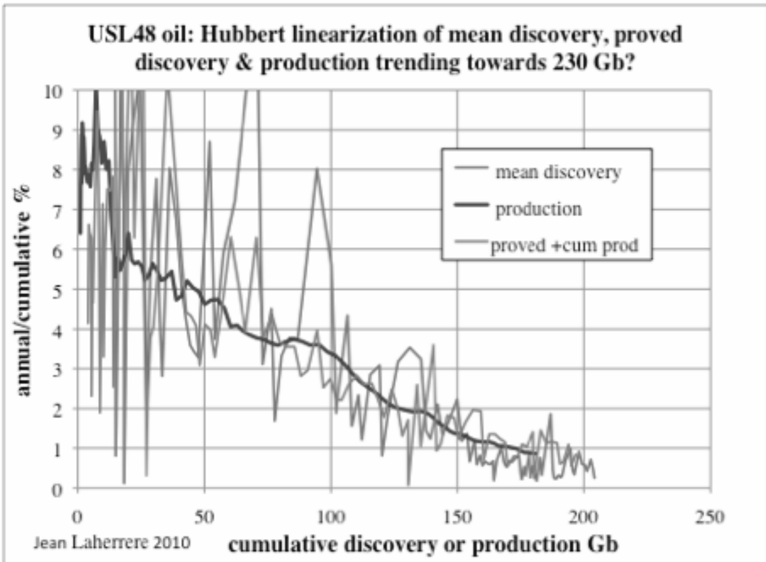

Fig. 23. USL48 oil Hubbert linearization from discovery (2P and 1P) and production 1900-2008

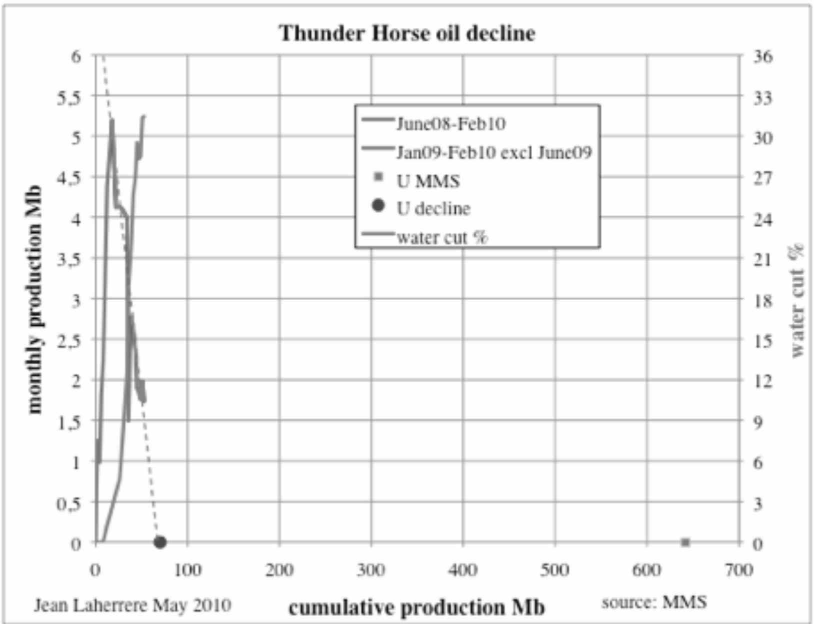

Fig. 24. Thunder Horse (largest? oilfield in the Gulf of Mexico) oil decline

But the mean backdated discovery data could be overestimated for deepwater. The deepwater Thunder Horse field in the Gulf of Mexico discovered in 1999 is reported by MMS as having 650 Mb (800 Mb in my database) but the production (from 4 wells) has peaked in less than one year and the decline for last year is 60%, with the water cut shooting from 4% to 31%. If this decline prevails the reserves are about 70 Mb and not ten times more!

In 1956 Hubbert was only saying that the production curve starts from zero, goes to a peak and ends at zero, the only equation was that the area below the complete production curve represents the ultimate reserves (reserves = recoverable resources) and there may be an infinite number of curves corresponding to this ultimate.

Hubbert's 1956 paper displays several forecasts with unsymmetrical curves, but US crude oil forecast was symmetrical and most people believe that Hubbert curve is symmetrical with the peak at mid-point. There is no reason for symmetry, because individual field production is unsymmetrical: rising quickly to a plateau followed by a slow decline. But adding many unsymmetrical fields production can be grossly symmetrical as explained by R.W. Bentley in 2009.

There is another reason for symmetry, as it is displayed in the USL48 oil production, where there are more than 20 000 companies producing oil and

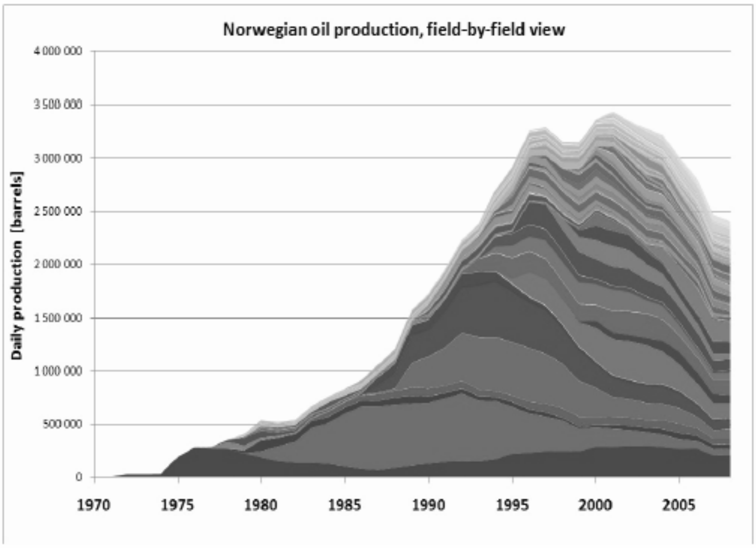

Fig. 25. Norway oil production from Bentley 2009

gas, whereas there are very few or even only one (Aramco) in countries in the rest of the world. With over 20 000 operators, the law of large number occurs because most companies behave independently (Brownian behaviour) and randomness rules (Gaussian law). Except when all operators are pushed to act in the same way: recession in 1930, proration in 1960 and high price in 1980: this is why the USL48 oil production is roughly symmetrical from 1900 to 1990. What is unexplained is why the two shoulders of 1960 and 1980 due to completely different reasons are at the same level of 2.6 Gb/a!

Alaska oil production is unsymmetrical because fewer fields and fewer operators.

All OPEC oil production constrained by quotas and politics is obvious chaotic and unsymmetrical.

But as shown in figure 3, USL48 crude oil production started to be unsymmetrical in 1990 because of the deepwater production with few fields and few operators.

2. Hubbert's other forecasts

2.1 world crude oil forecast

In 1956 Hubbert forecasted the world crude oil production (excluding unconventional) for a peak around 2000 at 13 Gb for an ultimate of 1250 Gb, but in 1981 for a peak around 1995 at 37 Gb for an ultimate of 2000 Gb.

In 1956 in 1981

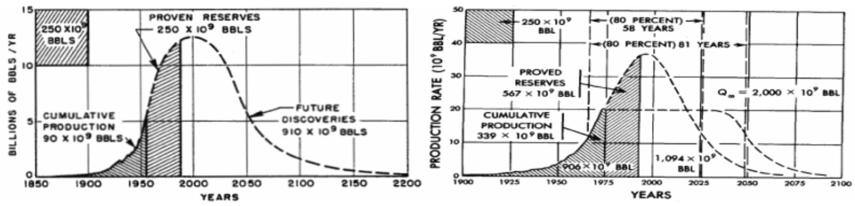

Fig. 26. Hubbert world crude oil forecasts

The ultimate for world crude less extra-heavy oil seems to be about 2100 Gb when in 1956 Hubbert estimated the crude oil ultimate volume at 1250 Gb. His peak forecast was about year 2000, at 13 Gb, when in 2000 the crude oil production was 25 Gb! His forecast for 2050 was 6 Gb for U = 1250 Gb, when it is 9 Gb for U= 2100 Gb on this world crude less extra-heavy (XH) oil forecast! But the oil demand includes in addition to crude oil, natural gas liquids, refinery gains and XTL (X to liquids X being C coal, G gas, B biomass including biofuels, S shale). In order to answer when oil demand will not be met by oil supply, it must include all liquids.

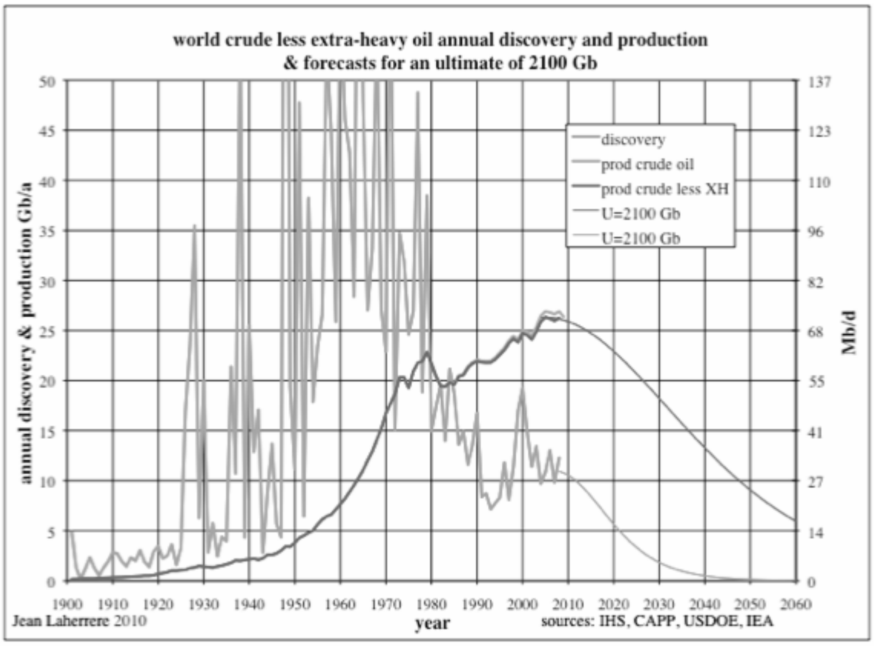

Fig. 27. world crude less extra-heavy oil discovery & production for an ultimate of 2100 Gb

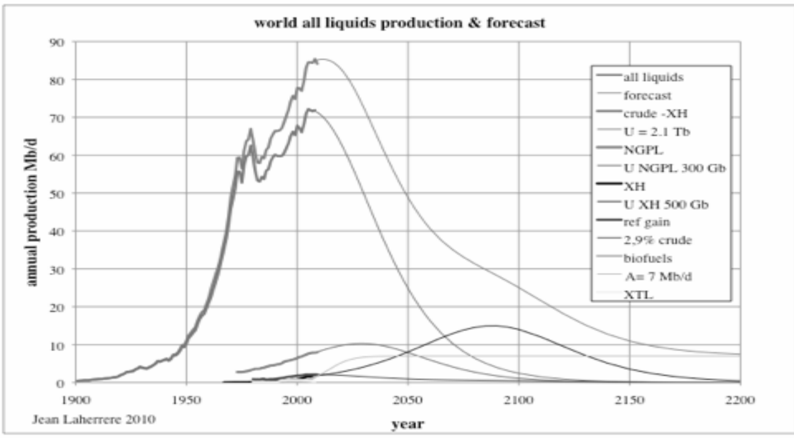

Fig. 28. world all liquids production and forecast for an ultimate of 3 Tb + biofuels asymptote at 7 Mb/d, assuming no above ground constraint

The following model includes crude less XH oil with an ultimate of 2100 Gb, XH with an ultimate of 500 Gb, natural gas plants liquids with an ultimate of 300 Gb, refinery gain being 2.9% of the crude less XH oil production, and biofuels being renewable having an asymptote of 7 Mb/d. The XTL are assumed to be less than the accuracy of the oil supply (actually 2 Mb/d between USDOE/EIA and IEA values).

2.2 Hubbert 1956 US natural gas forecast

Hubbert forecasted USL48 conventional natural gas production peaking around 1970 for an ultimate of 850 Tcf.

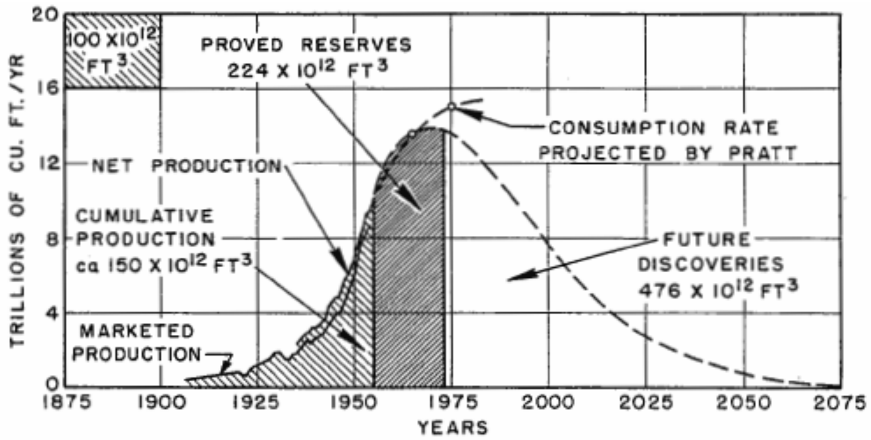

Fig. 29. Hubbert's 1956 forecast for USL48 natural gas production for an ultimate of 850 Tcf

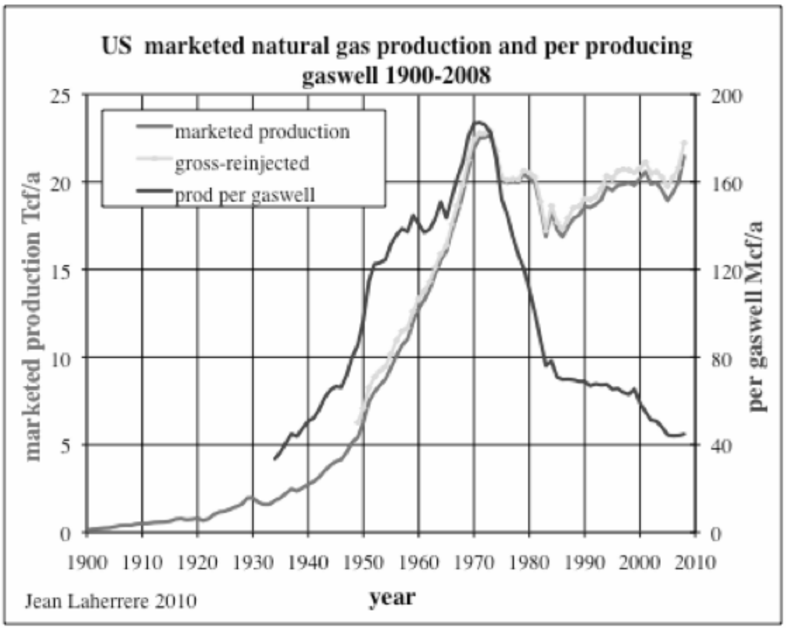

Fig. 30. US marketed annual production and per producing gaswell 1900-2009

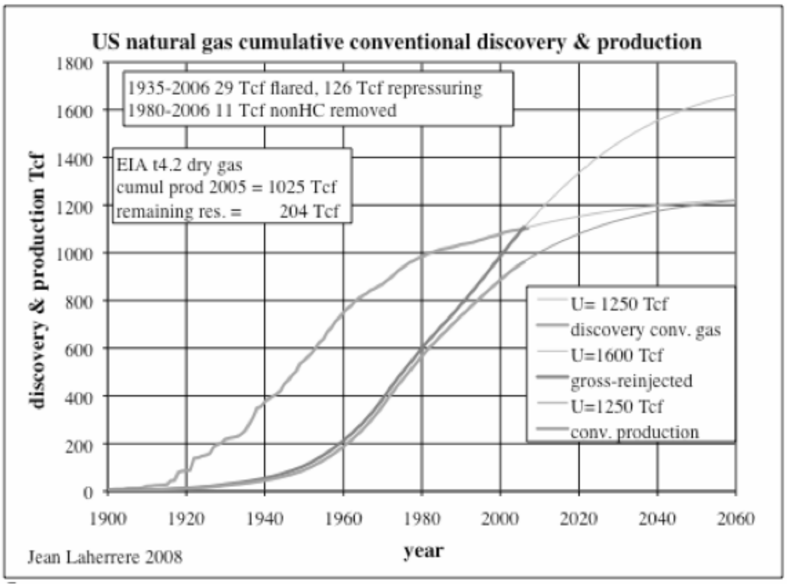

Fig. 31. US natural gas cumulative discovery and production

Hubbert was right about the peak date about 1970, but he was completely wrong on the volume of the peak: it was 23 Tcf instead of 14 Tcf. His forecast for 2000 was 8 Tcf: when in reality it was 20 Tcf!

The large gas reserves in Alaska are still unproduced by lack of gas pipeline.

The US marketed natural gas production did peak around 1970, but its decline is not at all what Hubbert had forecasted, it is the production per producing gaswell, which declined sharply after 1970.

The likely US conventional natural gas ultimate is 1250 Tcf. The large volume of reported gas shale represents resources in the ground and the amount of reserves depends on many factors: price, cost, pollution of shallow aquifers. Historical production data is just a few years and the life of most wells could be between a few years and 50 years as claimed by promoters. The US NG ultimate could be over 1600 Tcf!

2.3 Hubbert world coal forecast

Hubbert' 1956 forecast for an ultimate of 2600 Gt is a peak in 2150 at 6.2 Gt/a.

Hubbert diminished world coal ultimate to 2400 Gt in 1962 and to 2000 Gt in 1981!

Hubbert's forecast for 2008 was 3.3 Gt in 1956, but 4.7 Gt in 1981, when real production is 6,8 Gt!

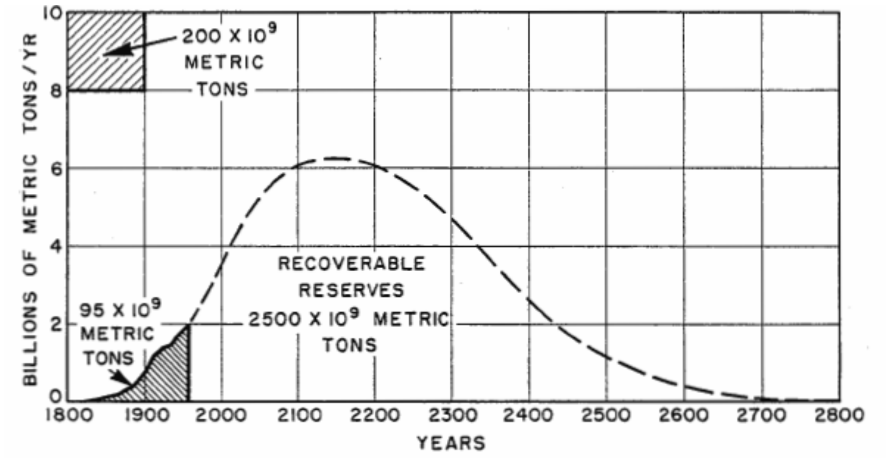

Fig. 32. Hubbert's 1956 world coal production for an ultimate of 2600 Gt

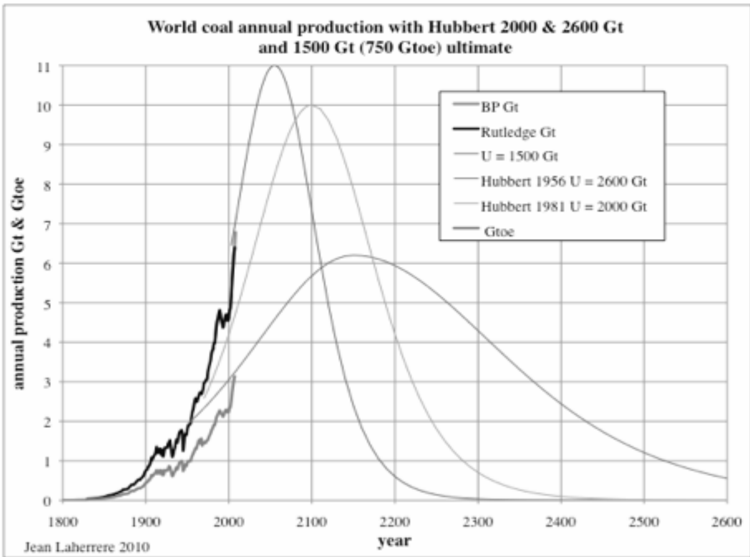

Fig. 33. world coal production for ultimates Hubbert 2600 Gt 1956, 2000 Gt 1981 and mine 1500 Gt

My forecasts for liquids (U= 3 Tb +7 Mb/d biofuels), natural gas (U= 13 Pcf) and coal (U= 750 Gtoe) shows that coal will return in the first place around 2020

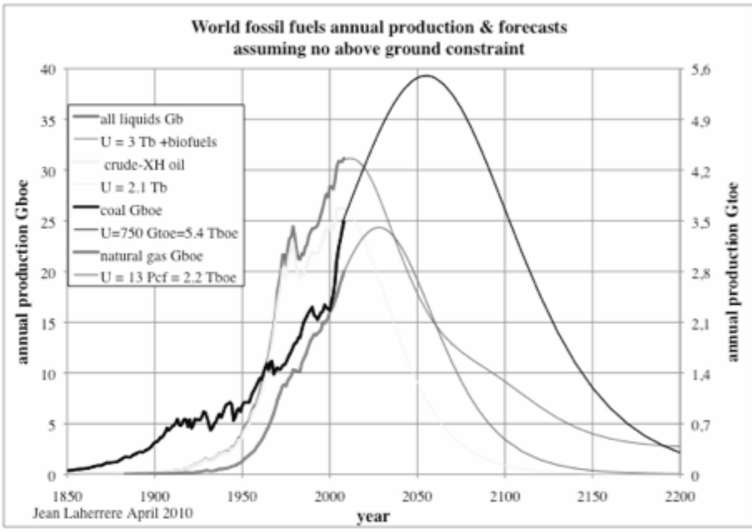

Fig. 34. world fossil fuels annual production & forecasts (assuming no above ground constraint)

2.4 gold, silver & copper peaks

The display of gold production & forecast for an ultimate of 250 kt is compared to oil (liquids) production.

It is amazing to find that gold and oil = black gold are peaking in our present decade, and their decline look parallel, in contrary to their rise where gold started millennia before!

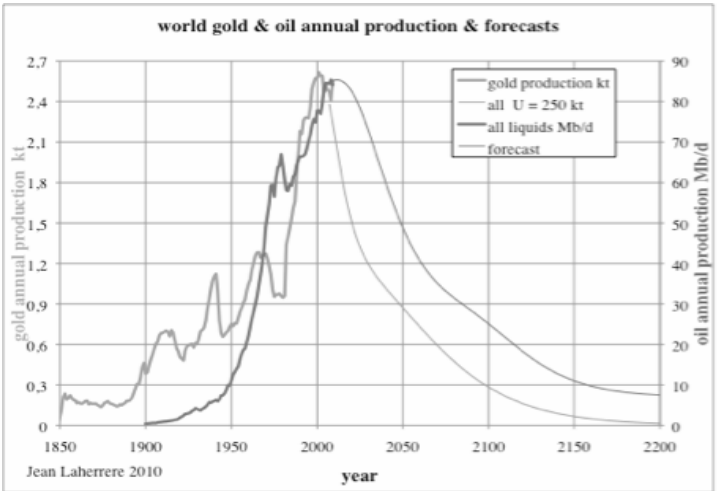

Fig. 35. gold and oil (liquids) production & forecasts 1800-2200

Gold and silver production had similar rise and likely similar decline for the next two decades.

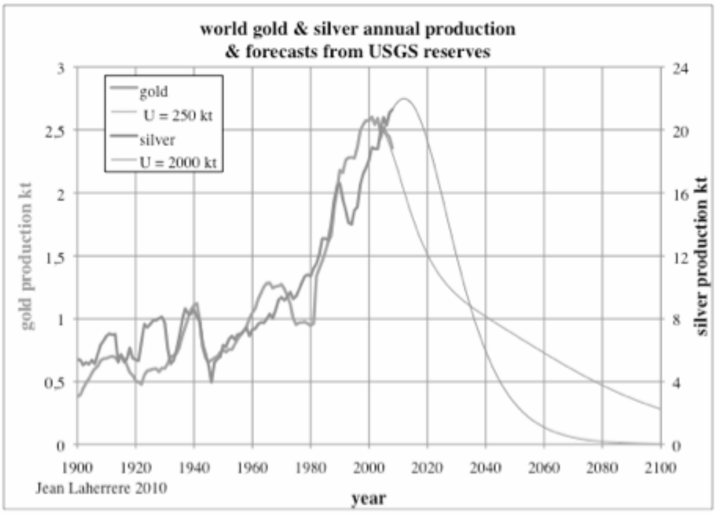

Fig. 36. world gold & silver annual production

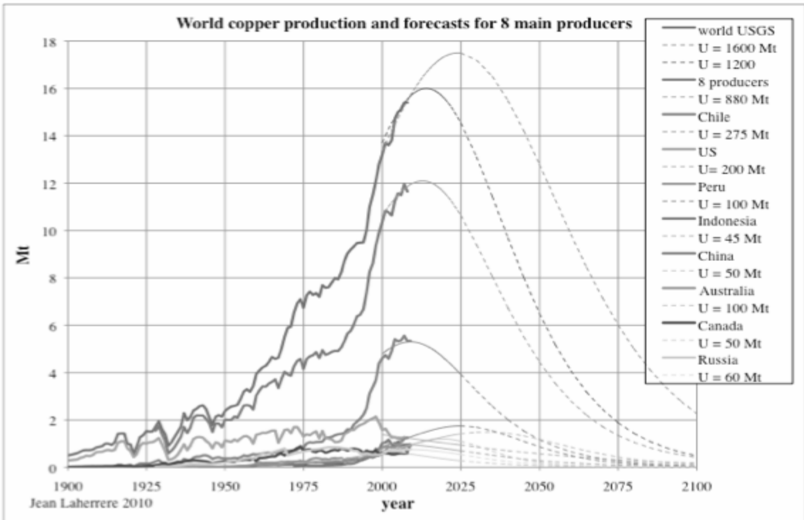

Fig. 37. world copper annual production & forecasts for 8 main producers 1900-2100

The world copper production will peak in the 20s, with Chile being the largest producer peaking in the 2010s

2.5 Population peak

There are very few world population recent forecasts (UN 2008, USCB 2008, IIASA 2007), but a world population peak is forecasted around 2065.

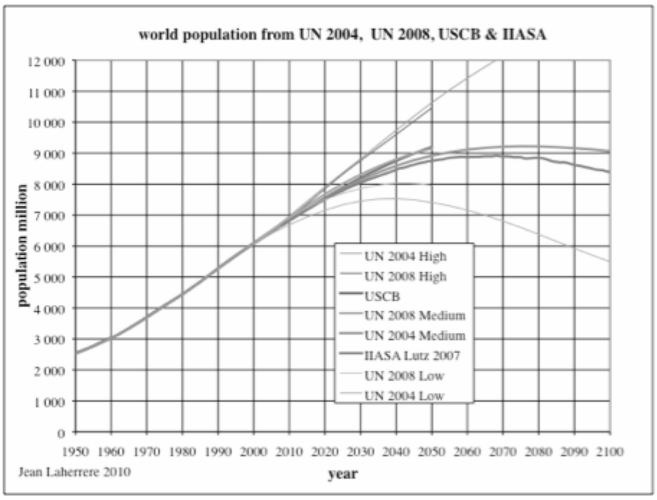

Fig. 38. world population forecasts from UN 2004, UN 2008, USCB & IIASA

2.6 Population and GDP

Politicians are judged on the growth of GDP. But GDP represents expenditures and not wealth of the country. GPD is completely different than the well-being (or happiness) of the people, but there is no world consensus on the definition for well-being!

It is interesting to find that the plot of GDP versus population displays a linear trend for France, which is surprisingly the same slope as the US slope for the period 1980-2008.

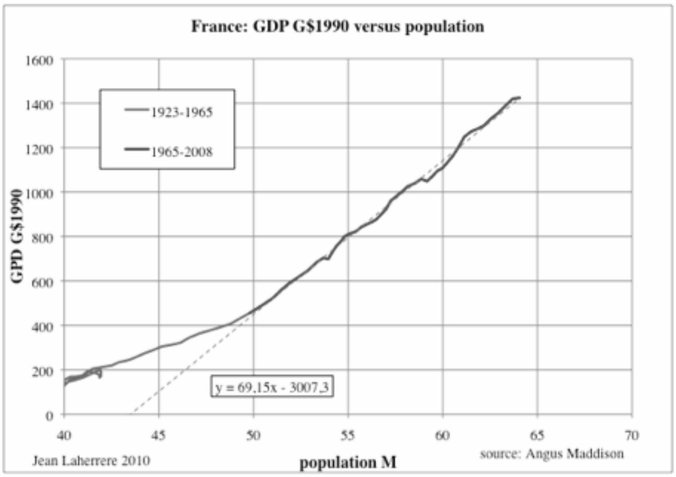

Fig. 39. France GPD versus population

The Portugal plot for the 1991-2008 period gives a close value with France and US

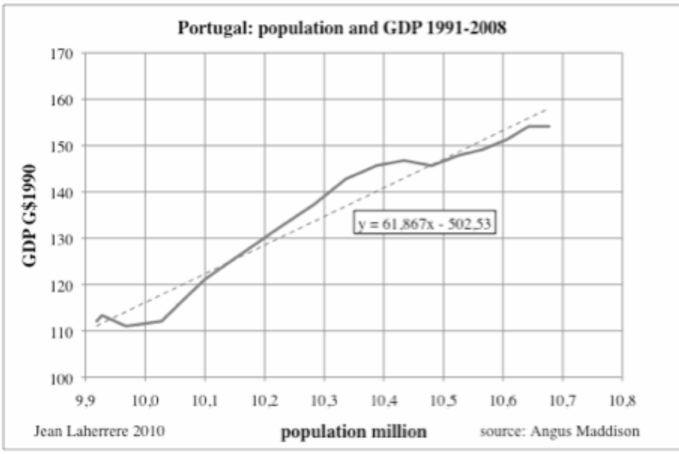

Fig. 40. Portugal GPD versus population

The comparison of the last linear trend of GDP increase per capita in k$2008 is as follows

Country	linear period	k$2008/capita
India	1992-2008	11
Brazil	1965-2008	12
Argentina	1952-1980, 2008	24
World	1995-2008	27
Chile	1985-2008	53
Portugal	1993-2008	95
Australia	1990-2008	95
France	1965-2008	104
US	1980-2008	104
China	2000-2008	114
Canada	1992-2008	117
Holland	1982-2008	131
Switzerland	1995-2008	132
Germany	1990-2005	158
Denmark	1985-2008	174
Norway	1970-2008	189
UK	1970-2008	231
Belgium	1969-2008	261
Italy	1977-2008	351
Greece	1995-2008	392
Spain	1993-2008	569

The last ones in the list, that is Spain, Greece and Italy, have displayed a strong GDP increase with population but also a strong debt. Portugal is not in the same boat.

2.7 The peak peak

During the period 2000-2020 period, many peaks will occur: gold peak, oil peak, silver peak, and Europe population peak.

It is also another peak that I feel: ASPO Peak.

At each ASPO meeting in the past I asked Colin: *when is ASPO peak*?

The goal of ASPO was to inform the world about the oil peak: it is done!

ASPO was mainly a bunch of geoscientists and the following picture shows most of them:

ASPO meeting 2003 May 28, Paris, France

ASPO Barcelona was the last meeting where most were present and it was the beginning of decline.

Looking at the past ASPO meetings, I feel that the peak was Lisbon 2005 and its success is due to Rui.

The end of Colin's newsletters also indicate that the peak is passed

Without Colin, ASPO is not anymore ASPO!

But peak is not the end of the world, just a change of way of life

We need to change our way of life of our consumption society.

Rui good luck in your retirement, you're welcome to join the club of many who have passed peak!

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Renewable Energies in the Iberian Peninsula. Future Scenarios.

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Abstract
The current energy system is regarded as unsustainable from environmental, technical and social-economic points of view. Besides, the Iberian Peninsula has a strong dependence on foreign energy supply, provided that more than 80% of the consumed primary energy comes from imported fossil fuels, which by far exceeds the 50% average value reported for the rest of the European Union. Important efforts are thus being undertaken in our countries in order to promote the gradual use of renewable energy sources.

The present manuscript is devoted to highlight the current status and the future development of those energy sources in the Iberian Peninsula, as well as to point out the challenges and barriers to be overcome in order to achieve targeted objectives. A brief description of the joint activities carried out in the ambit of Project *PETER* (Spanish acronym for *Transborder Experimental Park on Renewable Energies*) is given as an example of cooperation between Spain and Portugal. In addition, information about the projected *Iberian Centre for Renewable Energies and Energy Efficiency* (*CIEREE*), to be located in Badajoz, is also presented.

1. Introduction

The current world energy system is regarded as unsustainable from environmental, technical and social-economic points of view. In particular, environmental unsustainability lies in the fact that electricity generation technologies require the construction of large buildings and facilities, which generate a great visual impact, acoustic contamination, temperature rise in areas surrounding cooling equipments, etc. Thermal electric plants are also a source of environmental pollution, with high rates of greenhouse effect emissions like CO_2, water vapor, nitrogen and sulfur oxides, solid particle clouds, etc. As a direct consequence, global warming and acid precipitation are favored. 60% of central European forests are believed to be affected by those phenomena (Boyle, 1996). Moreover, residual radioactivity from nuclear power station wastes need to be stored for thousands of years, and rigorous nuclear surveillance protocols are needed to avoid eventual radiological release to the environment.

Sustainability is also a crucial issue. Diverse authors in the scientific literature predict a complete depletion of technically available crude oil resources in the following 60 or 100 years, according to current extraction rates. Predictions concerning gas resources decrease to 40 or 60 years. On the other hand, availability of coal seems to be guaranteed for up to 200 years before extraction becomes unprofitable.

Social economic conflicts mainly arise from the fact that fossil fuel resources are located in a few countries, most of which are unfortunately regarded as politically unstable. Besides, high energy needs are necessary to long-distance transport of the electricity produced in large power plants. Moreover, the centralization of electricity production makes the energy system too vulnerable due to eventual energy supply interruptions (accidents, terrorist threat, natural disasters, etc.)

The current energy system is also unsustainable regarding pure technological aspects. A detailed analysis of all the energy inputs, including raw material extraction (coal or crude oil, with increasing associated energy costs), raw material transformation, distribution to consumption points and final combustion for electricity or mechanic power production, leads to a value for the global efficiency of the energy system below 3%.

The global energy industry is basically supplied by fossil fuel resources. In particular, more than 80% of the energy consumed in our countries (Spain and Portugal) is reported to come from such kind of energy source. As aforementioned, fossil fuels are limited and their extinction –which should indeed be regarded as the extinction of "cheap" energy– is relatively close.

This problem is further aggravated by the strong increase of energy demand currently observed, which is moreover expected to rise over the forthcoming decades. Around 60% of that demand is associated to developing countries, mainly from Asia, which will positively lead to a strongly unbalanced energy consumption distribution.

In order to mitigate this problem scenario, the use of renewable energies is strongly promoted by governments in the European Union. In fact, the *White Paper* published in late 1997 (*White Paper, 1997. Energy for the Future: Renewable Sources of Energy. COM (97) 599*) lists specific actions to be undertaken by each of the member states in order to rise the percentage of renewable primary energy consumption up to 12% by late 2010. This target goal, however, has been recently extended to a value of 20% by late 2020.

The specific objectives to be achieved by the European Union policies are the following:

- Reduce the dependence on foreign energy supply, as well as the use of relatively simple "fast" implementation technologies.
- Increase security standards for power supply activities, given that energetic resources are distributed worldwide and appear as inexhaustible energy sources.
- Ensure environment protection.
- Diversify the primary energy sources.
- Promote employment.
- Increase cooperation with developing countries (particularly Spain and Portugal with Latin American countries).

The present chapter is devoted to the analysis of the current scenario and future prospects for renewable energy sources in Spain and Portugal. Two specific projects (Project *PETER* and construction of *CIEREE*, acronyms for the *Transborder Experimental Park on Renewable Energies* and for the *Iberian Centre for Renewable Energies and Energy Efficiency*, respectively) are described in order to highlight: *(i)* cooperation between Portuguese Alentejo and Spanish Extremadura regions; *(ii)* close collaboration between the University of Évora (Portugal) and the University of Extremadura (Spain) regarding both research and teaching (graduate and undergraduate) aspects. This is far from incidental, but is a consequence of vigorous attempts by people like Prof. Dr. Rui Rosa, from the University of Évora, who once bet on focusing efforts towards the Spanish border known as "the line" (close to the location of the University of Extremadura).

2. Renewable Energies in Europe

The global energy production in 2006 was led by the United States and followed by China, Russia and Saudi Arabia, in this order. In the particular case of Europe, primary energy production in the same year was led by Norway, United Kingdom, Germany and France. However, Germany and France are reported to have the highest energy consumption rates, followed by United Kingdom and Italy (see for instance www.eia.doe.gov). The following paragraphs show a brief status on each of the particular energetic sectors involved.

Wind Power

In 2008, wind energy production in Europe reached 53.6% of global wind energy production. From then on, the United States became world's first producer of this type of energy, instead of Germany (www.eurobserv-er.org).

Within the European Union, wind power sector is ranked as second amongst all renewable energy sectors, preceded by hydropower. Regarding offshore wind farms, Denmark was overtaken by United Kingdom in 2008 in terms of installed wind power (European Wind Energy Association. (www.ewea.org)).

Photovoltaic Solar Energy

A 159% increase was observed for the installed power in the ambit of solar energy from 2007 to 2008, which means a change from 1831.1 MWp up to the extremely high value of 4747 MWp. Part of such expansion of the solar market was due to the contribution of certain countries like Spain, Germany, Italy, France and Belgium.

Thermal Solar Energy

The European market regarding this energetic sector showed an increase of 51.5% from 2007 to 2008, exceeding an effective installed surface of 4.5 million square meters (3 172 MWth). This market is held by small private housing facilities, although the crisis in the building sector is significantly reducing the installation of thermal solar collectors (www.eurobserv-er.org).

Mini-hydropower

This sector includes all hydropower plants with outputs below 10 MW, which generated in 2008 a total of 43.5 TWh in Europe (9.2% over the preceding year production). Such an increase was due to favorable climate conditions along the year, with rainfall records exceeding the annual average. This way, energy production was significantly favored, although the installed power in that concrete year showed a slight increase of merely 1.6% over that of 2007 (www.eurobserv-er.org).

Geothermal Power

Two different types of energy use ought to be considered for geothermal power: electricity and heat generation.

The European production of electricity from geothermal power amounted to 5 809 GWh in 2008. Forecasts for late 2010 are not too encouraging, however. The installed geothermic power is expected to rise to 933.6 MWe in Europe, thanks to the construction of several plants located in Italy, Germany and some other member states.

On the other hand, eighteen European Union countries have developed technical facilities for heat production from geothermal power. The main producing countries are reported to be Hungry, France and Italy. The total installed power reaches 2 560 MWth in Europe, although such value is expected to approach 2 700 MWth by late 2010 (www.eurobserv-er.org).

Biogas Energy

Primary energy production from biogas in 2008 reached 7.5 million toe in Europe, which makes a 4.4% increase over 2007. Almost 50% of such production was obtained from agricultural waste, whereas municipal waste represented 13.2% of the total. The main biogas producing countries are Germany and United Kingdom, which cover 70% of European primary energy production from biogas and 68.3% of electricity production (www.eurobserv-er.org). However, current growth of this energy source is not sufficient to meet the goals projected in the *White Paper*.

Biofuels Energy

The biofuels market seems to have stagnated in Europe after the boom observed between 2005 and 2007. The growth in consumption of these biologic fuels dropped to 30% in 2008, while percentages of annual increase used to reach 70% for the preceding years. Consumption of biofuels by European vehicles in relation with other types of fuel was reported to be 3.4% in 2008. This represents a 0.8% increase over 2007. Among the different types of biofuels, biodiesel and bioethanol consumption increased by 35.8% and by almost 55% during 2007-2008, respectively. No other type of biofuel achieved growth in consumption. However, biodiesel is currently the most widely used biofuel and represents up to 78% of biofuels European demand (www.eurobserv-er.org).

European goals regarding biofuels consumption will be fulfilled by member states like France and Germany, but not by many other countries that will be forced to import raw materials (mainly cereals and oilseeds) to meet the collective goals.

Solid Biomass Energy

This type of energy resource became a safe alternative in 2008. Production of primary energy from solid biomass is reported for all member states in the European Union. The main European producing countries are France, Sweden, Germany, Finland and Poland, which generate 56.1% of primary energy production from biomass in the whole continent. The following types of solid biomass were used in European energy plants during 2008: 77.8% wood and related wastes, 15.4% black liquor from paper processing plants and 6.8% animal organic wastes (www.eurobserv-er.org).

Across the EU, the total production in biomass electricity rose up to 58.7 TWh along 2008, more than one half of which was generated in Germany, Sweden and Finland. Despite this, it must be noted that the percentage of biomass specifically devoted to electricity production in Europe approaches 27% of total amount of biomass for energy purposes. The remaining 73% is used for heat production (Cuadros, F. et al., 2010).

Thermoelectric Power (Thermal Solar)

Although the global production of this type of energy is still seen as poor, it is regarded to potentially achieve high rates of use. This way, many companies are focusing their efforts on strongly promoting this technology. In fact, up to 11% of global electric power demand is expected to be obtained from thermal solar energy by 2050 (Eurostat, European Commission http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Main_Page)

Countries like Portugal, which is the main manufacturer of parabolic mirrors in the world, are precursors to this development. Furthermore, a group of German, Argentinean, Swiss and Spanish companies have joined into a consortium in order to promote a macro-project to be carried out in the desert, which will generate up to 15% of electric power to Europe and North African countries. This project will provide up to 100 GW, and would raise the ratio of primary energy consumed in Europe obtained from renewable energy sources up to 20% (www.worldenergy.org).

Tidal Power

There are five major groups within the oceanic or marine types of power sources: tidal, ocean waves, ocean currents, osmotic pressure and thermal gradients in deep waters. Together the five of them might reach up to 120 000 TWh electricity production. The most developed out of those so far, and therefore the most relevant, is tidal power. France has the world's largest tidal power plant with 240 MW installed power, which represents 90% of that of the entire world. Viability studies are currently being held by United Kingdom to evaluate future installation of this type of energy plants along its seashore, and some plants are already under construction in South Korea with a total installed power of 254 MW. The World Energy Council estimates that Europe's electricity production from tidal power might reach between 15 and 35 TWh, from an installed capacity of 10 GW.

Osmotic pressure plants are poorly developed and suitable locations are scarce due to both fresh and salad water needs. Regarding this, Norway is a pioneering country with 2 to 4 kW prototype plants aimed at future large-scale installations by 2015.

Conversion techniques in ocean thermal currents are more suitable at tropical latitudes, and France is one of the countries with highest investment in that field. With regard to wave power, a few pre-industrial stage projects are reported to be developed in some European member states like Portugal, but this technology is not expected to definitively take off and join the energy market in the forthcoming years. The same applies to the energy use of thermal gradients between surface and deep ocean waters.

Renewable Energy Goals by 2010

The European Directive on renewable electricity requires member states to generate 21% of total electric energy consumption from renewable sources. This is consistent with the particular potential of each country, taking as reference the production reported for 1997. This target objective ought to be fulfilled by 2010. Germany and Hungry are the only states expected to meet such goal (see Table 1).

The new Directive 2009/28/EC estates, as two more ambitious and clear objectives, to raise the ratios of primary energy from renewable sources and of electricity generation from renewable sources up to 20% and 40% respectively.

Table 1. Electric power consumption (%) in 2008 and forecast for 2010 in the ambit of the European.

Share of renewable energies in gross electricity consumption in the EU countries for 2008 and 2010 (%)					
	2008	Goal 2010		2008	Goal 2010
Austria	62.30	78.10	**Holland**	7.80	9.00
Sweden	53.90	60.00	**Bulgaria**	6.80	11.00
Latvia	45.70	49.30	**Greece**	6.30	20.10
Finland	29.40	31.50	**United Kingdom**	5.40	10.00
Romania	28.10	33.00	**Hungry**	5.30	3.60
Slovenia	27.60	33.60	**Czech Republic**	5.10	8.00
Denmark	23.30	29.00	**Belgium**	4.70	6.00
Portugal	26.20	39.00	**Lithuania**	4.60	7.00
Spain	20.20	29.40	**Poland**	4.10	7.50
Italy	16.00	25.00	**Luxemburg**	3.30	5.70
France	15.70	21.00	**Estonia**	1.90	5.10
Slovakia	15.50	31.00	**Cyprus**	0.10	6.00
Germany	14.50	12.50	**Malta**	0.00	5.00
Ireland	11.60	13.20			
TOTAL EU	2008 **16.40**				Goal 2010 **21.00**

3. Renewable Energies in Spain

Energy dependence of the European Union on foreign countries has been progressively increasing up to a final ratio of 56% (85% for the particular case of Spain). At nation scale, crude oil consumption exceeds 50% of total energy consumption, while natural gas and coal approach 15% and 18%, featured by notable increasing and decreasing trends, respectively. At present, the annual expenditure involved in energy import approaches 20 000 million euro in our country.

As aforementioned, achieving a 20% ratio for primary energy from renewable sources in the European Union by 2020 was approved as a target objective by the Brussels European Council. However, specific commitments were required for each member state according to particular values of gross domestic product *per capita*. This way, Spain should raise the current share of renewable sources from 8.9% reported in 2008 up to 19.5% by 2020. In addition, the regulation of specific markets for renewable certificates, by which those member states failing to meet the targets should purchase renewable certificates as delay compensation, is planned by Spanish administrations (*White Paper, 1997. Energy for the Future: Renewable Sources of Energy. COM (97) 599)*.

Spain is seen to succeed in the accomplishment of the targets set for 2020 through expected participations of 22.7% and 42.3% for consumption of primary energy from renewable sources and for electric power generation from renewable sources, respectively. This surplus might be transferred to member states failing to meet the goal, within the ambit of flexibility mechanisms stated by the Directive for renewable energies. Doing so would save 2.7 million equivalent tons of crude oil. The projected itineraries to meet those target goals are focused on achieving 15.5% and 18.8% for the share of renewables in energy consumption by 2012 and 2016, respectively.

Specific contributions of the different types of renewable energies to meet target goal are listed below.

Table 2. Forecast on installed power from renewable sources in Spain by 2020.

FORECAST ON INSTALLED POWER FROM RENEWABLE SOURCES IN SPAIN BY 2020	
Renewable sources	**Installed power**
Photovoltaic and Thermoelectric (MW)	10 000
Thermal Solar and Geothermal (MWth)	10 000
Inshore and Offshore Wind Power (MW)	50 000
Mini-hydropower (MW)	4 000
Biomass (MW)	10 000
Ocean (MW)	500
Mini-wind power (MW)	500
Biofuels (total % of fuel)	15

Table 3. Primary energy production from renewable technologies in Spain during 2008.

ENERGY PRODUCTION FROM RENEWABLE TECHNOLOGIES (Spain 2008)	Power (MW)	Production in terms of primary energy (ktoe)
Electric power production		
Hydraulic	18 451	3 176
Biomass	374	740
USW	189	395
Wind Power	16 546	3 415
Solar Photovoltaic	3 270	422
Biogas	149	282
Solar Thermoelectric	61	14
TOTAL ELECTRIC	39 041	8 444
Thermal use		
Biomass		3 470
Biogas		26
Solar Thermal		129
Geothermal		8
TOTAL THERMAL		3 634
Transport		
Biofuels		601
TOTAL RENEWABLE ENERGIES		12 679
PRIMARY ENERGY CONSUMPTION		142 075
Renewable Energy/Primary Energy (%)		8.9

In order to achieve those objectives, Spanish administrations are willing to attend joint projects with other member states, and have called for improvement of technical facilities relating connection with the European electric distribution network.

The starting point is shown in Table 3, which lists the primary energy power generated from each of the aforementioned renewable technologies in Spain during 2008.

Forecasts for 2020 were made according to the following scenarios:

(i) Economic scenario. A gross domestic product growth of 1.8% is expected for 2011, with subsequent 2.7% annual increments until 2020.

(ii) Population scenario. A lower population increase than that of the last decade –due to heavy immigration– is expected for the forthcoming years. In particular, Spanish population is forecasted to increase from 46 million inhabitants in 2009 to 47 million by 2020.

(iii) Energy efficiency scenario. Energy and electric intensities are expected to achieve 2% and 0.6% annual reductions, respectively.

Forecasts for Spain show favorable progress towards the target goals set by the Renewable Energies Plan 2005-2010 (Institute for Energy Diversification and Save *IDAE* (www.idae.es)).

Renewable energy sources accounted for 7% of primary energy consumption in Spain in 2007, and generated 19.8% of electric power compared with 17.7% from nuclear power stations. Moreover, the primary energy consumption from renewable sources was reported to exceed for the first time ever the barrier of 10 Mtoe during that year.

The fact that Spain is currently experiencing a financial crisis makes the distribution of the activities regarding renewable energy business a quite encouraging occupational support. Most companies focus on three main activity axes: Solar Photovoltaic (57.6%), Solar Thermal (43.4%) and Wind (35.3%). Table 4 illustrates the distribution of total direct employment in the ambit of renewable energy business for 2007 in Spain.

Table 4. Current employment rates in Spain regarding different types of renewable energy sectors.

Spanish Employment Status regarding Renewable Energy Sectors		
Renewable Sources	Number of employees in sector	Percentage
Wind	32 906	36.97
Mini-hydraulic	6 661	7.58
Solar Thermal	8 174	9.28
Solar Thermoelectric	968	1.08
Solar Photovoltaic	26 449	29.90
Biomass	4 948	5.65
Biofuels	2 419	2.17
Biogas	2 982	3.45
Other	3 494	3.92
Total	**89 001**	**100.00**

An analysis of the specific activities held in Spanish in the ambit of the renewable sector shows that companies are devoted to the installation of specialized equipment (52.4%), to maintenance operations (21.6%), marketing of specific technologies (14.7%) and energy production (13%).

The concrete status of each type of renewable source in Spain is next reviewed.

Wind Power

Spain was regarded as second main European Union member state producer of wind power in 2008, right after Germany. Increase in installed wind power reported for that year was lower than that of 2007, as a consequence of the reduction of wind power production subsidies issued by Royal Decree 667/2007.

Photovoltaic Solar Energy

The Spanish market for photovoltaic industry reached 3 404.8 MWp installed power in March 2008, which made 2 670.8 MWp over the value corresponding to late 2007. Such an explosion was favored by Royal Decree 1578/2008, by which bonuses on photovoltaic kWh generated after September 2008 were reduced. This way, many projects were developed in advance in order to take advantage of more beneficial legislation. As a consequence, 31 000 new jobs were created in the photovoltaic sector, in contrast to 17 000 jobs during the preceding year.

Thermal Solar Energy

The Spanish thermal solar market was reported to achieve a 69.5% increase in 2008, with respect to the preceding year, which corresponds to the installation of 466 000 m² solar collector effective surface, as stated by the Solar Association for Thermal Industry (*ASIT* (www.asit-solar.com)). This growth is mainly justified by the new Technical Building Code, by which any new construction or restoration building must supply between 30% and 70% of heat and domestic hot water demands from thermal solar collectors. Nevertheless, the installation of 5 million m² solar collector surface nationwide (established as a target goal for the period 2005-2010 by the Spanish Renewable Energy Plan) will not be fulfilled. Only 1 463 036 m² were reported for late 2008. In addition, the solar thermal industry is unavoidably expected to lose relevance during 2009-2010 due to the major crisis faced by the building sector.

Mini-hydropower

The installed mini-hydraulic power for the period 2005-2010 in Spain is expected to increase 450 MW, from 1 749 MW in 2004 up to 2 199 MW by late 2010 (Institute for Energy Diversification and Save *IDAE* (www.idae.es)).

Geothermal Power

Despite its great potential use regarding thermal applications for electricity production at both domestic and industrial scales, this type of technology is not so relevant in Spain (International Energy Agency (www.iea.org)).

The development of the geothermal industry was interrupted after more than 25 years of continuous research in this field. The reason for this did not lie in factors related with technical considerations on subsoil, but in the poor planning and project management protocols, probable due to a lack of specific knowledge of the source and of inadequate business and financial approaches. No heat or electricity production plants from geothermal sources are currently reported in Spain. Although there are some companies focusing their interest on this sector, a detailed previous analysis on quantification and evaluation of such source in the country is required.

The government should also promote policies for R+D+i in the ambit of this sector by establishing regulations urging the use of this renewable source and, simultaneously, by specific economic incentives for companies and users.

The development of the geothermal industry is strongly hindered by the fact that an initial investment in research to evaluate the energy potential at a particular location is required, which makes itself a considerable risk factor. In addition, such energy potential is outdated in the particular case of Spain, provided that R+D activities have not followed a well-planned and continuous program for the last 15 years. One of the advantages of geothermal energy is that the production and maintenance costs per MWh are regarded among the lowest in the ambit of renewable energy industries.

Biofuels Energy

According to *IDAE*, around 520 ktoe biodiesel and 125 ktoe bioethanol were consumed in 2008 in Spain, which corresponds to a 65.6% increment over the preceding year. This represented 2% of total energy consumption for transport activities. This way, Spain will fulfil the target goal regarding incorporation of biofuels, set at minimum 3.4% by end of 2010. Spanish regulations for incentives to biofuels consume are very favorable, provided that such type of fuel is exempt from hydrocarbon taxes until the end of 2012.

4. Renewable Energies in Portugal

The European Union Directive 2009/28/CE sets the achievement of 20% of primary energy from renewable sources by 2020 as a target goal for all member states. This requires Portugal to produce 31% of total primary energy from renewable sources and reach 10% biofuels ratio for transport activities. This condition imposed by the European Union to Portugal is one of the most restrictive, only exceeded by those assigned by Swedish, Latvian, Austrian and Finnish regulations.

Electricity consumption in Portugal have shown a 66% increase in the last years, reaching 17 500 ktoe. It has shown a steady trend –and has even declined- from 2004 until today. Still, the target goals imposed by Portuguese regulations are expected to be fulfilled due to high rainfall regime reported for the last years and to the downward trend of electricity consumption in the country. A deep review of the energy target goals was carried out by the Portuguese government in early 2007. As a consequence, the objective set for 2010 regarding electricity consumption from renewable sources increased from 39% to 45%. In addition, the requirement relating the use of biofuels in transport activities was also raised from 5.75% up to 10% by 2010. The rates achieved for 2010 should be increased by 15% in order to meet the target goal set for 2020, which seems not to be a too difficult task. Table 5 lists the target goals set by Portuguese regulations for 2010 and 2020. Data regarding installed power for 2008 are included as reference.

Table 5. Renewable energies target goals in Portugal for 2010 and 2020.

Priorities of Portuguese Government in the ambit of renewable energies			
	Installed Power 2008 (MW)	Target goals (MW)	
		2010	2020
Hydropower	4 806	5 575	7 000
Wind	2 526	5 100 by 2012 + 600 with technical improvements	
Solar	21.4	150	
Tidal	0		250
Biogas	12.4	100	

Portuguese regulations state a set of priorities aimed at meeting the objectives imposed by the European Union. With regard to this, the electric power of Alqueva great dam is projected to be raised up to its maximum 520 MW. More investment on specific technologies, devoted to achieve an efficiency increase in energy production from renewable sources, is also projected. Another relevant project was the construction of a 46 MWp photovoltaic plant in Moura. The mandatory integration of thermal solar energy in new constructions, as well as the establishment of new incentives to promote the use of renewable technologies, will favor penetration in the Portuguese energy market (www.innovationobservatory.com).

The main strategies to support growth and expansion of renewable energy technologies are those referred to in the current legislation. Some of the most relevant are the following:

- Fixed bonus per kWh transferred to the electrical network, if obtained from renewable sources or by cogeneration process.
- Tendering procedures open to national and international markets for concessions relating electricity networking.
- Subsidies quantified as 40% over initial cost of the projects. Program *MAPE* (*Support Program for Maximizing of Energy Potential and Consumption Rationalization*), is mainly devoted to renewable energy technologies. Financial aid, as well as low-interest loans aimed at promoting renewable energy projects, is thus guaranteed.
- The introduction of incentives for particular goods and services regarding renewable energies. In this sense, new incentives are projected to be included in the current regulations in order to meet target goals for 2015.

Hydropower

Evaluation and optimization of the country's hydroelectric potential are priority tasks for the Portuguese government. In this sense, an investment state program known as *National Program for High Hydraulic Potential Dams* is currently being developed. The construction of ten projected new dams will raise the installed capacity up to 7 000 MW, thus setting for 2020 a 70% increment over the installed power reported for 2007. Total investment regarding such project is estimated at 1 140 million euro.

Wind Power

During the last years, the Portuguese government had undertaken relevant efforts aimed at promoting wind power technologies in the country. For the period 2001-2007, the average annual growth of installed wind power reached 62.4% and was regarded as one of the highest among all European Union member states. In addition to this, significant efforts to encourage the development of new projects in the ambit of the wind sector are currently being held.

The Portuguese government has regarded wind and hydropower technologies as playing the most relevant role in achieving the target objectives for 2010 and 2020 set for Portugal by the European administration. The nationwide promotion of wind farms is part of a broad social and policy scheme aimed at launching the wind sector in the country. A public offer to increase the installed wind power was promoted by the Portuguese administration in the period 2005-2006. The hiring of local manufacturing companies by jobbing contractors was set as mandatory requirement in tender conditions. By doing so, employment was favored and lower investment for the installation of wind power generators was achieved.

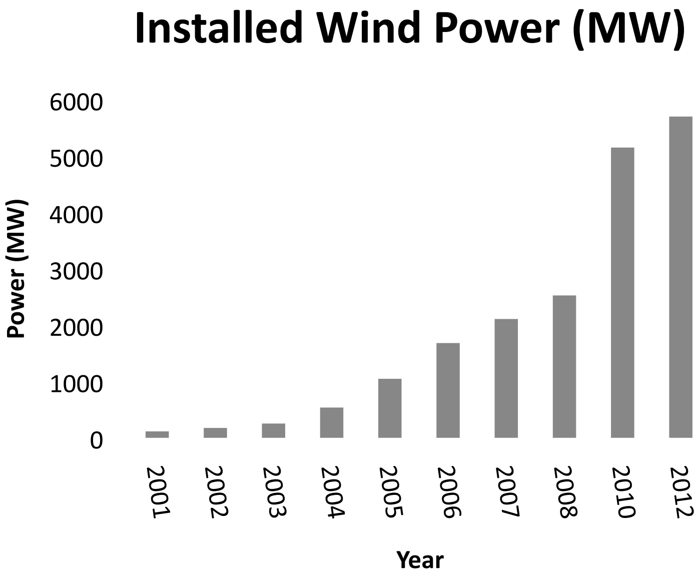

Fig. 1. Installed wind power in Portugal since 2001 and forecast for 2012.

The aforementioned scheme has attained notable success, provided that Portugal has achieved an important foreign investment in the wind energy sector. As a consequence, the continuity of these policies to further enhance such relevant sector is definitively guaranteed by Portuguese regulations (*APREN* (www.apren.pt)).

One of the largest wind farms in Europe –240 MW and 90% of generators fully manufactured in Portugal–, installed by the German company *ENERCON* in Alto Minho, might serve as a good example to illustrate how those policies have delivered. Portuguese wind turbines manufacturing companies are expected over the long haul not only to be involved in the ambit of national projects, but also to become an exporting country to other states like the United Kingdom. The diagram shown in Figure 1 represents the installed wind power in Portugal for the period 2001-2012.

Solar Energy

The average growth of solar photovoltaic energy in Portugal for the period 2001-2007 is reported as 50%. The construction of two new plants in the region of Alentejo will fulfill the 150 MWp photovoltaic installed power set as a target goal for 2010 by the government. These plants are projected to satisfy 49% of such capacity (www.innovationobservatory.com).

The first of those plants is located in the town of Amaraleja and approaches 46 installed MWp. It was projected by the Spanish company *Acciona*, although the Chinese company *Yingli Solar* was subcontracted for the manufacturing of the solar collectors. This plant is projected to reach 62 MWp in a forthcoming phase, with a total investment of 250 million euro. In 2007, *Acciona* built a photovoltaic collector manufacturing plant in Portugal, which will satisfy the technical needs for the completion of the second phase, and which will focus on the production of collectors for the international market. The annual production capacity of this factory is reported as 24 MWp (www.spel.pt)).

The other plant referred to in the preceding paragraphs is located in the town of Serpa, with 11 MWp capacity and designed as a joint project by Catavento, General Electric y Powerlight.

It must also be noted that thermal solar technology showed a notable growth in the country last year, mainly due to favorable changes in the Portuguese regulations regarding new constructions. At present, the total thermal solar collectors surface in Portugal approaches 600 000 m^2, 250 000 m^2 of which were installed during 2009.

Tidal Power

Portugal is regarded as one of the countries with best conditions to exploit tidal power. In fact, one of Europe's largest plants was built in 2008 in this member state. It is located three miles offshore in the north coast of Porto, and was a 9 million euro joint project by a series of Portuguese and foreign companies, of which the Scottish *Pelamis* is the major shareholder. The plant has three semi-submerged *Pelamis* model energy converters, and electricity is directly transferred to the Portuguese electric network by an underwater cable. The power capacity of the plant (2.25 MW) is sufficient to supply 1 500 homes energy demand.

This type of renewable energy technology is still underdeveloped in Portugal, although future relevant projects are yet being designed. This way, the number of wave energy converters is projected to reach 25 units nationwide, thus increasing total capacity up to 21 MW. This actions are promoted through specific regulations by providing 0.23€ per kWh transferred to the electric grid.

Geothermal Power

The whole Portuguese geothermal power production is concentrated in the volcanic Azores Archipelago, with 31 MWe installed capacity. The exploitable potential is reported as 25 MWe. The electric output from this renewable source showed a slight drop in 2008, although suitable conditions are currently being explored in Terceira –an island in the same Archipelago– in order to install a 12 MW plant to satisfy one half of the island energy demand (www.eurobserv-er.org).

5. Renewable Energies in Extremadura

The import/export energy balance in this region shows a favorable power of 12 775 GWh, as reported by Spanish Electric Network, which clearly sets Extremadura as an exporting region in terms of energy production. This is mainly due to the fact that the region achieves very high rates of energy production if compared with the rest of Spanish autonomous communities, but is also a consequence of the low energy demand by industrial facilities. Note that the region shows one of the lowest relative weights within the ambit of Spanish industrial sector.

Some particular geographical features set Extremadura as being especially suitable for the development of certain renewable energy technologies like those regarding solar photovoltaic, solar thermal or biofuels. The annual production of forestry biomass in the region is estimated around 400 000 tons, which approaches 7% of national production. Also, there are some relevant solar photovoltaic plants, like that located in Trujillo (Cáceres) with 30 MWp installed power.

Table 6 illustrates the current situation of renewable energies in Extremadura, as well as the forecast for late 2010.

Table 6. Forecast for 2010 in Extremadura.

Forecast for 2010 in Extremadura			
Technology	Target Goal for Spain, 2010 (MW)	Forecast for 2010 Extremadura (MW)	Contribution of Extremadura to national target goals 2010
Solar Photovoltaic	400	400	100
Solar Thermoelectric	500	300	60
Wind Energy	20 155	420	2
Biomass	1 317	26	2
Total	**22 372**	**1 146**	**5**

The target goals set for Extremadura, in the short to medium term, are to exceed 1 000 MW installed renewable power by 2010 and to ensure 33% of regional energy consumption from renewable sources by 2012: wind, solar thermal and solar photovoltaic and biomass.

It should be pointed out that renewable energies are playing a critical role in the energy, economic, environmental and social ambits of the Spanish and Portuguese regions Extremadura and Alentejo, respectively. A couple of illustrating examples on the transborder collaboration in the sector of renewable energies are highlighted along the following section: the Projects *PETER* –already carried out- and *CIEREE* –in progress-. All indicators suggest that the current situation should be regarded as a starting point to a further successful development of renewable energy technologies in our region.

6. Examples of joint activities on Renewable Energies between Spain and Portugal

6.1- Project *PETER*

The project known as *Transborder Experimental Park on Renewable Energies (PETER)* was a joint action developed by eight Spanish and Portuguese member institutions. Spanish members were the University of Extremadura (lead partner), the Provincial Council of Badajoz, the regional ministry of Infrastructures and Technological Development of the regional government *Junta de Extremadura*, *IDAE* and CIEMAT, while Portuguese institutions were the University of Évora, *INETI* and *ADRAL*. 75% of investment came from European funds regulated by the program *INTERREG III*, and the remaining 25% was contributed by the involved member institutions. One of the most relevant projected actions was the construction of an *intelligent zero-energy building* at the campus of the University of Extremadura in Badajoz. The concrete subprojects developed by the members of Project *PETER* are available at the reference (Rosa, R. and Cuadros, F., 2008).

Project *PETER* was finished by June 2009, and might be considered as fully completed with regard to the research aspects to be carried out by partner institutions.

The thermodynamic behaviour of the *PETER* building was modelled up and simulated according to the climatic conditions of Badajoz and to the particular features of the building enclosures. The heat loads of the building were calculated along the year, and the renewable energy facilities to meet the needs for guaranteeing inner thermal comfort were then estimated. In this sense, detailed studies were conducted by research teams from the universities of Extremadura and of Évora, from *CIEMAT* and from *INETI*. A virtual picture of the *PETER* building is shown in Figure 2.

Nevertheless, a number of problems regarding permit requests, bureaucratic aspects, time constraints, limited funding, etc., often beyond the control of the researchers involved in the project, have finally impeded the execution of the civil works. In this sense, Spanish actions have therefore not been fully developed.

IDAE has successfully leaded actions devoted to project's diffusion, like that conducted on November 7th 2007, the fair *FICON* held on May 2008 and the edition of the book *Renewable Energies on both sides of the frontier*.

The Provincial Council of Badajoz covered the costs of architect fees, but did not actively contribute in the implementation of the civil work since it finally was not carried out for the abovementioned reasons.

The Directory General for Research, Technological Development and Innovation of the regional government *Junta de Extremadura* has neither participated in the acquisition of technical equipment.

Calculation, design and implementation works regarding the renewable energy facilities (solar thermal and photovoltaic) located at the campus Mitra of the University of Évora were carried out. Unfortunately, scheduling constraints and some other bureaucratic problems impeded the construction of the biomass energy installations. The progress of the Portuguese contribution was drastically affected by the fact that transfer of building land made by the University of Évora in the campus Mitra was not accepted as a co-funding action (25%). The research teams from that university, from *INETI* and from the University of Extremadura were deeply involved in these activities.

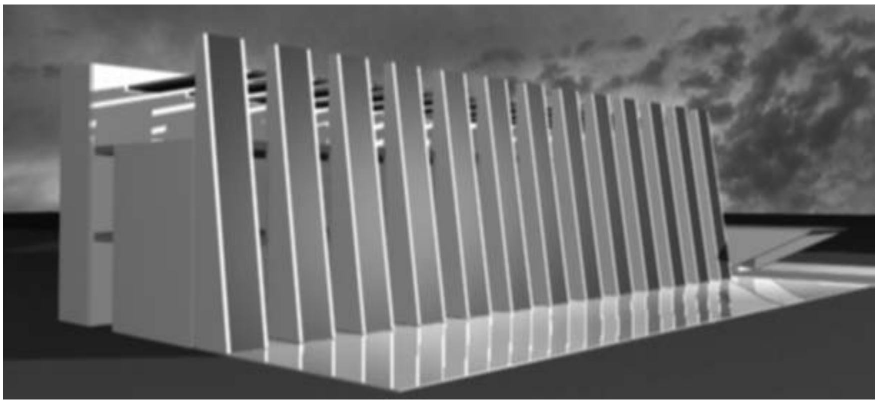

Fig. 2. Virtual mock-up of the *PETER* building.

As aforementioned, *INETI* has collaborated actively in all actions performed by the research team from the University of Évora.

ADRAL attended the Renewable Energy Fair held in Beja by spring 2008, designed the logotype and launched the Project's webpage, among other actions.

It should be noted that the results achieved by the research teams have been published in reputable specialized national and international journals, and have also given rise to a wide number of contributions to national and international scientific forums in the ambit of renewable energies. This confirms quality and scientific rigor of the research activities regarding Project *PETER*.

The aforementioned reasons allow assert that 85% of the initially projected actions have been successfully delivered. The remaining 15% are those with highest economic needs. However, we positively believe that the development stage achieved will permit to undertake future relevant R+D+i actions in the ambit of the renewable energies.

Project *PETER* is a joint sustainable project developed by Spain and Portugal, aimed at the construction of an energy efficient office and laboratory building by integrating the use of renewable energies.

6.2- Iberian Centre for Renewable Energies and Energy Efficiency (*CIEREE*)

This project was first anticipated in the context of the Hispano-Lusa Summit held in Braga on January 19th 2008. The construction of an Iberian Center for Renewable Energies and Energy Efficiency (*CIEREE*), to be located in the Spanish city of Badajoz, was agreed by the Spanish and Portuguese governments.

The centre will house all technical and human resources required to meet the projected objectives regarding research, technical development and innovation (I+D+i) on renewable energies, by setting collaboration programs with companies, European, national and regional administrations, institutions and national and foreign universities. In addition, it will serve to reinforce specific collaboration with Portugal as well as to create an international reference network in the renewable energy sector.

CIEREE is also aimed at promoting the creation of academic spin-off companies related with the renewable and environmental sectors. All these actions are focused on employment generation in regions with high rates of unemployment.

The technological development regarding renewable energy sources in Spain and Portugal, as well as the design of innovation programs to favor the foundation of new companies and to enhance technical progress among traditional companies, will also be promoted by *CIEREE*. In addition, it is also aimed at coordinating scientific university efforts towards the technology business development, and at creating a positive mood towards innovation among the various social agents involved.

Besides, *CIEREE* will perform training and popularization actions regarding the renewable energy technologies, as stated by European Union regulations, by which member states should promote the renewable energy sources so that penetration into the energy market is gradually achieved. In this sense, *CIEREE* should be regarded as a link for different university research teams, other research centres and European companies, to hold PhD courses, continuous training seminars, master courses, as well as actions targeted to the Spanish and Portuguese public at large and to Primary and Secondary school level students aimed at publicizing the economic, social and environmental advantages of renewable energy sources.

According to the aforementioned points, the main goals of Project *CIEREE* are set as follows:

- Promote R+D+i to companies of the renewable energy and the environment sectors as well as to specific departments of the administration.
- Optimize protocols for energy save and efficiency regarding industrial, construction and domestic sectors.
- Promote environmental advantages of renewable energies at Primary and Secondary School levels as well as to the public at large.

- Provide specific training support for the university degrees somehow regarding renewable energy sources: Industrial Engineering, Environmental Science, Agricultural Engineering, Forest Engineering, Chemistry, Physics, Mathematics, Biology, Economics, Veterinary Science, etc.
- Offer postgraduate courses in collaboration with companies of the sector and with other institutions or universities.
- Evaluate the environmental impact of energy technologies, as well as perform comparative analyses with those regarding renewable energy sources.
- Provide adequate facilities for R+D actions on novel testing methods regarding solar, wind and biomass technologies.
- Deliver certifications on durability and reliability of renewable energy equipments, as well as on energy evaluations regarding buildings and enclosures.
- Perform synergy analyses on the combined energy production from various renewable sources.
- Promote collaboration with other companies of the sector as well as with other institutions and national or foreign universities.

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Renewable Energies and Sustainable Development[1]

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Abstract
Many of the natural resources that we utilize in our daily lives are finite. i.e. they do not renovate themselves (at least on a time scale relevant to us, humans). On the other hand Nature has only a finite capacity to absorb the many impacts resulting from our activities.

Fossil Fuel based Energy is an excellent example to illustrate both statements: fossil fuels are getting close to their peak production capacities and their burning is the strongest climatic change agent as well as an agent for a roster of other environmental impacts.

On the other hand global energy demand rises strongly, in particular because of developing countries, with China and India being outstanding examples. This fact, together with demographic growth, resulting on at least 10 billion people at the end of the century, increases the pressure on energy supply and on environmental impacts to truly unsustainable levels. And this is true regardless whether the World does not correct the asymmetries in per capita energy consumption of today or even if it attempts to do so, lowering per capita energy consumption in developing countries and raising it in all others.

Thus it is really imperative that the global rise in energy use be made through clean and Renewable Energy forms, in parallel with intelligent use of energy (avoided use, Energy Efficiency, etc.) , this strategy being an essential aspect of what is presently referred as sustainable development.

It is argued that we further need to profoundly change our consumerist culture (which has unbridle growth as a core value) pervasive in the developed World of to-

[1] On the occasion of Prof. Rui Namorado Rosa's Jubilee, University of Évora, June 2010

day, by adopting a set of values of a completely different nature, one that will be compatible with Sustainable Development in an effective way.

Portugal has unique conditions to take advantage of the new boundary conditions imposed by sustainability and achieve competitive development in an European context, while it is grasping the situation and decides and plans to fully exploit its Renewable wealth.

1. The problem: several pieces of a puzzle that do not fit?

1.1- Piece #1:Fossil fuels, dependence and availability

All human activity, one way or another, uses natural resources. Many are finite, i.e., do not renovate themselves, at least in a time scale relevant to our everyday life.

Fossil fuel based energy – oil, gas, coal- is an excellent example to illustrate this statement.

In what follows a plot is shown, extracted from a recent communication of the International Energy Agency (Press release of the document WEO-World Energy Outlook, London, November 12, 2008), together with the associated comment about the need to a new capacity production 6 times larger than that of the largest present producer, Saudi Arabia.

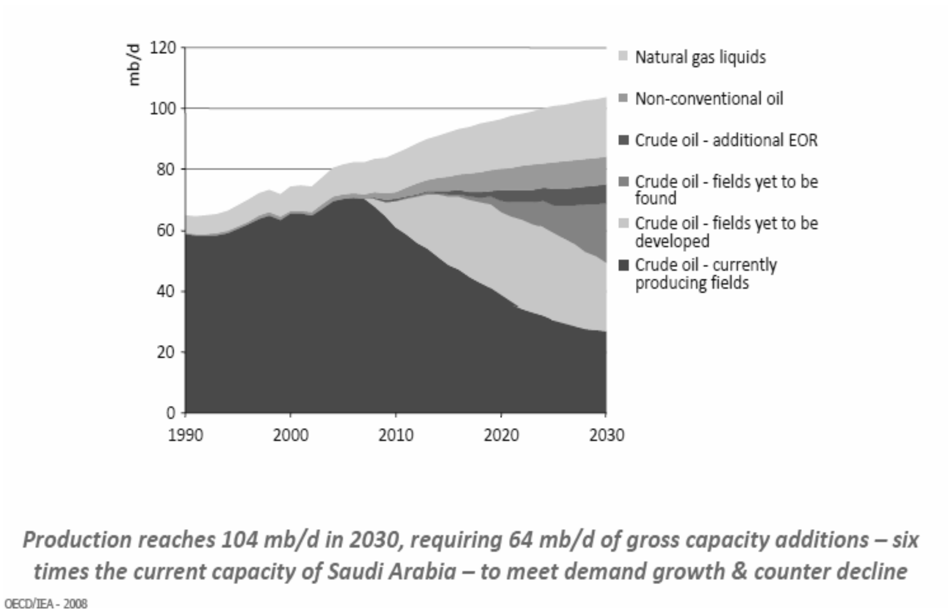

Fig. 1. World production until 2030, forecast by IEA, Nov. 2008

This capacity forecast until 2030 is not likely to come from Saudi Arabia, since 92% of the oil it produces at present comes from six large fields, the last one of which (Shaybah) was discovered in 1968.

It is really not known where it will come from [1] !

In fact the IEA, with this forecast (Fig.1) is making two important steps:
1) it confirms the forecast being put forward by others like ASPO through its dark blue curve "crude oil-currently producing fields", something unprecedented until the present date 2) until 2030 it already points at targets much lower than previous ones; the only remaining problem is that it gives us no clues about where those "yet to be developed" (light blue) and " yet to be found" (red) are to be found or come from.

A good summary of the present known production capacities and their historical evolution may be seen in Fig.2 and Fig.3, respectively reproduced from a communication by Prof. Rui Namorado Rosa, Univ. de Évora, Out. de 2008 (Fig. 2) and from "The Oil Drum", communication made by Luís de Sousa, September 2008.

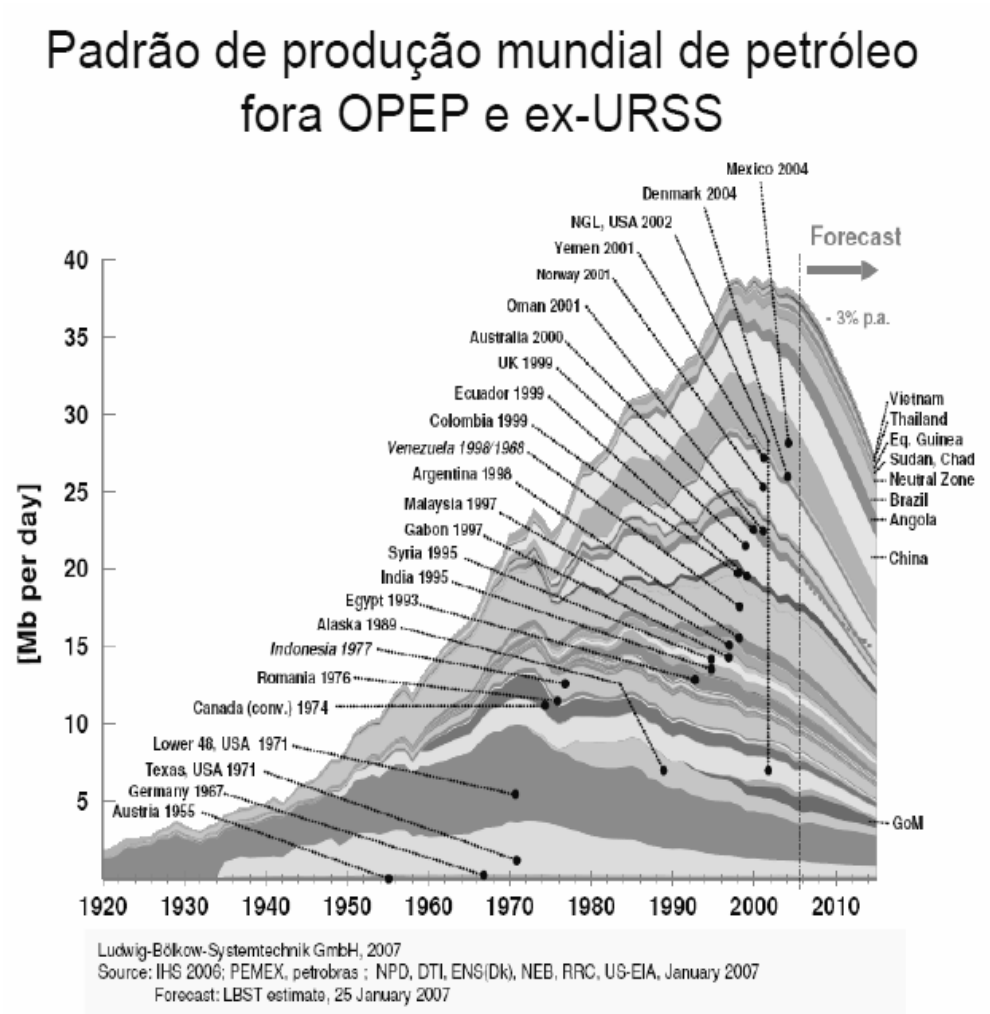

Fig. 2. World evolution of production capacity, by country, excluding OPEP and ex-URSS, displaying a clear post-peak behavior.

Fig. 2 and 3 are part of a Picture more pessimistic than that of the IEA.

In any case what should be emphasized is that, with a larger or shorter time lag to the peak, we are just a few decades away from the end of an extraordinary resource, to which we are seriously .This helps to explain why cheap oil is more and more a thing of the past (not considering economic recessions and moments where supply largely exceeds demand, for whatever reason…)

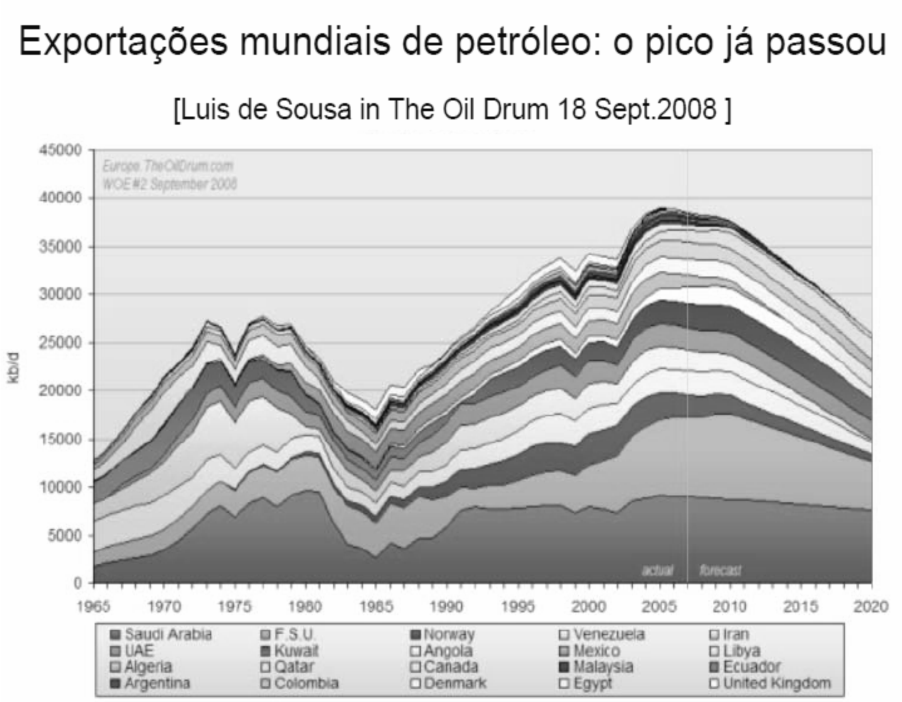

Fig. 3. History of oil production, past and future, all countries ("peak oil is behind us")

Similar plots may be obtained for gas [1] and for coal[14]. In the first case it looks as if its peak will occur on the order of 10 years after that of oil .The second case is now being studied with greater detail, exhibiting a tendency to yield a result which does not seem to be compatible with the usual figure of about 2 to 3 centuries given for coal reserves.

Recently we have seen the price of oil fall in an extraordinary way, from the very high value of $US 145.00/barrel value, at the end of 2008. This was the product of the recession that started then and with its associated drop in demand. It is manifesting a clear tendency to rise, as the World is edging out of the recession. It is likely to reach very high values again as the economy improves and probably up and down again, however with the oscillations pegged on a tendency to a permanent increase, as a result of the growing scarcity explained above. Yes, we have used up half of what was easy to extract. Almost as much as the other half, is the amount available in the harsh environments associated with serious potential environmental impacts, like those in very deep waters, polar regions, oil shales… This non conventional oil will have a much higher extraction cost.[2]

On a geological time scale or even in the time scale of Humanity's history on Earth, it can be said that we will have exhausted these fuels in the nick of a time, the time of "lighting a match" so to speak , a few mere hundreds of years.

1.2-Piece #2: Energy and Environment

On the other hand all human activity has an impact on Nature and Nature has a finite capacity to absorb these impacts, at least on a time scale that is ours. In the past, with few people on Earth, man's impact on Nature could be also be devastating on a local scale, but in regional or global terms this impact could be considered as a small perturbation, i.e. totally neglectable as a term in the equation Nature is always trying to solve. But as population grows these impacts become a term of the equation that can no longer be neglected!

Once again the example of fossil fuel based energy is an outstanding example. From extraction, to transport , to processing (oil refining, for instance), to storage, there are innumerous instances of impacts, not excluding, of course, those that result from accidents, wars, criminal acts (like Sadam Hussein lighting oil field fires in Kuwait before running away from American military pressure) . But it is mainly from the burning of fossil fuels that the most tremendous impact on Nature results, under the form of atmospheric pollution: ~60% of it comes from fossil fuel burning [2]. And it happens on various scales: 1) a local one (for instance as manifested in the highly contaminated air of present day large cities) 2) the regional one (for instance as manifested in the reality of acid rains) 3) the planetary (the infamous greenhouse effect and the resulting global warming).

Before progressing further, it is important to explain this connection between the accumulation of gases like CO_2 and CH_4 in the atmosphere, causing the greenhouse effect and the rise in global average temperature. For the overwhelming majority of the scientific community, this connection is one of cause to effect and not just simply a fortuitous coincidence as some very few insist in saying.

[2] The recent Gulf of Mexico crisis resulting from the uncontained BP well is a real shock and a powerful reminder of the new risks in store

Since half way through the 19th century, CO_2 concentration in the atmosphere has risen from 280ppm to about 380ppm at the end of the 20th century. In this same period there was a very serious rise in the combustion of oil and gas, in particular during the last 60 years (of that period). At the same time there was a significant increase in worldwide deforestation, hindering photosynthesis and its capacity to remove CO_2 from the atmosphere. The average global temperature rose 1ºC in the same period.

Observation of (fossil) air trapped in (fossil) ice allows us to go back in time hundreds of thousands of years. The trapped air bubbles may be analyzed and the presence of greenhouse gases detected and measured. Average global temperature can also be determined through known correlations with amounts of other trapped gases, isotopes of hydrogen and oxygen. The results show two important facts: 1) the variation of the amount of CO_2 and CH_4 in the atmosphere goes in phase with the variation of the global average temperature

2) the (natural) amount of both gases in the atmosphere never exceeded the levels known up to 1850 , i.e. the amount of CO_2 in the atmosphere had ups and downs but was never higher than 280ppm.

These facts show that the correlation between the presence of greenhouse gases in the atmosphere and the variation of the average global temperature is not accidental and that the difference with the last 100 years or so comes from direct human action, at a scale able to burst the natural dynamics of emission and absorption of those gases, causing their accelerated injection into the atmosphere as a result of fossil fuel burning and other activities.

The rise in average global temperature causes climatic changes with many possible consequences, a large number of them potentially very dangerous in local, regional and planetary terms. Let us consider two examples. Firstly there is the rise of the average number of cyclones on a yearly basis, form ~30/yr about 100 years ago to ~110/yr today. Secondly the progressive accelerated melting of polar ice caps, with the associated rise of average sea level, not to mention the possibility of halting the Gulf stream (at the end of 2005 the measurements made showed that it may be up to 30% slower already [3], which brings us closer to a new "ice age" in Europe…?!).

On the other hand the average residence time of a molecule of CO_2 in the atmosphere is larger than 100 years, and that gives an extra complexity to the problem. I.e. the true or practical stabilization of CO_2 concentration and effects to be achieved happens 100 to 300 years after and the corresponding average temperature stabilization a few centuries after again. An example is the average sea level rise and stabilization: it is provoked by sea water thermal expansion and by ice melting (mainly Greenland and South Pole…) happening up to hundreds and even a thousand of years after.

The several scenarios made up today, trying to model the evolution of the present situation with all the different possible inputs, lead to a frightening conclusion. Consider Fig.6 [5]. In it the difference between the average global Earth temperature and its 1990 value, is plotted against time. For most of the last 1000 years it is seen that is was always 0.5ºC below that 1990 value. However in the last 100 years it jumped for about 1ºC as explained before (the grey shade shows the error associated with the value of average temperature attributed to each year). What should be stressed is that all scenarios (including those that we will construct next) produce, up to 2100, a remarkable temperature rise, with a minimum value of 1.5ºC and possibly much higher. ALARM!!!!

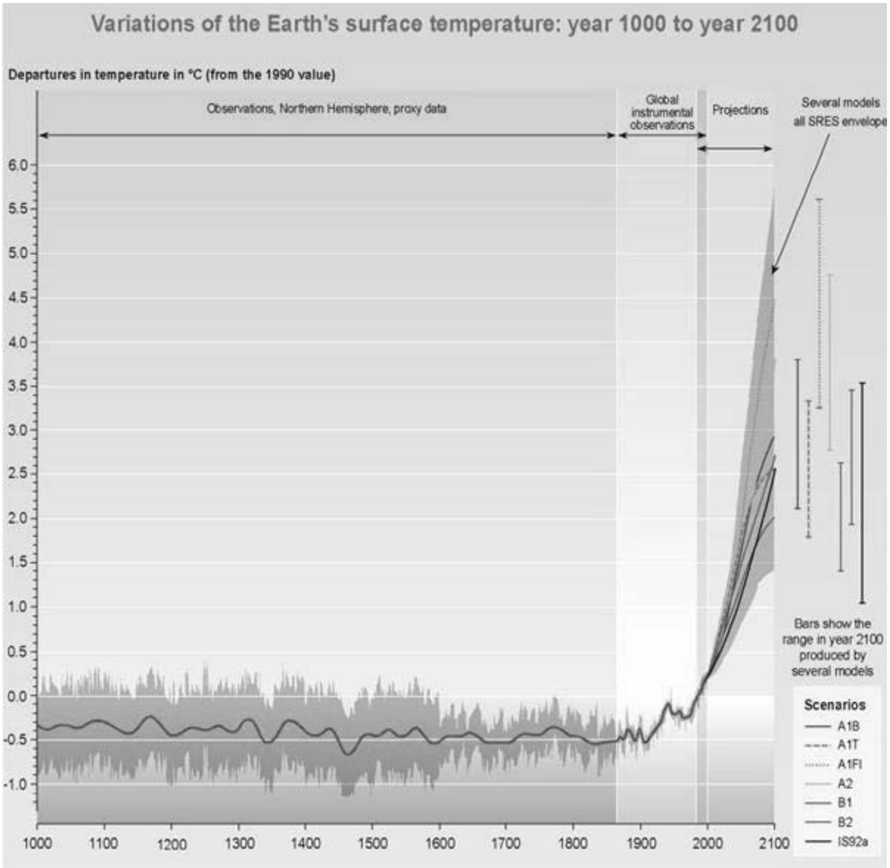

Fig.4. evolution of average global temperature (IPCC)

1.3 Pieces #3: Energy and Demography; Energy and Development

In the meantime, World population is growing [4] In Fig. 5 the evolution of World population is shown since 1500 (~500 million people in the whole World) up to the present day (more than 6000 millions). A succession of exponential growth stages with growing constants. It should be noticed that from the middle of the 19th century on, the population starts to grow at a much stronger level on cue with advent of the access to fossil fuels usage! Extrapolating with the same constant to 2100 would result in a prediction of World population on the order of 22 000 million by then!

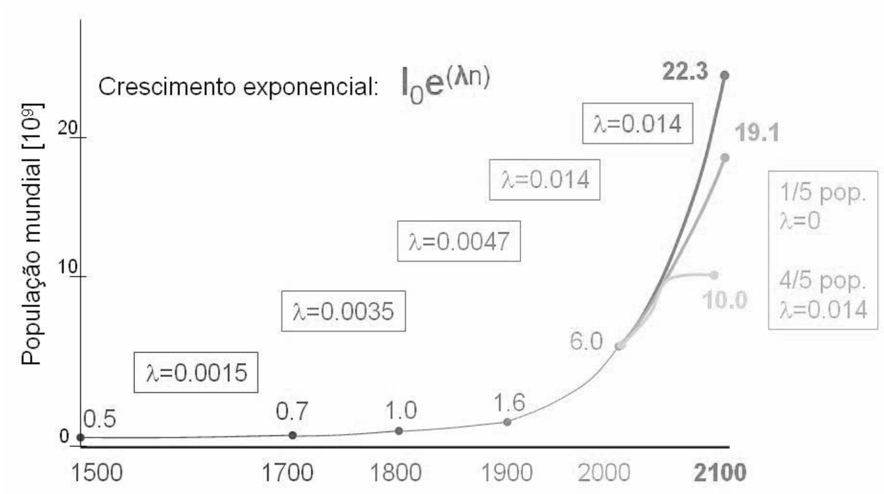

Fig. 5. Growth of World population, past and future

However the growth rate in the industrialized World (~1/5 of all Humanity, about 1200 million people) is practically zero. If the present growth rate is applied to the remaining 4/5ths only, then a value of 19 000 million is reached in 2100. The United Nations predicts that a clear tendency for stabilization will be felt towards the end of the century and that the value of only 10 000 million will be reached. Apparently the global growth rate (1.4%) is already about 70% of its peak during the sixties (2.06%) and, they say, should fall to about 25% of that value already in 2050…

It is not clear how and why, but that value is thus taken as a possible target, albeit an optimistic one.

Today, only 1/5 of Humanity (the so called industrialize or developed World) consumes 2/3 of all fossil fuels and the remaining 4/5 of the population, just 1/3. This is a highly distorted situation, very hard to sustain. Its consequences on the Environment will be truly dramatic. Let us see why.

Let us consider the situation with some more detail. In Fig. 6 the greenhouse gases emissions per capita are shown for each country/region. This plot is made in terms of emissions but it might have been made in terms of fossil fuels per capita consumption and be basically the same.

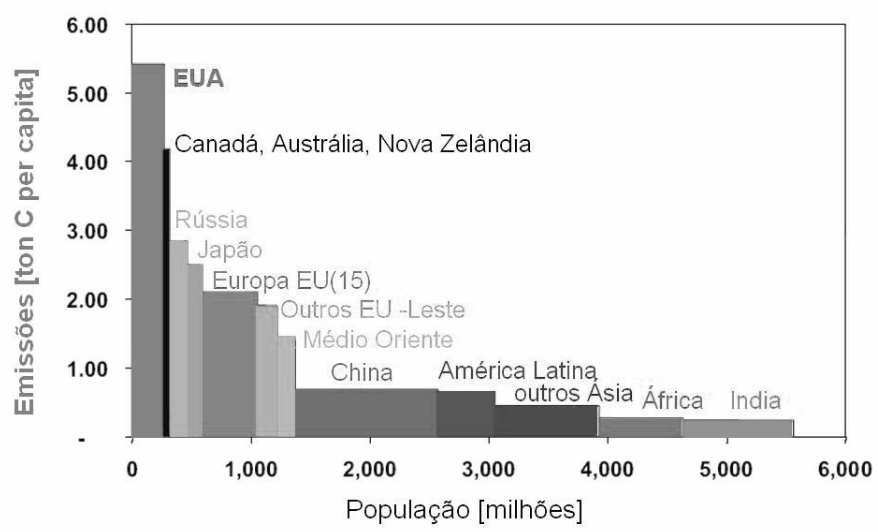

Fig.6. per capita emissions (ton per capita) per country/region in the World

This plot can be used to show that:

1) In the so called developed countries the per capita use of fossil fuel based energy is 5 times, on average, that of developing countries, but there is an enormous difference among the developed nations with the U.S. isolated, leading the pack , being responsible by itself, for about 25% of the total!
2) Emissions per capita, from Europe (a champion of the idea of the need to curtail them, starting now!) are less than half of the average of the developing nations; and yet life is not necessarily that worst when compared with that in the US; i.e at this level there is no explicit, direct relation between the use of energy and development![3]
3) The developing nations use really very little energy per capita and here it seems that indeed there is a relation between one thing and the other.

Developing countries are those were the population is growing with at strong rate. This means that if nothing is done to alter that rate and even keeping the per capita usage of energy at the same value ("business as usual"), in 2025 the present usage (1990 level) will be multiplied by a 1.5 times factor ~1.5vezes that of 1990 (see Fig.7, also [2]).

[3] This is a very important observation since, if the whole World had to aspire to the level of per capita energy usage that is observed in the US today, there might not be a solution to the whole problem

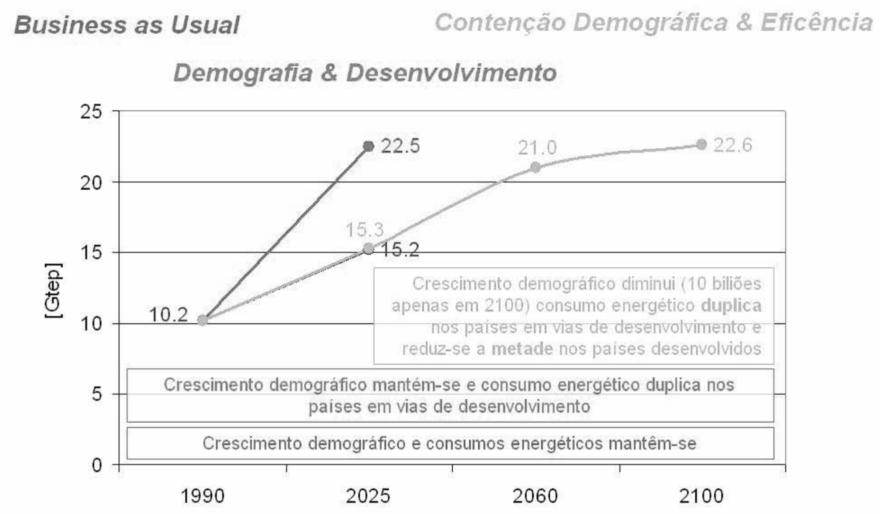

Fig. 7. evolution of energy usage in three different scenarios of demographic growth and per capita consumption : blue – business as usual; red – demographic growth is the same but per capita energy usage is twice the present the one; green-demographic growth is reduced (10 billion only in 2100) per capita consumption doubles in developing nations and is halved in developed nations

But, for instance, if in the meantime and as a result of countries like China, Brasil, India, the per capita in developing nations doubles , staying the same in the developed nations , in 2025 there will be an energy usage 2.25 times higher than that in 1990.

But if we decide to make an effort in the developed World, without any sacrifice of productivity and quality of life (it is possible, if we compare present US and European values) , that reduces the average usage per capita to half its present value in the developed World and take the measures necessary to stabilize the population at about 10 000 million at the end of the century with a per capita usage twice of what it is today, the same "1.5 times" more energy mark is reached in 2025 and the same "2.25 times" energy mark is reached in 2100. In short, a strong effort to produce a fairer and better balanced World leads us to a situation that, from the point of view of environmental impact, is more than twice worst than the present one, if all is achieved by fossil fuels! In other words, if now there is cause for alarm and we do not change, we should very, very much preoccupied with what will inevitably take place in a few tens of years!

1.4: Can we fit together the different pieces of the puzzle?

On one hand we are super dependent on the fossil fuel based energy, a good portion of which will not last even to end of the century (oil and gas). Even though we may have a progressive substitution of oil and gas by coal (synthetic fuels, gasification, etc.) there will be more environmental impacts and it will eventually come to an end soon after.

Anyway, the energy from fossil fuels has been cheap but the announced future scarcity (and the associated environmental impacts) will dictate the need to handle it in a different way, just because it is bound to become more expensive.

On the other hand 4/5ths of Humanity have a right to development, demanding a larger per capita usage of energy, and that aggravates the problem. Sustainability on a global scale demands the resolution of the **poverty problem** intimately connected (in truth it is simultaneously cause and effect) to a **very low energy usage per capita**.

The environmental impacts associated with rising fossil fuel usage are felt already today! It is not to be forgotten that their effects linger on, for hundreds of years into the future. We have initiated, years ago, a very dangerous game, which we do not control and whose consequences we know to be devastating, even though we cannot measure them with accuracy,. Just this thought should force us to act as of now with determination, to put the problem under some sort of control!!

2. What to do?

The only way to solve the puzzle requires a completely different look at the Energy question, introducing into the equation all the meaningful terms like Environment, Demography, Development, and Sustainability…

We have seen that strictly from the point of view of fossil fuel energy we are constrained not to look much beyond the middle of the century. With demand on the rise (the rising pressure from the developing countries) its duration will be even shorter. It might seem that this conclusion is a positive one, because of the resulting reduction of greenhouse gases production but, unfortunately, it will likely lead to a rise in coal usage, since this is the easy way of continuity, the way to keep value in the fantastic amounts of money invested in gasoline and diesel engines, boilers, gas and steam turbines, i.e. all the fossil fuel burning equipments that fill the World around us today.

In any case to go on using oil that cannot supply all of the demand and to go to coal transformed in different types of burning fuels (even if this will correspond to cleaner ways of using it[4]), guarantees continuity but surely at an ever higher price (i.e. we are at the **end of the cheap energy era**).

On the other hand the conscience that we are starting to have about the different environmental impacts will push us towards the use of cleaner energy forms and to internalize in the cost of fossil fuel based ones those externalities directly resulting from their consumption. Accords like the KYOTO one are taking longer than expected to finalize and they are but a first step to reduce these impacts. The cost of implementation will in part be taken by the fact that the era of cheap energy is over already!.

What seems important is not to lose any more time and start the equation solving using the many possibilities that are within our reach for the necessary change.

Some signs of change can be already felt with a tag of "no turning back" on them, giving us some right to be optimistic. The latest energy and environmental European Union directives are a case in point and even the way that is being followed by a country like Portugal in the latest years can be seen as rather different form the traditional past.

In what follows we will try to present and discuss the necessary conditions for change.

2.1 – Energy seen from the Demand side

We have been talking about coal, oil, gas, Primary Energy, the raw materials of energy. But what each citizen wants is useful energy! The Primary Energy form where it comes does not really matter. Each citizen wants to have the services energy provides, the comfort, the quality of life energy provides. Each citizen is on the Demand side, not on the Supply side. This mere perspective shift opens the door to a vast number of solutions, which may not be particularly energy intensive and which do not compromise quality of life. In some instances they may even avoid explicit use of conventional energy Supply. Some specific examples are:

1) Buildings well built (well conceived, well oriented, well insulated, well ventilated and naturally illuminated) need much less conventional energy supply than a conventional building

[4] Some examples:1) the efficiency of coal power plants may rise to higher values (up to 60%?) in the future [9];2)CO_2 sequester and storage technologies may be developed and applied 3) "decarbonization" technologies applied to coal prior to use, for instance with solar energy, may be a reality in the future …

2) Well designed urban space, as when streets run East-West rather than North – South, everything else remaining equal, result in a 20% lower energy use in their respective buildings [6]
3) Urban space or regional space well ordered and organized in order to minimize people's daily displacements from home to work and back, can drastically cut energy usage
4) Comfortable, efficient and available public transportation drastically reduces the use of private transportation (car driving), again with substantial energy savings.

Afterwards comes the enormous "resource" called Energy Efficiency, i.e. once we cannot avoid (as in the examples above) using conventional energy, we should now use it with the highest efficiency, getting the same service with less…

An excellent example of the potential associated with a Demand side approach as explained above can be seen in Fig. 6, comparing the per capita average energy consumption in the US and in Europe (15). And there are still many ways to be better in this matter even in Europe.

2.2- Energy from the Supply side

From the supply side the solution is in concentrating on energy forms with low or zero environmental impact, clean energy forms [2]. That is the case of Renewable Energies. Because they are abundantly available and they are clean, one might even conceive of not being so worried about wasting energy, as we must be with the fossil fuel base energy.

2.2.1- Renewable Energies

Renewable Energies are abundant and **are already distributed** through the Planet under one form or another; sometimes even all of them are present in the same country. This is one more topic – the Geography of Energy – which is very important and should be one more term in the equation we need to solve. In this short text we did not address this point, but this comment now should serve as a reminder of its importance. One of the problems associated with fossil fuels, in particular oil and gas, is the fact that their reserves are highly concentrated in a few spots on the Planet and that they require expensive transportation and distribution networks to reach each point of consumption.

The potential contribution of Renewable Energies is enormous. All have their origin in the energy that comes to us from the sun. The amount that gets to Earth on any given instant is~10000 times higher than the amount used on Earth my Mankind in that same instant. Therefore there are no availability limitations, neither now nor in any foreseeable future.

We can think of using Renewable Energies to supply any thermal energy demand (domestic hot water, space heating and cooling, heat for industry, etc) to be used in transports (mobility) through bio fuels and electricity and for electricity with the multiplicity of uses associated with it. Electricity in the transport sector, deserves one further comment: producing electricity form Renewables opens the possibility to think of it as a major source for the transport sector, once the necessary energy storage technology evolves sufficiently, not to mention the perspectives brought in by future by new energy vectors like Hydrogen.

Thus Renewable Energies (complemented by the Demand side perspective) will help take into consideration Demography and Development into the puzzle solving we set out to accomplish. Their contribution may grow as much as necessary. In particular in a way such that the development of the 4/5th of Humanity, energy deprived today, may take place without constraints since there will be no significant environmental impacts associated with it. Moreover it will correspond to the use of local resources and will progressively be within reach of local industry for the production of the necessary equipments. There is still the tremendous advantage associated with the fact that these energy forms are already distributed, by and large bypassing the need to build the same massive transport and distribution networks deeply associated with fossil fuel based energy and all their corresponding costs, which constitute a trade mark of the industrialized World of today.

As for energy costs, there are already Renewable Energy forms producing energy at a cost comparable or even lower than that of energy with a fossil fuel origin.

But in general it may be said that Renewable Energies often require a different way for the consumer to be in the energy market: they often require a payment upfront for equipment purchase and installation but then they deliver what is essentially energy for free during their long life time. When seen like this, Renewables are already and quite often, more economical than their fossil fuel based counterparts. However getting used to the new way will take time and entails a cultural change.

Present day equipments to capture and transform the different Renewable Energies, have been evolving to higher performance capacities and to lower costs, as it is usual with new technologies. And much can already be done with them as of today. However the scale of penetration of Renewable Energies that we are forecasting here will require massive R,D &I efforts to go much beyond the materials, the engineering the solutions of today . Some new developments will be quite spectacular and different from what we are using today. The strategic research agenda [17] of ESTTP- European Solar Thermal Technology Platform is a good example to mention, among many possible others.

In our own national terms it can be said that this new order, this change in relative terms, is very favorable for us, since **Portugal is very rich** in terms of Renewable Energies as opposed to fossil fuel reserves which the country does not possess and imports in its entirety. Energy policies of the last Governments have slowly evolved in the necessary direction, towards a larger penetration of Renewables, albeit with ups and downs. The present one is still too much centered on renewable electricity (even though Final Electricity corresponds only to about 20% of the total Final Energy) with something also on the Transport sector. However the major energy need is for Heating and for Cooling (more than 40% of the total) and that remains still very much left out. Just for electricity, if Portugal implements Renewables as proposed by APREN [12] ~80% of its Final Electricity will come from them in 2020, while at present that value is already above 40%. This will be a remarkable achievement!

2.2.2- Nuclear Energy

And what about nuclear energy? The conventional, commercial, solution for new reactors existing today (fission of U_{235}) is a prohibitively expensive one [16]. And there is no single reactor in operation that hasn't been heavily subsidized, directly and indirectly. U_{235} is but a small percentage of the most abundant U_{238} (<0.7% was the initial average figure for the good Uranium ores, today most mines are below 0.1%). This is a severe limitation. It is really not a sustainable, long term solution, since the U_{235} in the reserves available, if used as it is being proposed by the nuclear industry, would last no more than 30 to 50 years [7,8,11] (see Fig. 8). We can talk of "Peak U_{235}", just as we did of Peak Oil [11,15], with the irony that what remains to be mined in this case will last for less than oil itself. Reprocessing is really an option to be considered with "breeder" reactors only (see below).

Figure: *Past and projected uranium production. Forecasts are based on reasonably assured resources below 40 $/kgU (red area), below 130 $/kgU (orange area) and additionally including inferred resources. The black line shows the fuel demand of reactors currently operating together with the latest scenarios in the World Energy Outlook (WEO 2006) of the International Energy Agency.*

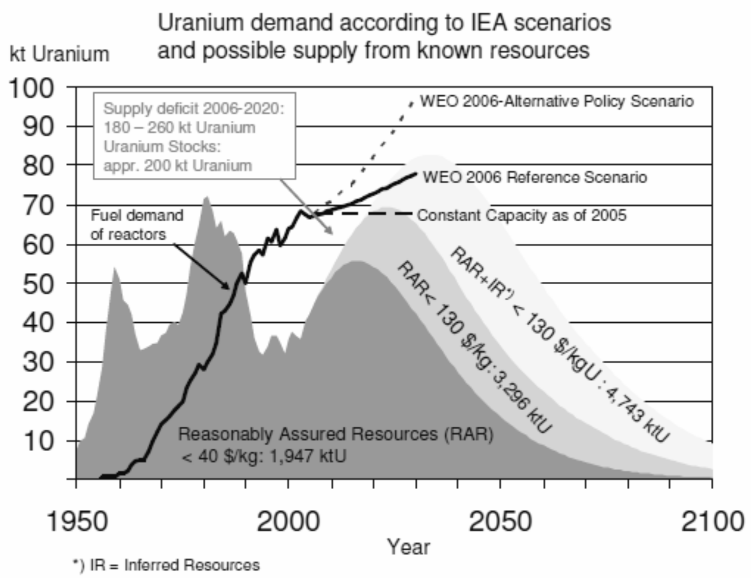

Fig. 8. Evolution of Uranium reserves

On the other hand the environmental impact associated with nuclear fission is large, both because the radioactive waste disposal problem has not yet been resolved satisfactorily and because there are accidents, some of which can be very deadly. When proclaimed to be clean, nuclear energy is only so because it is a low net emitter of greenhouse gases in comparison with thermal power plants of the same size (low net emitter and not zero emitter, since there are energy needs associated with mining, enriching, disposing of the Uranium fuel, and in building and dismantling the power plant). There is also the very serious and specific problem of nuclear proliferation and eventual use of nuclear weapons by rogue nations or by some "not so rogue" ones if they come to a point of desperation. This goes in parallel with the recent rise of terrorist threats, possibilities that a larger use of nuclear energy would help potentiate even more…

However today there are hundreds (~400) of nuclear reactors in operation, for a total installed capacity, worldwide, of ~350GW [11] .

There are very few new ones under construction, and there are also some countries that took the decision to abandon theirs. However most of those that have operating nuclear reactors, will likely go on using them, until the end of their operating lifetimes (about 1/3 are already aged more than 40 years) and/or until there is U_{235} available at acceptable prices.

In short: present day commercial fission power is not a solution for a sustainable energy future. However it will still cost the World quite a bit in decommissioning and dismantling the existing reactors once they reach the end of their operating life and in storing away the large piles of radioactive waste produced up to now.

Can nuclear ever have a different role? On a longer term basis, the perspectives for nuclear fission based energy may be a bit different with the commercial development of reactors able to use as fuel the U_{238}, which is ~150 times more abundant then $U_{235.}$ Technologies to do this exist today, but the reactors (breeders) are more dangerous and difficult to operate and lack commercial maturity. Today the level of wastes coming from these reactors is also of a worst kind. Thorium (Th_{232}) is another potential nuclear fission fuel requiring a similar reactor for its use . This would enlarge the long-term sustainability of the technology, since Thorium is more abundant then Uranium. It is fair to note that new interesting ideas, like having the reactor contain in itself the means to reduce the radioactivity of the generated waste, have been proposed and are being researched. Therefore it seems that if the proper R&D is made, nuclear fission may evolve to a situation where it can help resolve a small part of the puzzle, but not before the next 20 or even 30 years…

In any case nuclear energy produces only electricity and electricity is just ~20% of all total Final Energy use. Besides, nuclear plants can only be used as base load plants (they must operate in continuous mode and at capacity) and that further reduces the contribution they can hope to have for the total necessary electricity production and for total Final Energy . In smaller grids they will have a harder time to fit in, since today they tend to be offered in very large sizes (for reasons of cost).

As for nuclear fusion it constitutes an exciting possibility, pending on the demonstration of its feasibility. But also not before the next 40 or 50 years, after the first reactor of said "commercial" size , right now under construction in the south of France (ITER), demonstrates its potential, so that first generation reactor design may then start and establish the first commercial presence of the technology. A recent article [13] cautions about too much optimism around fusion, listing a large set of hard problems yet to be solved.

But, as was explained before, we need to act now and we cannot wait for developments [5] that, in truth, may not even be necessary.

[5] This text handles the nuclear question in global terms, not in national terms. This question would certainly deserve additional comments in the case of Portugal, since this is an option being proposed today. The solution being proposed is U_{235} based. It is very ex-

3. Is this all?

Do we need anything else to solve the puzzle? Yes… The magnitude of the problem requires deep change and that, as we have hinted at already, requires a new culture… It is not just about technology.

Analyzing more in detail, we verify that cheap oil based energy is deeply interwoven into the fabric of the World Economy and thus in our everyday life. As an example let us consider food and the fact that we have a diet ever more dependent on meat (its consumption rose a factor of 5 between 1950 and 2000 and that mainly in the industrialized world). This evolution is very heavy on energy usage but also very heavy on the use of other resources like land and water… Another example: one calorie in an onion produced in Chile (out of season in Europe), requires 66 calories to be transported for its consumption in Europe, a few days later. All of this is possible because energy (oil) has been very cheap and the impact of air transport on the greenhouse gases production hasn´t even been considered in the accounting of emissions and in emissions control strategies. Intensive agriculture today is extraordinarily dependent on oil. The dependence list includes: fertilizers, pesticides, direct usage, storage/conservation and transportation of products, not just locally but globally.

This is just an example of what can be found in almost any other area of human activity today.

The topic of energy for transportation is essential to the globalization we are witnessing and taking for granted. But it seems that we may soon be forced to go into the opposite direction. In World of the future, the free and generalized circulation of material goods may not be sustainable and thus will

pensive as explained. It is in counter cycle and at the end of its cycle and does not fit into Portugal's present electricity production policy. It would take many years to build thus not being able to address any of our present and immediate future energy needs. It would be a mistake of large proportions. The proponents have a vision of the whole energy question that seems to reflect a "business as usual " stance , in my view a position not sustainable and thus wrong, as this paper tries to explain (the referred stance can be summarized in one sentence:"there is no need to do anything else, nuclear energy will solve everything!")

slowly fade away. Globalization will grow but it will have, more and more, a virtual character (information!). As for equipments, material goods of all sorts there will then be a strong tendency to revert to the local, to the regional (at the most), to the seasonal, to the resources around us. This will be a good thing, preserving local identities, local agriculture and local industry. Will this produce a much more balanced and sustainable society? I think that the concept of sustainability will likely be intimately connected with this idea…

All of this will be the cause but also the consequence of a deep level of change at the cultural kevel, a new paradigm, new values to substitute those of our consumerist society, where we are so deeply immersed that we tend to lose the very notion of it. Cheap fossil fuel based energy, disregard for the environment, constitute necessary conditions of the pervasive culture of the day. If these conditions persist they will kill us in a short while!

But after all, in some countries, in particular northern European ones, a new culture seems to be emerging: beyond possessing material goods people are really valuing more and more some intangibles like free time (for culture, for relaxation, for social interaction) or the quality of the air they are breathing. These are signs of change towards a society able to find alternatives, not only for its energy supply but also in the adoption of goals and consumption patterns that are facilitators, promoters even, of future sustainability.

In the limit it is a question of **culture.** That is why true change is neither easy nor fast. That is at the heart of the difficulties ahead. The best Science of the day provides an accurate diagnosis. The best Science of the day points at possible solutions. However their automatic adoption implies a perception and a cultural level which is not yet that of the day. What we are achieving now is still the stage where we are looking for a breach leading us into the culture of the future… Meanwhile reality around us evolves, inexorably hard and dangerous. Is it possible to find a short cut that will help us save our future and that of our descendants?

Unfortunately it is not only here that Science – beyond the technological evolution it engenders, which, in turn, places in our hands all sorts of new technologies and equipments – does not yet really belong in our everyday life, not yet taking an automatic part in the definition of the policies that govern us, explicitly or implicitly [10]. This is, in my opinion, a large "deficit" with which we should really be concerned.

But the acknowledgement of the importance of Science is also the "raison d'être" of this book, since it is at the essence of the homage being paid to Prof. Rui Namorado Rosa and to his life dedicated to Science and to the teaching of Science. The path chosen by him was the correct one and the way that path was walked is an outstanding example for all of us.

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A Significant Break in Tradition: the Election of the First Woman to the Sciences Section of the Lisbon Academy of Sciences

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Abstract
On 4 April 1980 Lídia Salgueiro responded affirmatively to a letter addressed to her by the then-Vice President of the Sciences Section of the Lisbon Academy of Sciences, José Pinto Peixoto. This letter, dated 28 March 1980, expressed the Academy's Physics Section's decision to propose her name as official Associate Fellow of the Sciences Section of said Academy. Subsequently, on 9 April 1981, Lídia Salgueiro is officially and unanimously elected as Associate Fellow of the Sciences Section of the Lisbon Academy of Sciences, following the Academician António de Silveira's official nomination, thereby breaking the centuries-long tradition of an all-male membership of said Academy, originally founded in 1779. This paper will explore the interrelationships, personal and professional affinities, collaborations and family ties underlying the entire election process.

1.

On 14 April 1980, Lídia Salgueiro responded affirmatively to a letter addressed to her by the then-Vice President of the Sciences Section of the Lisbon Academy of Sciences, José Pinto Peixoto. This letter, dated 28 March 1980 (Document [Ofício] #: 149/80), expressed the Academy's Physics Section's decision to propose her name as official Associate Fellow of the Sciences Section of said Academy. In accordance with the Statutes for election, a written statement by the candidate must precede this nomination in which the candidate declares his or her acceptance of the proposed election as Fellow or Associate Fellow. If elected, the candidate would subsequently fulfil his or her responsibilities with respect to the Academy's norms and statutes. On 9 April 1981 Lídia Salgueiro was officially and unanimously elected as Associate Fellow of the Sciences Section of the Lisbon Academy of Sciences, following the Academician António de Silveira's official nomination of her, thereupon breaking the centuries-long tradition of an all-male membership of said Academy, founded in 1799. Silveira justifies his proposal affirming that he feels extremely honoured to nominate as Associate Fellow someone "who has had a markedly innovative influence in the area of teaching as well as had a decisive influence on future researchers and their training (Silveira, 1981) further affirms that she has played an important role in the transmission and diffusion of science, having been editor-in-chief of the *Gazeta de Física* [Physics Gazette] for several years. This was a periodical dedicated to the diffusion of science and highly respected by its informed readership, in particular high school teachers of physics. Silveira goes on to say that Lídia Salgueiro was also a member of the Board of Referees for the journal *Portugaliae Physica*, a periodical publication which sought to publish original research being carried out by the Portuguese scientific community, specifically in the area of physics, and which had had a significant impact not only because it gave these scientists the opportunity to publish their research during the war years of 1939-1945 but also because it encouraged the exchange of ideas and research appearing in foreign publications possessing a much more international readership. Thus this Portuguese publication gave its national readership access to research being carried out abroad that would have otherwise been totally inaccessible. Moreover, there exists a veritable exchange of publications at this time between Portugal and other European countries.

However, this was not the first time that the Academy heard the name Lídia Salgueiro invoked. In fact, already in 1961, the Academy of Sciences had honoured her with the "Artur Malheiros" Prize, received "ex aequo" for her work entitled "A Contribution to the Study of the Disintegration Scheme of ^{229}Th, with Nuclear Plates." Furthermore, this was also not the first time that the Academy had elected a woman as one of its Fellows since, on 13 June 1912, both Maria Amália Vaz de Carvalho and Carolina Michaëlis de Vasconcelos—two major figures of the Portuguese literary *intelligentsia*—had been elected Associate Fellows to its Letters Section. It should be noted, however, that, with respect to this Letters Section of the Academy, no new female members were elected until 1975.

Over the past twenty-five years, in fact, only seven female Fellows have been elected to the Sciences Section of the Academy (one of whom is a Foreign Associate Member). Moreover, the women elected to this Section amount to a mere 7% of the total number of Fellows and Associate Members of the Academy active today. Lídia Salgueiro, however, continues to be the only female member of the 2nd Section, in Physics. At present there are still only two women elected as Fellows into the Academy, the first being Manuela Ferreira Chaves, elected in 2001, to the 7th Section in Engineering and Other Applied Sciences, and the second, Maria Salomé Pais, in 2005, to the 5th Section in Biological Sciences.

Table 1 shows both names and dates of nomination for each Section of Sciences as well as the distribution of Associate Fellows and Fellows according to Section:

Table 1: Women in the Sciences Section of the Lisbon Academy of Science

SECTION	**ASSOCIATE FELLOW**	**FELLOW**
1ST- MATHEMATICS	--	
2ND – PHYSICS LÍDIA SALGUEIRO (31.12.1917)	09.04.1981	
3RD – CHEMISTRY	--	
4TH – EARTH SCIENCES AND ANA MARGARIDA VEIGA (07.05.1941)	27.04.1995	
5TH-BIOLOGICAL SCIENCES MARIA SALOMÉ PAIS (17.08.1938)	04.11.1999	
WANDA VIEGAS (07.03.1950)	03.07.1997	
		24.11.2005
6TH – MEDICAL SCIENCES MARIA DE SOUSA (17.10.1939)	07.02.1985	
CARMO FONSECA (09.08.1959)	17.07.2000	
7TH – ENGINEERING AND OTHER APPLIED SCIENCES MANUELA FERREIRA CHAVES (10.09.1946)	03.03.1994	06.12.2001
FOREIGN ASSOCIATE FELLOW ZULEIKA LOPES CARRETTA (28.02.1935)	02.05.2002	

Table 2 is more general in its scope and offers a comparison with Academies in countries such as Austria and France. With regard to Portugal the election of a woman as Associate Fellow or Fellow of the Lisbon

Academy of Sciences was indeed a belated event when compared with similar elections occurring in the Royal Society (Marjorie Stephenson and Kathleen Lonsdale in 1945, following an earlier failed attempt to elect Hertha Ayrton in 1902) and in the Académie des Sciences (Marguérite Perey, Associate Fellow in 1962 and Yvonne Choquet-Bruhat, Fellow in 1979). It should also be noted that all the women elected as Associate Fellows of the Lisbon Academy of Sciences were working within the university community at the time and all of them were in fact full professors at the time of their election. A summary analysis of the available data also permits us to affirm that the two women

Table 2: Percentage of Female and Male Members of Sciences Academy in Austria and France

Science Academies
% of Female and Male Members

	Total	Female		Male	
	Number	Number	%	Number	%
Austria	638	40	6,3	598	93,7
France	488	29	5,9	459	94,1
Portugal	250	21	8,4	229	91,6

Sources:
Österreichische Akademie der Wissenschaften (2006) http://www.oeaw.ac.at/
Académie des Sciences de l'Institut de France (2006) http://www.academie-sciences.fr/

elected were married to Fellows at the time of their election. (We further note that the day of Lídia Salgueiro's election as Associate Fellow, her husband (and former student) José Gomes Ferreira was elected Fellow of the same Academy although his election as Associate Fellow had occurred five years before. Moreover, his election as Fellow occurs despite the fact that he had hitherto had a much shorter research career than that of his wife.) Another female Associate Fellow was in fact the daughter of a Fellow. It should be pointed out that there are similar cases of female relatives (either through family relation or through marriage) of Fellows being elected in other European Academies as well.

Born in 1917 Lídia Salgueiro began her studies in the private family sphere. She received her primary school instruction in the small southern town of Palmela under the tutorship of an aunt. However, her secondary-level studies began inauspiciously at a commercial school. Her mother was now a widow and consequently Lídia's education was seen as a means to remedy the family's now diminished resources. Nonetheless, she is subsequently allowed to study at the "Liceu" [high school], signifying an important change in the direction of her studies which she enthusiastically embraced and which will mark the beginning of a long life of study. She will later study in a Lisbon high school for two years before ultimately completing her high school education in a regional high school located outside the Portuguese capital, specifically, in the small provincial town of Viseu. She recalls an excellent teacher of physics and chemical sciences at that time, Professor Beirão, who influenced her decision to pursue her studies in this field upon her enrolment at the university. She began her undergraduate studies in the university town of Coimbra (1934-37), subsequently completing them in Lisbon (1939-41). She would receive her undergraduate degree with honours in Physico-Chemical sciences in 1941.

Upon completion of her undergraduate degree in July 1941, Lídia Salgueiro was contacted by Manuel Valadares (1904-1982)—the prestigious Portuguese physicist who had previously trained at several foreign universities—, who wished to know whether she would be interested in belonging to his research group. Valadares (1933) who had previously written his doctoral dissertation at the Faculté des Sciences of the Université de Paris, with the title "Contribution à la spectrographie par diffraction crystalline du rayonnement γ" [A Contribution to the Spectrography of Gamma Radiation by Crystalline Diffraction], whose jury president had been Jean Perrin (and whose examiners were Mme Pierre Curie and M. A. Debierne). Valadares had dedicated his dissertation to "Mme Pierre Curie, hommage respectueux" as well as "à ma Mère." An important figure in the history of the Portuguese scientific community, he was responsible for stimulating scientific research in Portugal and continued to do so until his political exile in 1947, whereupon he was summarily stripped of his university position. Facing exile, Valadares subsequently decides to move to France where he will henceforth acquire considerable renown in his field. Valadares later recognized in the doctoral candidate Lídia Salgueiro her strong desire to become a professional researcher. It is at the urging of Manuel Valadares, as well as following her life-changing reading of Eva Curie's biographical account of her Nobel Prize-winning mother, that Lídia Salgueiro decides to devote her professional activities to research. Nonetheless, despite her great enthusiasm as an aspiring researcher, aware as she was of the many challenges of an academic career, the young Lídia decides to teach both at the secondary and university levels for a year. She tutored during this period, an experience she then believed would, if necessary, guarantee her a high school-level teaching position in case her still nonexistent university career proved unsuccessful. However, in March 1942, Lídia Salgueiro definitively leaves her high school teaching position after she is promised a full-time lectureship as "assistente" [teaching assistant] at the university. This was not the first time that the university had hired a woman to teach physics. In fact, Maria Angelina Fortes had already taught physics during the academic year 1931-32, but it was an experience which lasted only one year. Furthermore, for the academic year 1942-43, three out of a total of ten academics teaching physics (of this group two were full professors) were in fact women: Lídia Salgueiro, Marieta da Silveira, and Judite Pereira. Thus, Lídia Salgueiro spent the period from 1941 to 1945 in a highly stimulating and enriching personal and professional environment. As she states in a recent interview with us, she recalls that:

> [d]uring this period I enjoyed the good fortune of being able to become acquainted with individuals who possessed a highly developed scientific and moral stature as well as a sense of humility, which resulted in the creation of the perfect environment for much productive research. […] In fact, research greatly depends on the dedication, enthusiasm, and scientific training of its contributors, but it is greatly influenced by the moral strengths of researchers themselves as well (Salgueiro, 2008).

The aforementioned Manuel Valadares would later become Lídia Salgueiro's mentor (and subsequently friend). It is he who proposes the study of crystalline diffraction of the transmutation RaD-RaE—a theme of great interest given the theoretical and experimental discrepancies then observed—as the subject of her doctoral dissertation. Interestingly, her dissertation was further made possible by the generous offer of old radon needles belonging to the Physics Laboratory of the Institute of Health of Rome, where her supervisor, Manuel Valadares, had previously trained in 1940.

In 1945 Lídia Salgueiro receives her doctoral degree for her work entitled "Espectro gama dos derivados de vida longa do radão" [Gamma Spectrum of Long-life Derivatives of Radon]. She dedicates her doctoral project to her mother. She includes only 27 citations in total, which suggests the originality of her research. She also includes a note of acknowledgement to the Director of the Laboratory, Professor Cyrillo Soares, and to her supervisor Doctor Manuel Valadares, the latter for having "proposed the subject of her dissertation" and supervised, as she states, "its progress, guiding my research with his good counsel and suggestions as well as for our discussions concerning my research results," as well as to the Instituto de Alta Cultura [The Institute of Culture], which had granted her a research scholarship allowing her "to dedicate herself solely to teaching and research." Finally, she thanks "the lab technician, Sr. José Ferreira, for his expert care of the equipment needed to carry out successfully our research."

Scientists of her generation still lived at a time when equipment was built by the researchers themselves, a time when researchers needed to have two fundamental traits along with their willingness to work both intensely and arduously, as Lídia Salgueiro states, when referring to the work of Jean Perrin, i.e., "an extremely acute critical sense and a profoundly inventive spirit." It is our conviction that these traits and capacities are fully present in Lídia's own life and career in addition to her great humanity and intellectual generosity. Her generation was in fact characterized by many instances of international collaboration. In fact, research for her dissertation had been made possible by the generous offer of used radon needles by the Physics Laboratory of the Institute of Public Health in Rome, where her dissertation adviser Manuel Valadares had previously trained in 1940 (Salgueiro, 1983).

In the same year (1945), Marieta da Silveira, her colleague, defended her doctoral dissertation entitled "Contribuição para o estudo das radiações do urânio X complexo" [A Contribution to the Study of Complex Uranium X Radiation]. Both Lídia Salgueiro and Marieta da Silveira subsequently became the first women of the Physics Sector of the School of Sciences to be promoted to Senior Lecturers.

It would not be until thirty years later, however, that Lídia Salgueiro would be named full professor on 1 February 1974 and officially vested in 1977 by the Secretary of Higher Education (*Diário da República*, 1977). She would retire four years later in 1978.

An analysis of the data presented in Figure 1 shows that the gender distribution in academia amongst those of highest rank resembles that of Europe in general. The scissors diagram (Figure 1) permits us to visualize the disappearance or loss of female scientists as responsibilities, social recognition and respective salaries increase. We note that this is a tendency present both in the academic as well as in the entrepreneurial sectors of society.

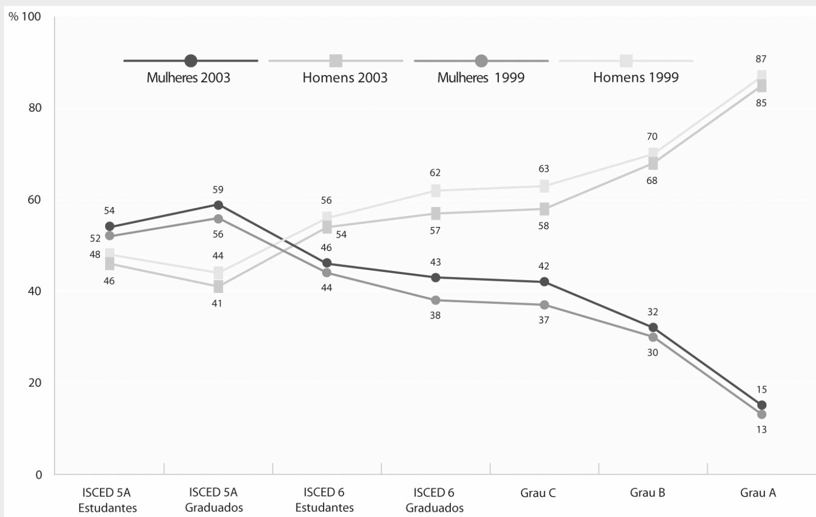
We will now consider the research and teaching career of this exceptional pioneer of Portuguese women active in the field of science. Particular emphasis should be given to her contributions to the Physics Research Centre, a Centre whose goal was the founding of a true research school in Portugal under the supervision of Manuel Valadares. This Centre was unfortunately not successful in realizing its goal due to reasons of a political nature which led to the expulsion en masse of all university professors opposed to the Salazar regime, in 1947. On 15 June of that year, the Portuguese government had an unofficial notice published in the newspapers referring to "the ideological mission [being waged against the government] to the detriment of the carrying out of their university duties." Subsequently, twenty-one full or associate professors and lecturers along with several army officials would be expelled (*Diário de Lisboa*, 1947).

Lídia Salgueiro's colleague Manuel Valadares subsequently left for France following an invitation to work there by Mme Irène Joliot-Curie. He left behind the "spirit of camaraderie and inclusiveness, as well as the sustained institutional support and collaborative unity given to all researchers" which had prevailed until then at the Centre. Lídia recalled many years later in an unrecorded personal reminiscence that despite this turn of events "even if at that moment I had not been allowed to continue my university career, the fact that I had had the privilege of collaborating with highly talented and dedicated individuals endowed with superior moral qualities had already been reward enough."

From 1942 until her retirement, Lídia Salgueiro was in charge of the following courses: Medical Physics (12 years), Optics, General Physics, Elements of Atomic Physics, and Introduction to Quantum Mechanics, X-Ray Spectroscopy and Advanced Atomic Physics. She is the author of 4 volumes: *Medical Physics* (1967), *Introduction to Atomic and Nuclear Physics* (2 volumes, 1970, 1975), *Elements of Physics for a Biology Course* (1972), and *Introduction to Biophysics* (1991), the last three publications in collaboration with her husband José Gomes Ferreira.

Lídia Salgueiro's research activities were carried out on an international level (University of Edinburgh, Scotland, at the Dept. of Natural Philosophy, headed by Professor N. Feather; Orsay, Paris; Amsterdam and Utrecht, Holland; and Heidelberg, Germany). With regard to her supervision of doctoral dissertations and the creation of her own research group, while some of her students completed their research in Portugal, several completed their doctoral studies abroad (England, France, and the United States). She was also very active in the Luso-Hispanic Conferences for the Progress of Science and contributed to the founding of two Portuguese science journals, the *Portugaliae Physica* (the majority of articles in this journal having been published in French) and *Gazeta de Física* [Physics Gazette], having belonged to the Editorial Board of both journals). (We will address her activities at the Academy and with her research group in a future study.)

Lídia Salgueiro's collaboration with Manuel Valadares, her stature as an independent-minded researcher and avid supporter of successive generations of researchers, as well as her devotion to the diffusion of scientific knowledge in Portugal, served to establish her as a highly singular voice and presence in twentieth-century Portuguese science. Through her multifaceted and dynamic career, Professor Salgueiro has for generations stood out as a prestigious scientist (achieving ultimately full recognition by her male colleagues), rightfully elected to an academic institution that had long neglected the contributions of female scientists.



Fonte: She Figures 2006

Fig 1. Gender Distribution in High Ranking Positions in Portuguese Academic Institutions (We wish to thank our colleague Professor Rosa Paiva for permission to use this figure taken from her lecture given at the School of Sciences and Technology

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Leibniz, Newton, os irmãos Bernoulli e o problema das *causas finais*

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Abstract
Leibniz, Newton, Bernoulli brothers and the problem of *final causes* — The Principle of Least Action, or, in a more general way, the variational principles have a very special place in the physical description of nature. The idea that nature follows a principle of least effort, which it does not anything in vain or that it has a way of saving something in all its processes, is a pretty old idea that, for millennia, tried to be applied to the domain of natural laws. Nature would be governed, in its own rationality, by some sort of teleological or a final causes principle. In the seventeenth century, Fermat devised the principle of minimum time to explain the refraction of light, an idea that, in face Descartes optics, was strongly criticized. The principles of minimum as the Fermat one, were present on the ideas of leading philosophers of nature and geometers in the last quarter of the seventeenth century and throughout the entire eighteenth century. This text seeks to address, on this subject, the thought of Leibniz, Newton and the Bernoulli brothers.

1. Introdução e uma explicação

O Princípio da Menor Acção ou, mais apropriadamente, os princípios de acção estacionária ou princípios variacionais têm um lugar de destaque particular na descrição física da natureza. Estes princípios surgem da suposição que os fenómenos naturais podem ser matematicamente descritos por um processo de minimização (ou sendo mais preciso, de extremo — máximo ou mínimo —) de uma determinada grandeza física. Todo o processo de cálculo matemático é complexo, envolve algum detalhe analítico, e, numa relação de cumplicidade mútua, esteve sempre associado à própria descoberta destes princípios.

A ideia que a natureza segue um princípio de esforço mínimo e que nada faz em vão, que poupa e economiza em todos os seus processos, é uma ideia bastante antiga que, desde há milénios, procurou ser transportada para os domínios de descrição das leis naturais. Foi o que fez Herão de Alexandria para explicar a igualdade entre os ângulos de reflexão e de incidência da luz.

Modernamente o Princípio da Menor Acção foi inicialmente enunciado por Maupertuis (1698-1759) em 1744, devendo-se a Euler (1707-1783), exactamente no mesmo ano, os primeiros passos para a sua formulação matemática rigorosa que acabou sendo concluída por Lagrange (1736-1813) na aplicação geral a sistemas mecânicos de energia constante, aproximadamente quarenta anos depois. Até à formulação de Lagrange muito se haveria de discutir sobre a natureza de um princípio deste tipo ou a necessidade de um princípio teleológico, ou de causas finais, para a explicação das leis naturais.

Os antecedentes, na génese moderna deste princípio, surgiram com Fermat (1601-1665) ao demonstrar que, geometricamente, a lei da refracção da luz obedecia a um princípio de mínimo, isto é, o trajecto seguido pela luz é tal que o seu tempo é mínimo; a ideia de Fermat foi atacada pelos cartesianos que lhe lançaram o anátema de «princípio moral», retirando-lhe qualquer propósito de ser um «princípio físico». Mas este funcionamento de mínimo da natureza, simples hipótese matemática de Fermat, foi sendo, posteriormente, lembrado: primeiro por Leibniz (1646-1716); depois por João (I) Bernoulli (1667-1748), já na viragem do século, ao utilizá-lo para resolver o problema da braquistócrona. O contexto do aparecimento deste princípio, dentro da filosofia natural, foi marcado pelo debate entre, por um lado, o dinamismo newtoniano e, por outro, a defesa dos princípios de conservação (mais propriamente a conservação da *vis viva*) — um dos aspectos bastante em evidência na célebre controvérsia entre Leibniz e Samuel Clarke (1675-1729).

Nas linhas que se seguem abordar-se-á o período posterior à polémica entre Fermat e os Cartesianos em torno do princípio de tempo mínimo. Procurar-se-á mostrar como sobreviveram algumas ideias fundamentais, ou instrumentos matemáticos essenciais, que sustentaram, ou combateram, a necessidade de um princípio teleológico para o entendimento da natureza em Leibniz, em Newton (1642-1727) e nos irmãos Bernoulli, Jaime (1654-1705) e João (I).

O texto aqui exposto corresponde a uma versão simplificada, de um trabalho um pouco mais extenso que, a breve trecho, se pretende publicar sobre a história d' O Princípio da Menor Acção e onde se incluirão versões portuguesas de textos científicos e filosóficos bastante significativos na trajectória histórica deste Princípio. Porque é um dos trabalhos que temos vindo a desenvolver e pela oportunidade que nos é dada de participar nestas «Jornadas», julgamos ser esta a forma mais adequada de exprimirmos ao Doutor Rui Namorado Rosa, não só a nossa estima e consideração, granjeadas por mais de um quarto de século de convívio académico e pessoal, como também pela amistosa cumplicidade que ambos temos cultivado no gosto e na prática da investigação em História das Ciências.

2. As causas finais e o pensamento de Leibniz

O encontro em Paris, no início da década de setenta do século XVII, de Huygens com Leibniz, um encontro deliberadamente procurado por este último, foi determinante na formação do filósofo alemão, tal como o demonstra a carta que dirige ao sábio holandês e donde se extrai o passo seguinte:

> «(…) posso dizer que o [presente] que me destes em Paris da vossa obra excelente sobre os relógios de pêndulo [*Horologium Oscillatorium*] foi uma das causas do progresso que tenha feito desde então nestas ciências (…)» (*in* Taton, 1982: 101[TA])[1]

Leibniz vai debruçar-se sobre três temas que vão ser chave para a futura construção do Princípio que virá a ser designado pela «Menor Acção»: a óptica ou a explicação matemática da lei da refracção, a mecânica ou a explicação e descrição do movimento, o cálculo diferencial e integral ou o estudo analítico das propriedades especiais das curvas. Por outro lado, quase quarenta anos depois da sua morte, escritos supostamente da sua autoria, vão ser o motivo próximo para uma acesa polémica na Academia de Berlim que envolverá algumas das figuras cimeiras do meio académico europeu.

No ano da criação da *Acta Eruditorum*, logo num dos seus primeiros números, Leibniz publicou um trabalho com um título assaz sugestivo «Um princípio unitário da Óptica, Catóptrica e Dióptrica» onde escrevia

> «Temos, portanto, a redução de todas as leis dos raios confirmadas pela experiência à geometria pura e ao cálculo através da aplicação de um único princípio, tomado a partir de causas finais se se considerar a questão correctamente: para um raio definido a partir de C não se entende como poderia mais facilmente atingir o ponto E ou D, ou G, nem é dirigido por si próprio para estes pontos, mas o Criador das coisas criou a luz de tal modo que da sua própria natureza o resultado mais perfeito surgiria. Assim, aqueles que rejeitam as causas finais na física de Descartes erram muitíssimo — para não falar num tom mais áspero — uma vez que, mesmo para além da admiração pela sabedoria divina, elas também nos fornecem o melhor princípio para descobrir as propriedades daquelas coisas cuja natureza íntima ainda não é tão claramente conhecido por nós que seríamos capazes de usar causas eficientes próximas e explicar as máquinas que o Criador empregou para produzir aqueles efeitos e, com o propósito de alcançar os seus fins. Assim, também entendemos que as meditações dos antigos sobre estes assuntos tal como se apresentam não devem ser menosprezadas tal como o parecem fazer actualmente algumas pes-

[1] Sempre que a tradução seja da responsabilidade do autor destas linhas, aparecerá na referência a indicação [TA].

soas. Parece-me que notáveis geómetras, como Snell e Fermat – muito versados na geometria dos antigos – estenderam esses métodos à Catóptrica e à Dióptrica» (Leibniz, 1682: 186).

É a defesa da utilização de um princípio de causas finais cujos resultados são extraídos pela aplicação de um processo de cálculo que se baseia, como ele escreve, no «meu método dos máximos e mínimos» (LEIBNIZ, 1982: 187). Leibniz perfila-se ao lado de Fermat e do seu princípio, ressalvando contudo a sua discordância em relação às hipóteses físicas por este defendidas. O pensador alemão defende o princípio do «caminho mais fácil» para vencer a resistência do meio. E maior resistência do meio significa que o raio luminoso tem maior dificuldade em penetrar nele ou, por outras palavras, o meio acaba por se tornar mais compacto; ao penetrar num meio mais compacto, mais «apertado», o raio vai adquirir uma maior velocidade, conclusão que o leva a estar de acordo com a relação entre as velocidades estabelecida por Descartes (1596-1650) e não com a firmada por Fermat ou Huygens (1629-1695). Se ao meio (1), definido por uma resistência *m* e uma velocidade de propagação da luz v_i, se suceder o meio (2), definido por uma resistência *n* e uma velocidade de propagação da luz v_r, Leibniz deduz para o trajecto do raio luminoso (lei de Snell) a expressão $\frac{sen(i)}{sen(r)} = \frac{v_r}{v_i} = \frac{n}{m} = C$ em que $v_r > v_i$ (Quadro 1).

Se no trabalho mencionado, Leibniz assume a necessidade de um princípio de causas finais, uns anos depois reafirma essa opinião no seu «Discurso de metafísica», uma das obras que se pode considerar como uma síntese de todo o seu pensamento filosófico, que

> «(…) a via das causas eficientes, que efectivamente é a mais profunda (…) é em contrapartida bastante difícil quando se desce ao pormenor (…) o caminho das causas finais é mais fácil e não deixa servir muitas vezes para descobrir verdades importantes e úteis que se levaria muito tempo a procurar por esse outro caminho mais físico (…)» (Leibniz, s/d: 72).

Expondo, logo a seguir, como defesa do que acabara de escrever, o exemplo de Snell (1580-1626) e Fermat, aproveitando também para atacar Descartes, como já fizera no seu artigo de óptica em 1682,

> «Também sustentarei que Snellius que é o primeiro inventor das regras da refracção, teria esperado longo tempo para as encontrar se quisesse procurar primeiramente como é que a luz se forma. Mas seguiu, aparentemente o método de que os antigos se serviram para a catóptrica: Para levar um raio de um ponto a um outro ponto dado, pela reflexão de um dado plano (supondo que é esse o desígnio da natureza), encontraram a igualdade dos ângulos de incidência e de reflexão, como se pode ver num pequeno tratado de Heliodoro de Larissa e noutras partes. O que o senhor

Snellius, como creio, e depois dele (ainda que sem o saber) o senhor Fermat aplicaram mais engenhosamente à refracção. Porque quando os raios observam nos mesmos meios a mesma proporção dos senos, que é também a das resistências dos meios, acha-se que é a via mais fácil ou pelo menos a mais determinada para passar dum ponto dado num meio a um ponto dado num outro meio. E falta muito para que seja tão boa a demonstração que o senhor Descartes quis dar desse mesmo teorema pela via das [causas] eficientes. Pelo menos há razões para supor que nunca a teria encontrado por aí, se nada tivesse aprendido na Holanda da descoberta de Snellius» (*ibid.*: 72)

Ainda na mesma obra, ao debruçar-se sobre a «utilidade das causas finais na Física», defende depois a «conciliação das duas vias, a das finais e a das eficientes, no sentido de satisfazer tanto aqueles que explicam mecanicamente a natureza como aos que recorrem a naturezas incorpóreas»,

«Como não gosto de julgar ninguém desfavoravelmente, não acuso os novos filósofos que pretendem banir da Física as causas finais (…) no entanto sou obrigado a confessar que as consequências desta opinião me parecem perigosas (…) como se Deus, ao agir, não se propusesse nenhum fim ou bem (…) e tenho para mim, pelo contrário, que é aí onde é preciso procurar o princípio de todas as existências e das leis da Natureza» (*ibid.*: 65)

Sublinhando que um princípio de causas finais é a explicação por excelência de todas as leis da natureza, embora seja à custa das causas eficientes que se compreende grande parte do comportamento do mundo que nos cerca. A constatação desta conciliação entre as duas vias (as causas finais e as causas eficientes), pois ambas deverão propor as mesmas soluções, virá a influenciar fortemente Euler na forma matemática de aferição do método que, utilizando as causas finais (um princípio de mínimo), lhe permite encontrar soluções para diversos problemas da mecânica[2].

Ao contrário de Fermat, Leibniz mergulhou plenamente na justificação metafísica do uso de um princípio teleológico, foi muito para lá da justificação matemática simples construída pelo geómetra francês, escrevendo:

«É minha opinião, que por razões determinadas de sabedoria e de ordem Deus teve a obrigação de estabelecer as leis que se observa na natureza ; donde aparece mesmo, o que já pessoalmente sublinhei noutra altura (…) que a causa final não serve unicamente para a virtude e a piedade em ética e na teologia natural, mas ainda na própria física para encontra e descobrir as verdades escondidas». (*in* Brunet, 1938 : 13 [TA]).

[2] Cinquenta anos depois Euler confirma a solução de um problema pelo método das causas finais, ao mostrar que, matematicamente, essa solução é idêntica à obtida pelo método das causas eficientes.

Está-se perante a fundamentação de um princípio teleológico, tentação a que, como já se disse, Fermat nunca cedeu. Esta postura distinta, entre dois defensores de um princípio deste tipo na explicação do fenómeno da refracção, terá muito a ver com as atitudes diferentes perante a explicação dos fenómenos naturais: enquanto que Leibniz procurou construir um sistema de explicação do mundo natural, Fermat quedou-se pela forma matemática, pura e simples, de explicar um determinado fenómeno, sem qualquer pretensão de ir mais além, de encontrar um princípio geral que sustentasse um qualquer sistema (até porque não o tinha!).

Se, na óptica, Leibniz se distancia de Descartes e ainda mais de Huygens, na mecânica adoptará alguns pontos de vista deste último e demarca-se da teoria cartesiana do movimento. Em Leibniz, na sua teoria do movimento, o grande princípio, também de carácter finalista, é a conservação. Atacando a física cartesiana, em particular o princípio da conservação da quantidade de movimento, defende:

> «É conforme com a razão dizer que a mesma soma da potência motora conserva-se na natureza, que esta soma não diminui, pois nunca observamos que um corpo perde alguma força que não seja transferida para um outro; que esta soma também não aumenta, pois o movimento perpétuo é, neste ponto, irreal que nenhuma máquina e, consequentemente, toda a natureza não pode conservar a sua força sem novos impulsos exteriores» (*in* Dugas, 1954 : 474 [TA]).

Em 1691, no «Ensaio da Dinâmica sobre as Leis do Movimento», escreve

> «(…) é a força viva absoluta ou o que se estima, pelo efeito violento que ela possa produzir, que se conserva e não a quantidade de movimento. Porque se essa força viva não pudesse jamais aumentar-se e existisse um efeito mais potente que a causa ou o movimento perpétuo mecânico, isto é, que poderia reproduzir a sua causa e qualquer coisa a mais, o que é absurdo. Mas se a força se pudesse diminuir, ela seria completamente destruída, porque não podendo jamais aumentar e podendo diminuir ela iria sempre decaindo cada vez mais, o que é, sem dúvida, contrário à ordem das coisas. A experiência confirma-o também e chegar-se-á sempre que, se os corpos convertem os seus movimentos horizontais em movimentos de ascensão, eles poderiam sempre elevar o mesmo peso à mesma altura antes ou depois do choque, supondo que nenhuma parte da força não foi absorvida no choque pelas partes do corpo, quando estes corpos não são perfeitamente elásticos, sem falar do que absorve o meio, a base e outras circunstâncias» (*ibid.* : 483[TA]).

Para o filósofo de Hanover o que está em causa é a conservação da grandeza mv^2, a *vis viva*, retoma assim a hipótese de Huygens — este é o grande princípio da sua mecânica. A importância da conservação da *vis viva*, do papel que Leibniz lhe atribui, enquanto «força do movimento» está na base daquilo que vem a alimentar a «controvérsia sobre as forças vivas», iniciada pela sua declaração sobre o «erro de Descartes»: — «(…) o seu grande princípio, a conservação da quantidade de movimento na natureza é um erro(…) (*ibid.*: 474).

A par do que já foi dito sobre os trabalhos de mecânica e de óptica de Leibniz, é preciso lembrar que, em 1684, publicou na *Acta Eruditorum*, um artigo, «Um novo método para máximos e mínimos, bem como tangentes de que não há impedimento para quantidades fraccionadas ou irracionais, e um tipo de cálculo notável para este efeito», onde expõe um método que, matematicamente, permite a determinação, através do conceito de derivada, de pontos notáveis, de uma curva — máximos ou mínimos — bem como de outras características tais como a concavidade e os pontos de inflexão. E, como ilustração das potencialidades deste novo método de cálculo, Leibniz propôs a sua utilização na resolução de alguns problemas e, entre estes, encontrava-se o célebre cálculo da determinação do ângulo de refracção, já demonstrada por Fermat utilizando o princípio do percurso de tempo mínimo. Na sua comunicação de 1682 sobre óptica, fizera alusão ao novo processo de cálculo. Para Leibniz, associado à ideia de conservação, está a procura d' «a via mais fácil», o que implicaria a noção matemática de extremo (máximo ou mínimo) que lhe fora sugerido pelo cálculo diferencial; ou a ideia de «conservar», o que implicaria uma variação mínima dessa grandeza.

Para Fermat o princípio de mínimo era de índole matemática e sustentado pela comprovação empírica da lei de Snell, jamais invocou qualquer generalização para o comportamento geral da Natureza. Para Descartes e os seus seguidores, este princípio correspondia, no mesmo nível, à defesa que faziam da conservação do movimento (ao pilar metafísico da física cartesiana), mas tinha que ser combatido pois não apresentava uma argumentação sustentada no movimento (justificação física), a sua razão de ser jazia no domínio da metafísica enquanto princípio de causas finais ou de natureza teleológica. Huygens defende o pilar metafísico de Descartes, a conservação, mas aplica-o ao que viria a chamar-se *vis viva*, a hipótese física, ou axioma, dos seus estudos mecânicos. Huygens usa a conservação da *vis viva* enquanto princípio físico, liberto de argumentação metafísica; aqui o sábio holandês aproxima-se da postura de Fermat. Para Leibniz a conservação desta grandeza poderia estar englobada num grande princípio de «causas finais» em que, tal como já foi descrito, a sua justificação é apresentada na seguinte forma

> «(…) por razões determinadas de sabedoria e de ordem Deus teve a obrigação de estabelecer as leis que se observa na natureza» (*in* Brunet, 1938 : 13 [TA]).

Estas leis pressupõem a ideia de que à partida, desde o início, foram estabelecidas regras para o comportamento do Mundo, regras essas que podem conter, ou sugerir, a existência de um mínimo na variação de uma «grandeza fundamental. Na *Acta Eruditorum* de 1695, Leibniz escreveu,

> «A acção não é o que pensais, a consideração do tempo entra aí, é igual ao produto da massa pelo tempo ou do tempo pela força viva. Percebi que, nas mudanças dos movimentos, ela se pode tomar geralmente como um valor máximo ou mínimo. Daqui podemos extrair várias propostas de grande consequência: poderia ser usada para determinar as curvas que descrevem os corpos atraídos para um ou mais centros. Quero tratar dessas coisas, entre outras, na segunda parte da minha Dinâmica (..) » (*ibid.*: 11 [TA]).

Neste texto a grandeza *acção*, aqui relacionada com a força viva, aparece mencionada pela primeira vez, sendo-lhe atribuída a característica de *máximo ou mínimo*, e serviria para estudar o movimento. Importa, perante esta última citação, sublinhar dois aspectos relevantes: primeiro, a imprecisão da definição desta grandeza que «não parece digna do sábio filósofo» (Brunet, 1938: 11); segundo, além de, muito provavelmente, ter servido como motivo inspirador para o criador do Princípio da Menor Acção que foi Maupertuis, servirá também de pretexto, como se verá noutros capítulos da história deste Princípio, para a acusação de plágio de que este virá a ser acusado…

É com Leibniz, na esteira do que já fizera Fermat mas de uma forma muito mais potente, que se abre, por via da sua criação do cálculo diferencial, a resolução de problemas concretos da Física através da determinação de extremos. Nele há a junção, ou sobreposição, de dois planos: o físico, o da explicação das leis naturais a partir de uma grandeza sujeita ao princípio de causas finais; e o matemático, a utilização do cálculo diferencial para determinar as características dessa mesma grandeza. É no percurso desta sobreposição que caminharão os Bernoullis e, com maior sucesso Euler. Newton, o autor da obra cume do tratamento matemático do movimento e das suas causas, *Principia Mathematica Philosophiae Naturalis*, como se verá adiante, afasta-se decididamente desta visão finalista na explicação dos fenómenos naturais.

3. A polémica com Newton (ou como o pensamento de Newton se afasta das causas finais)

Isaac Newton escreveu no *General Scholium*, com que encerra os *Principia*,

> «(...) um deus sem domínio, providência e causas finais, nada mais é do que o Destino e a Natureza (...) toda a diversidade das coisas naturais que encontramos adaptadas a diferentes épocas e lugares poderiam surgir do

> nada, mas as ideias e a vontade de um Ser têm que existir necessariamente». (Newton, 1984: 546)

Aqui, Deus, ou o princípio teleológico, intervêm no instrumento, na razão e na determinação, mas as leis revelam-se pelo funcionamento da Natureza, não por qualquer razão pré-estabelecida ou argumentação em torno de causas finais; não há necessidade de invocar qualquer finalismo subentendido nas ideias de conservação ou de um princípio de tempo mínimo. O newtonianismo manifesta-se contra a ideia de «o mundo ser uma grande máquina, movendo-se sem a intervenção de Deus», o que implicaria que qualquer princípio de conservação tornaria supérflua, desnecessária, essa intervenção: a intervenção era só inicial e tudo se passaria nessa conformidade. Esta oposição de Newton à ideia de conservação é de tal modo veemente que, pela pena do seu discípulo, Samuel Clarke, sustentou, na polémica contra Leibniz, o seguinte:

> «A ideia do mundo ser uma grande máquina, que se movimenta sem a intervenção de Deus, tal como um relógio que continua a funcionar sem a assistência de um relojoeiro, é a noção do materialismo e do destino, e tende, (sob o pretexto de fazer do Deus uma inteligência *supra-mundane*) a excluir, na realidade, o governo e a providência de Deus do mundo» (*in* Alexander, 1976 : 14)

Deus manifesta-se, segundo o pensamento de Newton-Clarke, exactamente pela necessidade de intervenção sobre o funcionamento da natureza (… e intervém quando necessário). O carácter da intervenção divina no universo é, nesta polémica célebre, um dos objecto da atenção de Leibniz e, na sua terceira carta, argumenta no sentido de exemplificar o tipo de actuação divina. Uma argumentação que consiste em reafirmar a necessidade da invariância:

> «(…) se a força activa diminuir no universo, devido às leis naturais estabelecidas por Deus, assim ele deverá actuar no sentido de restaurar aquela força, tal como um artista burilando as imperfeições da sua obra, a desordem não está de acordo connosco, como não está de acordo com Deus. Ele deve tê-la evitado e tomado medidas para evitar tais inconveniências (...)» (*ibid.* : 29)

É uma referência explícita à ordem, à constância, a qualquer coisa que é imutável enquanto forma de preservar a natureza do caos e da desordem. A necessidade da conservação é o substrato da defesa do um princípio de causas finais. Clarke, na réplica seguinte, contraria a ideia de conservação, assumindo que, no universo, o tipo de forças, que Leibniz pensa conservarem-se, diminuem, concluindo então que este comportamento não representa nenhuma imperfeição,

> «(…) não há qualquer inconveniência, à desordem e à imperfeição na execução do artífice do universo (...) é uma consequência da natureza dos corpos dependentes» (*ibid.* : 34)

Para Leibniz a conservação da *vis viva* era uma questão central da sua dinâmica e, em particular, como regra a que os choques entre corpos teriam que obedecer; Clarke mostou que existiam choques onde tal conservação não se verifcava. O próprio Newton no Escólio referente aos Axiomas e Leis do Movimento dos *Principia* sustenta que

> «... depende da Lei III o que fizeram, Sir Christopher Wren, Dr.Wallis e o Sr. Huygens, os maiores geómetras de todos os tempos, para determinar as regras do impacto e da reflexão dos corpos (…)» (Newton, 1984: 22).

De outro modo, a própria conservação do momento linear, que se verifica nos choques de corpos, não é tomada como um princípio em sim, mas como uma decorrência da sua terceira lei… Não admira que na última peça da polémica, Samuel Clarke negue a conservação como princípio fundamental regulador do movimento universal (ou como forma de Deus manifestar, não a sua intenção de intervir, mas a sua intervenção efectiva e inicial na marcha do universo), deixando em aberto uma pergunta:

> «(…) não tem Deus a liberdade para fazer a natureza, que deve continuar na sua presença o tempo que lhe aprover, podendo ser alterada de qualquer modo que ele queira?» (*in* Alexander, 1976 : 113)

Este carácter da intervenção de Deus na regularização da marcha da natureza vai ser essencial na aceitação do newtonianismo, ou na separação entre este e as ideias de Descartes e Leibniz. Contudo, alguma restrição nesta liberdade de acção de Deus na natureza, permitirá a adequação do newtonianismo à existência de um princípio de causas finais (a que Newton parecia ser tão avesso). Newton defendia acerrimamente a não aceitação de um qualquer princípio de conservação como causa explicadora do movimento no universo: devem existir forças originais responsáveis pelo movimento, contudo não há que se preocupar com a explicação da origem dessas mesmas forças. O problema das causas finais não está no seu horizonte… No final dos *Principia* escreve

> «Mas até agora não fui capaz de descobrir a causa dessas propriedades da gravidade a partir dos fenómeno e eu não finjo hipóteses, pois tudo o que não é deduzido dos fenómenos deve ser tomado como uma hipótese; e hipóteses, quer metafísicas ou físicas, quer de atributos ocultos ou mecânicos não têm lugar na filosofia experimental» (Newton, 1984: 547).

Na óptica, a solução de Newton é muito semelhante à de Descartes e contraria a conclusão de Fermat e Huygens. Newton estabelece como postulado (axioma V) que a razão entre os senos dos raios incidente e refractado é (aproximadamente) constante e com isto tem o problema resolvido, pois não é chamado a provar nenhuma lei, este é um dado imposto pela observação. Contudo, perante o fenómeno da dispersão, vai ter que provar que a lei da refracção é verdadeira para o caso dos raios de diferente refrangibilidade obtidos (aquilo que hoje se chamaria, para os diferentes comprimentos de onda), é o que trata na proposição VI do Livro I. A conclusão é a seguinte,

> «(…) esta Demonstração sendo geral, sem determinar o que é a Luz, ou qual a Força responsável pela refracção ou indo um pouco mais longe assumindo que o corpo que provoca a refracção actua sobre os raios segundo linhas perpendiculares à superfície [de separação dos dois meios]» (Newton, 1979: 82)

E toda a demonstração assenta na assunção que a velocidade de propagação da luz (corpúsculo) é superior no meio mais refrangente do que no menos refrangente. Explicitamente nada é dito sobre esse «corpúsculo de luz», mas implicitamente essa ideia está sempre presente e, como adiante se mostrará, é explicitada nos *Principia*. De todos os seus antecessores, na construção de uma teoria da luz, o único nomeado é Huygens; uma nomeação respeitosa e necessária para acentuar a sua discordância quanto à teoria ondulatória defendida por este.

O *Query* 29 da *Óptica* de Newton abre com uma interrogação, «Não são os raios luminosos corpos muito pequenos emitidos pelas substâncias brilhantes?» (*ibid.*: 370), e umas linhas mais à frente acrescenta

> «Se a refracção é devida à atracção dos raios, os senos do ângulo de incidência devem estar para os senos dos ângulos de refracção numa dada proporção como mostrámos nos nossos Princípios de Filosofia, e esta regra é comprovada pela experiência» (*ibid.*: 370)

Newton remete a demonstração dessa regra para o que já escrevera nos *Principia*. Nesta obra, na última secção do Livro I, intitulada, «O movimento dos corpos muito pequenos quando provocados por forças centrípetas dirigidas para as várias partes de qualquer corpo muito grande», no primeiro período do escólio, o próprio Newton esclarece:

> «Estas atracções têm uma grande semelhança com a reflexão e a refracção da luz feita de acordo com uma dada relação das secantes, tal como foi descoberto por Snell, e, consequentemente, numa dada razão entre os senos, tal como foi exposto por Descartes» (Newton, 1984: 229).

O que mostra porque é que a solução de Newton é muito semelhante à de Descartes, explicando que

> «Portanto, por causa da analogia que existe entre a propagação dos raios de luz e o movimento dos corpos, pensei que não era errado juntar as proposições seguintes com objectivos de utilização em óptica, não com a preocupação de qual é a natureza dos raios luminosos, ou interrogando se são, ou não, corpos, mas apenas para determinar as curvas descritas pelos

corpos que são extremamente semelhantes às descritas pelos raios» (Newton, 1979: 370).

A utilização de uma secção dos *Principia* para expor matéria relacionada com a óptica pode parecer um pouco estranho, mas há dois motivos que talvez o justifiquem: primeiro, às observações astronómicas e aos fenómenos ópticos a elas associados; segundo, à já conhecida determinação da velocidade de propagação da luz feita por Roemer em 1676 e comunicada à Royal Society e à Academia de Paris.

É também na sua *Óptica* que Newton introduz um conceito de índole muito equivalente aos «percursos mais fáceis» de Leibniz: é a teoria dos acessos de fácil reflexão e de fácil transmissão («*Fits of easy Reflection*» e «*Fits of easy Transmisssion*») — definição seguinte à duodécima proposição do livro segundo, parte terceira — para explicar os fenómenos das lâminas delgadas (*ibid.*: 281). A natureza desta explicação mostra como Newton também escorregou, e não ficou imune, a argumentos de cariz teleológico.

Quadro 1. Síntese dos resultados sobre a refracção óptica dos principais intervenientes

	Princípio		
Descartes	Leis do movimento	$\frac{sen(i)}{sen(r)} = \frac{v_r}{v_i} = \frac{m}{n} = C$	$v_r > v_i$
Fermat	Princípio do Tempo Mínimo	$\frac{sen(i)}{sen(r)} = \frac{v_i}{v_r} = \frac{n}{m} = C$	$v_r < v_i$
Huygens	Teoria Ondulatória	$\frac{sen(i)}{sen(r)} = \frac{v_i}{v_r} = \frac{n}{m} = C$	$v_r < v_i$
Leibnitz	«caminho mais fácil»	$\frac{sen(i)}{sen(r)} = \frac{v_r}{v_i} = \frac{n}{m} = C$	$v_r > v_i$
Newton	Teoria corpuscular	$\frac{sen(i)}{sen(r)} = C$	$v_r > v_i$

4. Os Bernoulli e a aplicações do cálculo diferencial e integral

Como já se escreveu, Leibniz publicou em 1684 o seu artigo fundador de um novo cálculo, ilustrando as potencialidades deste método na resolução de alguns problemas físico-geométricos. Um outro matemático, o primeiro da mais célebre dinastia familiar de matemáticos, após conhecer os artigos de Leibniz, mostrou-se muito interessado no novo cálculo:

> «Efectivamente, pouco depois da sua nomeação em 1687 para a Universidade de Basileia, Jaime Bernoulli, pede, numa carta datada de 15 de Dezembro de 1687, a Leibniz vários esclarecimentos sobre certos aspectos do novo cálculo; mas este último ausente de Hanover (…) só responde três anos mais tarde através de uma carta datada de 24 de Setembro de 1690 (…) Entretanto Jaime Bernoulli não perdeu o seu tempo, sozinho assimilou o novo cálculo» (Blay, 1992: 25 [TA]).

Em 1687 Leibniz propusera, como aplicação do novo cálculo, a resolução doutro problema, a determinação da curva por si apelidada de isócrona — «uma curva descrita por um ponto material sob a acção do peso uniforme e cuja velocidade na vertical fosse constante» — e Jaime Bernoulli, como resultado do seu estudo, resolve o problema, mostrando que a solução é uma parábola semi-cúbica $y^2 = kx^3$ publicando-a na *Acta Eruditorum*. Jaime, a pedido do seu irmão mais novo João (I), inicia-o na nova arte do cálculo. E, a partir de 1690, os irmãos Bernoulli passaram a ser os grandes interlocutores matemáticos de Leibniz, empenhando-se activamente no estudo e na aplicação do novo método de cálculo.

Foi na estadia de João (I) Bernoulli em Paris, inverno de 1691-92 que o Marquis Guillaume de L'Hospital (1661-1704) foi iniciado por aquele no novo método leibniziano, permitindo-lhe a publicação, em Junho de 1699, do primeiro tratado de calculo diferencial, *Analyse des infiniment petits pour l'intelligence des lignes courbes*. Esta obra de L'Hospital, resultado das lições parisienses de Bernoulli, contribuiu decisivamente para a difusão do novo cálculo por toda a Europa académica.

Afastados da controvérsia das causas finais, não se pronunciando sobre a metafísica dos princípios, mas embrenhados na matemática, os irmãos Bernoulli, Jaime e João (I), passaram rapidamente de aderentes entusiastas das ideias matemáticas de Leibniz a proponentes activíssimos de novos problemas passíveis de serem resolvidos pelo novo processo de cálculo. É muito importante prestar atenção ao papel que desempenharam, porque a sua influência será determinante no rigor da formulação matemática do que virá a ser o Princípio da Menor Acção, o que se revelou de maior relevância do que as interpretações finalistas ou metafísicas de que foi sendo alvo.

Como afirmam alguns autores (aqui menciona-se só um):

> «A história da mecânica racional não é nem experimental nem filosófica (…) é uma história de problemas particulares, exemplos muito concretos para a resolução dos quais houve que criar novos princípios e métodos (…) o caso particular não era um fim em si mesmo, mas um guia para generalizações correctas (…)» (Truesdell, 1968: 96).

E nesta atitude pragmática de lançar novos problemas, suscitando novas resoluções, participam activamente os Bernoulli que vão fazer escola pelas suas contribuições para este tipo de desenvolvimento da mecânica racional: partindo da solução de problemas particulares criam novos métodos. Os problemas são essencialmente de carácter físico-geométrico: determinar uma trajectória para condições particulares do movimento, o que implicava essencialmente determinar a curva matemática descrita e estudar as suas propriedades, esta era a questão fulcral — talvez fosse mais correcto dizer que os problemas eram essencialmente cinemático-geométricos; noutros casos, procurava-se encontrar a forma da curva, ou da superfície (as suas propriedades), que correspondiam a situações de equilíbrio de corpos, como é o caso da vela (*velaria*) ou da cadeia suspensa (*catenária*).

O problema da catenária foi lançado pelo mais velho dos Bernoulli — «a determinação da curva descrita por um fio quando deixado cair livremente e estando suspenso entre dois pontos fixos». Galileu (1564-1642) pensara que a curva que resolvia este problema era uma parábola, mas estava errado[3]. O problema vai ser resolvido por Leibniz, Huygens e João (I) Bernoulli nas *Acta Eruditorum* de junho de 1691. Este último encontrará a solução por intermédio do cálculo infinitesimal, chegando à equação diferencial $\frac{dy}{dx}=\frac{s}{c}$, onde s representa o comprimento do arco entre os dois pontos de suspensão e c é uma grandeza que depende do peso específico do fio, a solução é dada pela função $y = c\cosh\left(\frac{x}{c}\right)$. João (I) Bernoulli, o segundo da dinastia Bernoulli e que se sentia ofuscado pelo talento do seu irmão mais velho (ou que se pretendia libertar do facto de ser o irmão mais novo…) ficou extremamente vaidoso por ter conseguido resolver este problema, coisa que o seu irmão, o proponente, não conseguira. A partir desta altura a relação entre os dois irmãos deteriora-se bastante, assumindo uma rivalidade publica bastante conflituosa (Peiffer, 2006)…

Entre outros problemas, ou desafios, que os Bernoulli lançam aos matemáticos da época, está, por exemplo, o célebre problema da braquistócrona — proposto na *Acta Eruditorum* de Junho de 1696 por João (I) Bernoulli — «linha percorrida por um ponto material quando se desloca de uma posição para outra ao longo da trajectória que corresponda ao menor intervalo de tempo». Problema a que Galileu também já se referira, avançado, contudo, com uma solução incorrecta[4].

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3 «(…) suspendamos nestes dois pregos uma corrente muito fina (…) esta corrente ao ser dobrada toma a forma de uma parábola (…)» (Galileu, 1988: 144).

4 «(…) o movimento mais rápido entre dois pontos não acontece na linha mais curta, nem na linha recta, mas por um arco de círculo (…)» (Galileu, 1988:235).

Parece que a este desafio não responderam os matemáticos de França, dos Países Baixos e de além Mancha, o que o levou, por proposta de Leibniz, a prolongar o prazo de resposta. O desafio voltou a ser repetido, na mesma revista, em Dezembro do mesmo ano, estipulando-se para prazo de entrega da solução a Páscoa de 1697. E o lançador do repto, João (I) Bernoulli, propôs-se divulgar a sua solução, bem como a de Leibniz, caso ninguém resolvesse o problema em causa (Goldstine, 1980:31). Em carta, João (I) Bernoulli já colocara o problema a Leibniz e este respondera-lhe de imediato, dando-lhe conta de uma solução possível. No sentido de facilitar a divulgação do desafio, os problemas enunciados (além da braquistócrona, Bernoulli juntara um outro) foram também publicados nos *Philosophical Transactions* e no *Journal des Savants*, tendo Wallis e Newton recebido cópias pessoais. Apareceram, além da solução apresentada pelo autor, outras cinco pertencentes a Newton, Leibnz, L'Hospital, Jaime Bernoulli e Tschirnhaus. Todas as soluções foram publicadas nas *Acta Eruditorum*[5]. A solução do proponente tinha a particularidade de se basear no Princípio de Fermat, abrindo deste modo o caminho para o cálculo variacional ou, indirectamente, para a aplicação matemática de um princípio de mínimo na explicação do comportamento da natureza. Sobre a resposta de Newton, dada a conhecer anonimamente, referencia-se, a este propósito, o relato da sobrinha deste, Catarina:

> «Quando em 1697 o problema foi enviado por Bernoulli - Sir I. N. estava em plena azáfama de uma grande cunhagem de moeda e só regressou a casa da Torre muito cansado por volta das quarto » (*in* Westfall , 1996: 582).

Nesse mesmo dia, 30 de Janeiro, Newton enviava uma carta a Charles Montagu (1661 – 1715), Presidente da Royal Society, onde constavam as soluções dos problemas em causa e que virão a ser publicadas anonimamente nos *Philosophical Transactions* desse mesmo mês[6]. É o próprio João (I) Bernoulli, autor do desafio, que escreve numa carta para Basange de Bauval:

> «(…) de facto, no número de Janeiro dos Philosophical Transactions, que devido á vossa amabilidade me chegaram, mostra que eu não me enganei, pois inclui a construção de uma curva de grande declive (descida rápida) que serve perfeitamente para o problema. Embora o seu autor, na sua excessiva modéstia, não revele o seu nome, podemos certamente, e para lá de qualquer dúvida, afirmar que é o célebre Senhor Newton. Mesmo que não tivesse nenhuma informação além desta, deveríamos reconhecê-lo

5 Maio de 1697: Leibniz, 201-205; João (I) Bernoulli, 206-211; Jaime Bernoulli, 211-217; Marquês de L'Hospital, 217-218; Tschirnhaus, 220-223.

6 Vol. 17, nº 224, reimpressa nas *Acta Eruditorum* de maio de 1697 (223-224).

pelo seu estilo, tal como o leão pela sua juba (...)» (*in* Chandrasekhar, 1995: 572).

A análise das diferentes resoluções deste problema pode ser consultada em (BLAY, 1992). Estes desafios constantes, lançados publicamente no meio académico, com o objectivo de resolver problemas diversos que envolvem movimentos particulares, vinha sendo uma prática de João (I) Bernoulli: em 1695, no suplemento das *Acta Eruditorum* aparecera o enunciado do problema da curva de igual pressão — tratava-se de encontrar, no plano vertical, a curva descrita por um corpo descendo livremente sob a acção do seu peso e de tal modo que em todos os seus pontos exista uma força constante igual ao seu peso. Este é mais um exemplo que permite mostrar que os problemas do movimento eram mais um pretexto do que um fim em si; o objectivo era a descrição da curva, utilizando para tal a nova conceptualização do cálculo Leibniziano. Reduziam-se os problemas do movimentos, ou outras questões físicas, a problemas eminentemente geométricos. Contudo todo este esforço vai reflectir-se quer no desenvolvimento da própria mecânica quer nos métodos matemáticos que lhe estão associados e, em particular, na formulação matemática do Princípio da Menor Acção. Um exemplo paradigmático desta situação são os problemas dos isoperímetros lançados por Jaime Bernoulli em 1697, como resposta ao desafio feito pelo seu irmão quando propôs o problema da braquistócrona. Este novo problema dará origem a um longo artigo na *Acta Eruditorum* de 1701 onde o mais velho dos Bernoulli expõe um método novo e eficaz para tratar este problema.

Jaime Bernoulli morreu em 1705 e a sua cátedra de matemática na Universidade de Basileia passou a ser ocupada pelo seu irmão João que nessa altura era professor na universidade da cidade holandesa de Groningen. Figura maior da matemática continental, apoiante incondicional do método de Leibniz e um partidário da teoria dos vórtices cartesianos, enquanto alternativa à gravitação newtoniana, foi a João (I) Bernoulli que se deveu a «descoberta» e a formação do jovem Euler. João (I) Bernoulli teve uma importante intervenção no debate sobre a *vis viva* (a controvérsia sobre as forças vivas) que em 1728 animou a Academia de Paris, tomando partido pela dinâmica leibniziana, sustentando o modelo dos vórtices de Descartes contra o modela da força de atracção de Newton.

Foi na resolução de problemas concretos que se destacaram os irmão Bernoulli, propondo soluções importantes e descobrindo novos métodos, mas será a Leonardo Euler, filho do seu ensino, que se ficará a dever o trabalho completo sobre o problema dos isoperímetros, publicado em 1744 e onde constam dois apêndices em que se aplicam, os métodos matemáticos aí descobertos, a dois problemas físicos — a flexão da lâmina elástica e o movimento resultante da aplicação de uma força central. Esta obra fará história no estabelecimento do Princípio da Menor Acção e mostra que foi pela via do cálculo matemático, não por quaisquer considerações ligadas às causas finais de Leibniz, ou outros, que Euler foi lançado no problema da minimização de uma grandeza, estabelecendo os primeiros passos para a formulação rigorosa desse Princípio... E, curiosa coincidência, foi também no ano de 1744 que Pierre-Louis Moreau de Maupertuis apresentou na Academia Francesa uma comunicação intitulada «*L'accord de différentes lois de la nature qui avaient jusqu'ici paru incompatibles*», onde aparece pela primeira vez enunciado o Princípio da Menor Acção.

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Práticas comemorativas – práticas científicas: o ciclo de 1937, em Lisboa.

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Abstract
The cultural and scientific practices of commemorations are part of the history of science in social context in order to get the image of construction of a scientific and institutional memory. It's our intention to do the archaeology of «words and ideas» in the commemorative cycle Lisbon Polytechnic School (1837 - 1937): an important assessment to understand the scientific scope *Escola Politéncia* Street, the heart the scientific and cultural heritage as the **Hill of Science in Lisbon**, in 2010.

1. Introdução: a colina da ciência, em Lisboa

A Rua da Escola Politécnica em Lisboa assume-se na malha urbana da capital como um espaço de valorização patrimonial científico de grande porte e de grande importância para a história da ciência de Portugal e da Europa[1].

Importa, hoje, saber caracterizar e reconhecer espaços e estruturas de produção científica no contexto da actividade científica de uma comunidade profissional, historicamente analisada. É necessário ter me conta na perspectiva de uma história cultural e social das ciências a vida das instituições científicas como entidades culturais e produtoras de saberes, que conduziram, em determinado momento, ao triunfo do espaço do Laboratório (Citsul 1996, 1998).

[1] Este texto resulta do cruzamento de várias investigações levadas a cabo no âmbito do CEHFCi – Centro de Estudos de História e Filosofia da Ciência, uma realidade institucional que muito deve ao espírito visionário do Professor Rui Namorado Rosa, como universitário de vários saberes interdisciplinares. Em 2002, a lição apresentada para a Agregação em História Cultural Contemporânea subordinou-se ao tema ***História da História da Ciência em Portugal: 1872-1953. Da construção cultural de uma memória à identidade da comunidade científica em Portugal***. Nos anos seguintes este tema foi trabalhado no âmbito do CEHFCi, especialmente com Augusto Fitas; muitos dos seus contributos foram tema para seminários de Mestrados e de Programas de Doutoramento na Universidade de Évora. Sob o ponto de vista de memória pessoal cultural a temática foi enriquecida por longas deambulações pela Rua da Escola Politécnica de Lisboa com o Professor doutor Fernando Bragança Gil (1927-2009).

Neste contexto, a circulação, e a utilização, de objectos científicos devem ser perspectivadas como uma das consequências da profissionalização da investigação científica que à medida que se vai socialmente afirmando vai construindo uma comemoração de memória científica como uma prática cultural reconhecida e valorizada pela sociedade (Commemorative Practices 1999 –Osiris; On Time 2000-BJHS)

Uma das consequências – em termos de projecção futura – desta capacidade de fixar memória científica é a possibilidade de fazer emergir no contexto colectivo a vertente do património científico. Um campo de intervenção para os historiadores, num trabalho interdisciplinar de «applied history», que permite, hoje, entender a dinâmica de processos culturais e científicos que se encontram inerentes ao núcleo de Museus da Universidade de Lisboa – popularizados como os museus da Politécnica - tendo como um dos epicentros patrimoniais e museológicos o Laboratório de Química, oitocentista, único na Europa (Lourenço e Carneiro 2009).

Pretende-se articular o ciclo comemorativo oficial do primeiro centenário da fundação da Escola Politécnica em Lisboa – em 1937 – com a valorização de uma memória científica organizada, sistematizada, disponível para em outros contextos de dinâmica da sociedade portuguesa se poder pôr em marcha projectos de valorização e de utilização social e cultural de uma memória científica fixada num tempo específico: o ciclo de comemorações dos anos trinta do século XX em Portugal: 1837-1937 (Fitas, Rodrigues, Nunes 2008; Nunes 2004).

2. Memória Científica

A análise e o estudo da construção cultural e social da memória, desde Maurice Halbawachs (1968) têm sido um tópico fundamental para cruzar a perspectiva do Positivismo com a construção historiográfica da realidade cultural, mental e social do final do século XIX e de todo o século XX. Sinal inequívoco desta fixação do tempo (dito) contemporâneo, marcado por variados ciclos de comemorações e homenagens, são as grandes tarefas do Estado francês em torno das (bi)comemorações da Revolução Francesa, levantando uma série de inovações, ao nível da encenação dos festejos, mas sobretudo ao nível de novas perspectivas de análise e de investigação sobre a memória e os vários significados dos signos *festa* vs. *comemoração* (Nora 1984-1998; Nunes 1998)

A par das práticas de representação cultural e de manifestações cívicas e públicas dos ciclos de comemorações e de rituais de realizações festivas – desde o culto cívico dos centenários oitocentistas às comemorações oficiais, e não oficiais, das feiras de vaidades e de manifestações colectivas dos Descobrimentos, culminando na Expo' 98 – procurámos canalizar este olhar de desmontagem de história cultural *vs.* história da cultura para a celebração de memórias ligadas à história da actividade científica, da comunidade e das instituições científicas em Portugal, desde o final do século XIX até meados do século XX.

Antecedes: Coimbra, 1872. As determinações de Júlio Máximo de Oliveira Pimentel – enquanto Reitor da Universidade de Coimbra – marcam uma gramática de referências para se celebrar e se comemorar a Reforma Pombalina, ou seja o sentido de inovação e de modernidade europeia que Sebastião José de Carvalho e Melo e os autores do *Compêndio Histórico* pretendiam dar à (única) Universidade Portuguesa da época. Marcam, afinal, uma matriz de fixar, pela escrita e por rituais, a construção da memória de acontecimentos, de biografias, de instituições, de espaços e de produção de textos a editar e a alimentar os corredores de leitura de cultura científica (Cruzeiro 1988)

Centenários: História da Ciência

A memória das instituições – a produção endógena do passado/história de uma instituição científica. A Academia das Ciências de Lisboa – o papel da publicação de relatórios de balanços históricos, dos índices remissivos nas suas publicações; as edições de homenagens e de ciclos de comemorações. A organização de biblioteca, do arquivo e de material museológico existente. Da Escola Politécnica e da Academia Politécnica às Faculdades de Ciências de Lisboa e Porto, respectivamente – a fixação de uma memória científica institucional em paralelo com a da Universidade de Coimbra. Regras de fundamentação, de exclusão e de afirmação no seio da comunidade científica portuguesa (Bries et all 1996).

Comemorações e Cerimoniais Científicos – Rituais e produção de discurso científico 1934 – 1937 – 1940; do III Congresso Internacional de História da Ciência (1934) às Comemorações do signo **POLITÉCNICA**; a história da actividade científica em Portugal no contexto dos Congressos do Mundo Português – uma outra «festa» para comemorar e celebrar a «política do espírito» de António Ferro (Nunes 2004; Congrès 1936).

3. 1937- Rua da Escola Politécnica: eixo da colina da ciência de Lisboa

Do itinerário efectuado verificamos a existência de sinais inequívocos da construção física, material, editorial e simbólica de uma memória científica, fundamentalmente em Lisboa, Porto e Coimbra. Encontramos ligações entre a produção de discursos e a existência/preservação de espaços científicos construídos, arborizados – Jardins Botânicos – musealizados – em activo ainda, vivos, podendo efectuar-se uma proposta de roteiro de locais, de espaços de sinais vivos da perpetuação da memória científica e da identidade da comunidade científica guardada em bibliotecas, em espólios colectivos e individuais, em sótãos ainda por desvendar, abrir e catalogar.

Encontramos, no campo da edificação e da construção material da memória científica inscrições deixadas no espaço público pelas «sentinelas de pedra» que sobreviveram ao efémero da comemoração, e da festividade de uma aparente onda de afectividade colectiva da comunidade científica (Léonard 1999).

Consideramos que algumas dessas sentinelas foram construídas com a deliberação da Faculdade de Ciências da Universidade de Lisboa, em 1937 – comemorar o «I aniversário da fundação da Escola Politécnica [...] esta celebração veio pôr em foco cem anos de actividade científica e pedagógica, com profundos reflexos na vida social e económica da Nação, veio comprovar, recordando essa actividade, a razão que assistia aqueles que, há um século, com inteligente visão, reconheceram a necessidade de alargar as possibilidades do ensino superior no nosso país [...] Porque isto se reconheceu e porque a comemoração centenária constituía, para a escola, hoje, motivo de justificado júbilo e causa de natural estímulo, neste primeiro número da *Revista da Faculdade de ciências da Universidade de Lisboa* pareceu justo e acertado dar conta, para o futuro, ainda que em resumida notícia, do que foi essa comemoração» (*Escola Politécnica de Lisboa. Comemoração 1º Centenário* 1937:5)[2].

A Faculdade de Ciências entendeu que o conjunto de actividades celebrativas públicas deveriam constar, pormenorizadamente, de um número especial da publicação oficial da instituição, incluindo os relatos circunstanciados dos discursos, do programa social e cultural existente e fornecendo à comunidade académica da Universidade e à opinião pública a possibilidade de tomar contacto com a positividade das fotografias oficias tiradas para a posterioridade.

Este aspecto da reportagem fotográfica oficial parece-nos de um duplo interesse para a investigação em história das ciências. Por um lado temos um testemunho material visível para, no futuro, se olhar as estruturas de património científico e os de registos sociais e culturais de uma época. Numa outra perspectiva, estas imagens eram publicadas na imprensa informativa da época, como os jornais *O Século*, o *Diário de Notícias*, ou obrigavam a referências episódicas nas revistas científicas de história da ciência existentes, caso de *Petrus Nonius* (Fitas, Rodrigues, Nunes 2008).

A observação das figuras 1, 2 e 3 permite-nos uma sequência de registos que nos permitem obter algumas pistas de reflexão. Em primeiro lugar, o impacto que uma realização da Faculdade de Ciências teve na Academia das Ciências de Lisboa, o capital simbólico do saber e do poder usados para

[2] Nas breves transcrições que realizamos, usamos a grafia actualizada.

cimentar algo de fundamental para a Universidade de Lisboa: marcar o início do ensino superior das ciências em Lisboa, ocupando o antigo espaço do Colégio dos Nobres, um traço de permanência científica na colina lisboeta que contempla, igualmente, a existência da sede da Academia das Ciências de Lisboa, na rua do mesmo nome.

Um jogo de toponímia lisboeta que contempla várias camadas de memória científica para um mesmo local, numa perspectiva de longa duração, desde o terramoto de Lisboa de 1755. Quando o Noviciado da Cotovia não desabou e pode albergar as colecções científicas estrangeiras para o pombalino Colégio do Nobres em 1761. Informações que se encontram incorporadas na textura da memória comemorativa do 1º centenário da Politécnica (Fig. 3), onde não faltam as referências de erudição bibliográfica oitocentista sobre todo este processo, caso de Alexandre Herculano ou de José Silvestre Ribeiro e a monumentalidade da sua História dos Estabelecimentos científicos em Portugal (18 volumes).

Uma clara aliança entre o ofício de construtor de memória e o dever científico e cultural de comemorar a memória de um estabelecimento científico e académico que se havia imposto na geografia da capital portuguesa.

Presidência da sessão solene realizada no salão nobre da Academia das Ciências

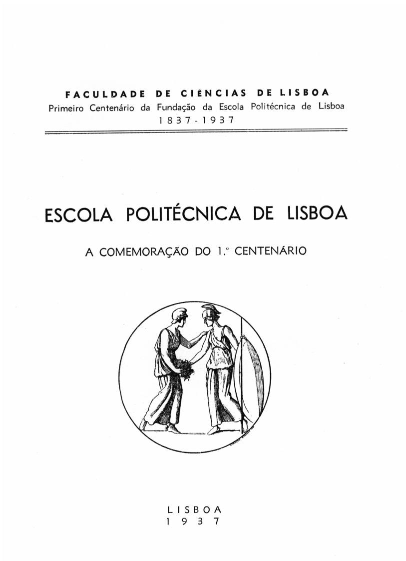
Fig. 1. Aspecto da sessão solene realizada no Salão Nobre da Academia das Ciências de Lisboa, 1937.

Um aspecto da assistência à sessão solene realizada na Academia das Ciências

Fig. 2. O público presente na Academia das Ciências de Lisboa, ou aspectos da sociabilidade científica e cultural da comunidade académica de Lisboa, em 1937.

Duas imagens de aspectos da sociabilidade de época que podem ser úteis para o estudo da história da vida privada das instituições, que pode ser comparada com outras reportagens fotográficas semelhantes, as dos rituais sociais dos Congressos científicos, nacionais e internacionais.

Estamos em crer que estes aspectos mundanos da história da ciência podem ser campos de investigação muito férteis para se entrar nos domínios das projecções sociais, políticas e ideológicas dos actores científicos que protagonizam os eventos. Por outro lado, estas galerias de fotografias a são um excelente repositório informativo para se visualizarem no tempo e no espaço a construção de redes de ligação da comunidade científica, quer a nível nacional quer a nível internacional (Fitas, Rodrigues, Nunes 2008).


FACULDADE DE CIENCIAS DE LISBOA
Primeiro Centenário da Fundação da Escola Politécnica de Lisboa
1837-1937

ESCOLA POLITÉCNICA DE LISBOA

A COMEMORAÇÃO DO 1.º CENTENÁRIO

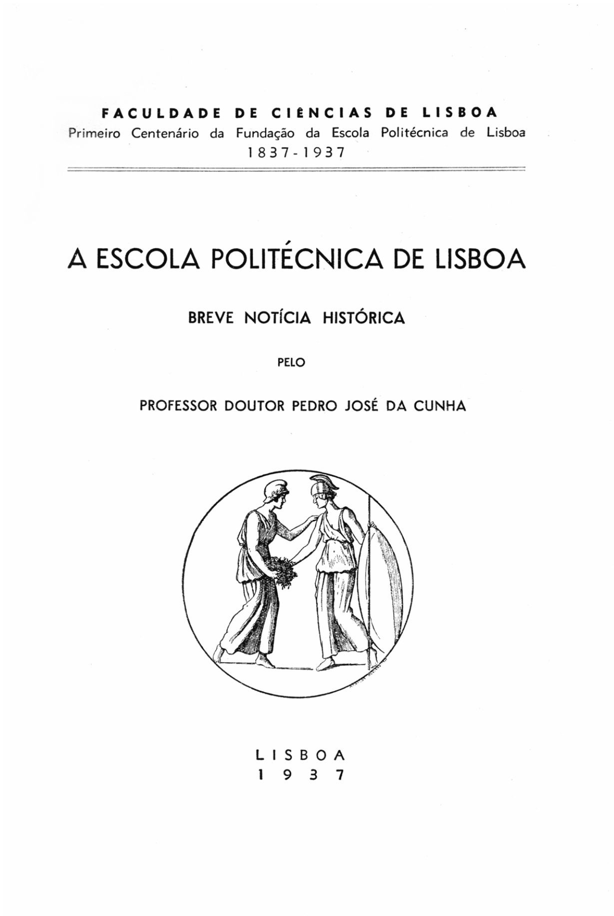
LISBOA
1937

Fig. 3. Capa do número temático da *Revista da Faculdade de Ciências de Lisboa* dedicada ao primeiro centenário da Fundação da Escola Politécnica de Lisboa 1837-1937. Um relatório que cobre os discursos dos Directores de Faculdades das Universidades de Lisboa e do Porto, para além das alocuções dos Reitores das duas universidades. Regista-se a ausência de representação da Universidade de Coimbra, nesta celebração do centenário da Politécnica em Portugal. Como complemento da parte protocolar a publicação oferece ainda a possibilidade de visionar aspectos da «festa de confraternização realizada no «Club Maxim's» – com destaque para vários antigos alunos da antiga Escola Politécnica».

O conjunto de estudos preparados e publicados no tempo da organização do Centenário da Politécnica constituem um verdadeiro património científico para o conhecimento da história daquele espaço desde o século XVII – Noviciado da Cotovia, Colégio da Companhia de Jesus – consagrado ao ensino e á Filosofia Natural, às Ciências, depois da legislação republicana de 1911.

O que nos importa reter neste ciclo comemorativo é a enorme importância de os historiadores da ciências (a trabalhar com os profissionais do património científico e da museologia das ciências e dos espaços científicos) poderem usufruir de material de fontes, a par de um discurso de valorização do espaço referente às várias camadas arqueológicas que o tempo de devir foi compondo. A diversidade das áreas científicas que os vários contributos inserem neste ciclo de edição comemorativo da *Revista da Faculdade de Ciências* constitui um caleidoscópio preciso para caracterizar a colina da ciência de Lisboa. A

Lisboa. A sequência das imagens 4, 5, 6 e 7 remetem para uma consulta obrigatória deste espólio documental global sobre as instituições que se ergueram e funcionaram no espaço em apreço: laboratórios, observatórios, jardim botânico...



FACULDADE DE CIÊNCIAS DE LISBOA
Primeiro Centenário da Fundação da Escola Politécnica de Lisboa
1837-1937

A ESCOLA POLITÉCNICA DE LISBOA

BREVE NOTÍCIA HISTÓRICA

PELO

PROFESSOR DOUTOR PEDRO JOSÉ DA CUNHA

LISBOA
1937

Fig. 4. Pedro José da Cunha e a (sua) memória histórica.1937.

FACULDADE DE CIÊNCIAS DE LISBOA

Primeiro Centenário da Fundação da Escola Politécnica de Lisboa

1837-1937

ESCOLA POLITÉCNICA DE LISBOA

O MUSEU MINERALÓGICO E GEOLÓGICO

PELO PROFESSOR

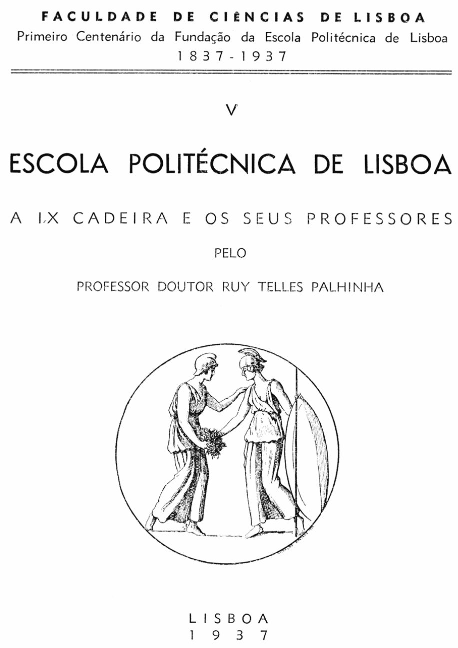
DOUTOR ALFREDO AUGUSTO DE OLIVEIRA MACHADO E COSTA

DIRECTOR DO MUSEU

LISBOA

1937

Fig. 5. Um texto documental de grande importância para o registo da «museologia científica» e a sua articulação com o espaço da Escola Politécnica ao longo do século XVIII-XX, em articulação com os demais espaços de ciência/ museológicos naturais.



FACULDADE DE CIENCIAS DE LISBOA
Primeiro Centenário da Fundação da Escola Politécnica de Lisboa
1837-1937

V

ESCOLA POLITÉCNICA DE LISBOA

A IX CADEIRA E OS SEUS PROFESSORES

PELO

PROFESSOR DOUTOR RUY TELLES PALHINHA

LISBOA
1937

Fig. 6. A Botânica, o Jardim Botânico e os cultores da Agricultura científica no século XIX-1937. As redes científicas dos botânicos em Lisboa: Escola Politécnica, Museu Nacional de Lisboa, Jardim Botânico, além de evidenciar os contactos científicos dos heróis científicos nacionais: José Maria Grande, João Andrade Corvo, Conde de Ficalho, Xavier Pereira Coutinho e Ruy Telles Palhinha, fotografado com traje académico.

Uma sequência de referências que podem ser completadas com os contributos da dupla Achilles Machado - António Pereira Forjaz para as cadeiras de Química e os textos de Amorim Ferreira para a Física Experimental e Matemática e para a monografia do Observatório do Infante D. Luiz, património histórico da climatologia em Portugal. Textos, fotografias identificadas, material de arquivo cruzadas com impressões vivenciais escritas pelos protagonistas deste primeiro centenário da Politécnica. Afinal um conjunto de referências que constituem um espólio documental fundamental para a actualização de hipótese e de trabalho no campo da história da ciência em Portugal (Faculdade de Ciências 1987; Memória de Professores 2001)

4. Uma colina da ciência, numa capital europeia

Em 1994 Lisboa, tempo de uma capital da cultura na Europa, inventou a designação da 7ª colina. Um espaço urbano que se insinua a partir da fonte pública setecentista do Largo do Rato e se projecta para o Tejo, abrangendo o Bairro Alto, abraçando o Camões e o Chiado, ao mesmo tempo que se apropria da Rua da Escola Politécnica, do Príncipe Real, da Rua da Academia das Ciências de Lisboa, mas também do Alto de Santa Catarina e do Museu de Farmácia, entidade privada, mas *ex-libris* da museologia científica internacional.

A contemplarmos a construção da memória científica do espaço do noviciado da Cotovia até ao complexo dos «Museus da Politécnica» – sob jurisdição da Universidade de Lisboa - percebemos que este eixo de Lisboa se insinua ao viajante, ao estudioso, ao forasteiro sem rota como um itinerário obrigatório para um percurso de turismo cultural e científico. Urge elaborar este guia de Lisboa, tal como existe para Madrid (Lafuente 1998) e a sua elaboração de combinação de rigor histórico com sedução para recantos únicos só pode ser construído após uma análise sistemática, laboriosa e intensiva do ciclo de produção de textos do I Centenário da Escola Politécnica de Lisboa.

Estes arquivos informativos – personalizados pelo seu Autor – são o rosto colectivo da Faculdade de Ciências nos anos trinta do século XX. Constituem uma documentação que não pode ser nem esquecida nem relegada para um plano secundário quando se trata de pensar o que fazer com o património científico da Politécnica, com um potencial de camadas de história da Europa cultural e científica fundamental para o cidadão do século XXI. Uma gramática de estilo na qual se aprende a pensar na interligação entre instituições, nacionais e internacionais, nas múltiplas sociabilidades científicas e lúdicas do rosto colectivo – e humanizado – de uma instituição que marcou várias etapas da vida científica nacional cruzando-se com a perspectiva internacional e comparada da Ciência, da cultura científica e humanística da Europa (Godinho 1998; Diogo *et all* 2000; Fox 2006).

Uma herança de código genético fundamental para visionar o presente e sonhar o devir das próximas décadas, no âmbito de um projecto de cidadania global com respeito pelos valores de património cultural e científico que o passado foi depositando nos anais da história das instituições científicas, contribuindo para a comunidade científica poder construir, a par do seu tempo vivencial, identidades científicas e identidades culturais que se encaixam na memória e no presente de uma da Europa patrimonial (Jesuíno 1995; Fortuna 1999; Gonçalves 2001).

O ciclo de práticas comemorativas de 1937 não esgotou o tema da Escola Politécnica. Ciclicamente o tema da história – memória colectiva da actual Universidade de Lisboa vem para o debate do espaço público. 2011 será o próximo grande ciclo comemorativo – o I Centenário da Universidade de Lisboa e da Faculdade de Ciências. Decerto um bom pretexto para o eterno retorno da oficina da história e voltar a reler, a reflectir sobre o abundante material que os professores da Faculdade de Ciências souberam organizar e divulgar no seio da sua comunidade académica (Philosophical Imagination 1993).

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Energia, natureza e sociedade nos textos de Lavoisier e Séguin

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Resumo
Através de uma breve incursão aos textos de Lavoisier e Séguin sobre a respiração dos animais, 1789-1791, apresentados à Academia das Ciências em Paris, pretendemos mostrar como a utilização da História da Ciência em contextos educativos tem as suas especificidades. No caso presente, em pleno reinado do calórico, deparamos com um dispositivo físico e narrativo que muito poderá ajudar na construção do conceito de energia. Tendo como *corpus* principal o texto *Premier Mémoire Sur la Respiration des Animaux* (1789), discutiremos os conceitos de ciência, natureza e sociedade aí inscritos.

1. Introdução

"The unrewarding,
eventually impossible, task of the […] teacher is to
help the pupil to uncover a secret,
which even the teacher himself cannot know."

Kurki-Suonio noted in
his farewell lecture (1998)[2]

Muito se tem escrito sobre as vantagens e os perigos da utilização da História e Filosofia da ciência em contextos educativos. Não é nossa intenção fazer a síntese do pensamento que sobre ela tem sido produzido mas apenas dar sentido e submeter à discussão algumas ideias que me têm orientado na minha investigação.

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[2] Citado por Siemsen, H e Siemsen, K. H., 2009, p.314

Permitam-me recuar um pouco mais de um século (1890) e ouvir algumas partes do importante pensamento pedagógico de Ernst Mach (citado por H. Siemsen e K.H. Siemsen, 2009)[3] no que diz respeito à forma como aproximar a ciência dos estudantes: " Como poderemos, então, preparar as mentes dos estudantes para anuírem a uma proposição e captarem o seu sentido? Simulando um caminho semelhante ao percorrido pelo inventor; investigando os poucos factos que o inventor estudou em primeiro lugar; reproduzindo as análises e as extensões através das quais se chegou à lei geral". Com efeito Mach não se cansa de proclamar: "there is only one way to enlightenment: historical studies" Ou seja, os estudos históricos eram já preconizados como a forma mais significativa de aproximar os estudantes da ciência. A expressão "estudos históricos" talvez se adapte melhor à utilização que pretendemos fazer da História da Ciência.

Porquê este recuo se temos tanto pensamento sobre o assunto desenvolvido essencialmente nas últimas três décadas? Porque nos continua a interpelar no que diz respeito às finalidades da educação científica. Com efeito, esta frase, numa primeira leitura, poderá parecer banal mas ela encerra na sua clareza e simplicidade, uma preciosidade (segredo) que traduz bem o pensamento pedagógico deste pensador: começar por "prestar atenção" a factos concretos e experienciá-los na sua concretude (os factos) e no seu lado imaginativo (as extensões).

Esta ideia central do pensamento pedagógico de Mach tem sido valorizada nalguns estudos contemporâneos nomeadamente num texto de H. Siemsen e de H.K. Siemsen (2009) onde é defendida a ideia de que o sucesso da educação em ciências na Finlândia se deve à presença de um pensamento pedagógico de raiz "macheana". No que aqui nos interessa este pensamento traduz-se contra uma história geral e portanto abstracta. Para além disso, parte do pressuposto que a única forma de compreender conceitos e teorias científicas é através dos estudos históricos que incluem os não vencedores. Para Mach os caminhos percorridos, as questões colocadas poderiam ter sido outros e os não vencedores são igualmente importantes do ponto de vista educativo.

No que à educação científica diz respeito interessa-nos salientar a crítica emergente aos contextos de mudança conceptual. Estes têm, ao longo dos anos, influenciado reformas, práticas, metodologias de investigação, mas não têm ganho os estudantes para a ciência. Ora a partir dos anos 80, com os textos de Bruner, começou a pensar-se a importância das narrativas na educação científica. Com elas o significado, o valor do conhecimento, a ligação ao mundo, começam a tomar relevância. E as narrativas históricas começam a ser alvo de grande interesse. Veja-se, por exemplo, o texto de Stephen Klassen (2009), *The Construction and Analysis of a Science Story*, em que é apre-

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[3] p.315

sentado o caso da utilização de uma narrativa que pretende valorizar a experiência que os estudantes universitários realizam sobre a absorção da radiação por diferentes substâncias. De facto, a narrativa faz-nos interessar pela problemática da protecção à radiação de uma forma forte transformando o aborrecimento que muitas vezes habita a experiência (registo mecânico das contagens do contador Geiger) em algo de vivo e de precioso.

Se seguirmos o autor deste artigo constatamos que a primeira questão que se coloca é a de saber que perspectiva de história da Ciência se veicula quando se concretiza uma narrativa. As perspectivas são muitas e variadas O historiador da ciência trabalha, de forma geral, numa determinada perspectiva. Nos contextos educativos são utilizadas diferentes perspectivas de acordo com a questão educativa que colocamos e uma narrativa pode incluir diferentes aproximações à História da Ciência. A História do historiador tem de ser mediada e recriada para poder ser utilizada em contextos educativos. Este aspecto tem colocado muitos problemas e dado origem a discussões acesas entre diferentes correntes[4].

2. Uma experiência

> "I [...] regard sense impressions as the source of all experience, but I do not believe that they should be consigned to oblivion again as soon as physical concepts have been formed"
>
> Ernst Mach, 1909[5]

Para tratar a temática proposta disponho da narração de Lavoisier de uma das mais bonitas experiências da História da Ciência. E digo bonita porque para além de nos impressionar pela ocupação que faz do espaço, qual instalação artística, impressiona-nos pela elegância dos gestos, pelo conhecimento e imaginação nela encapsulados, pela acção e artificialização nela contidas, e sobretudo pela relação especial sujeito-objecto. A experiência, registada visualmente por Madame Lavoisier, e aqui representada na figura 1, ocorreu num momento em que o conceito de energia ainda iria precisar de 50anos para se desenvolver e emergir com clareza. Estamos em pleno reinado do calórico. E, no entanto, todo o dispositivo físico e narrativo poderá ajudar a contactar com um conceito científico de forma significativa: a energia.

O conceito de energia que hoje utilizamos não é susceptível de compreensão. Lê-se, por exemplo, num manual escolar do 10ºano: "os cientistas

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[4] Para quem as queira seguir remetemos para a consulta da revista Science & Education.

[5] p.37

descobriram que, num sistema isolado, a quantidade total de energia permanece sempre a mesma ao longo do tempo". Estamos perante uma proposição geral, inacessível, com significado formal mas com pouco significado conceptual e, portanto, pouco mobilizadora do pensamento. Do ponto de vista de Mach seria um mau exemplo de aproximação aos alunos. É de tal forma pouco mobilizadora do pensamento que nem ocorre ao aluno questionar o que é a energia? Para alguns cientistas esta questão não fará sentido pois estão instruídos numa tecnociência que lhes permite desenvolver formalismos, importantes sem dúvida, mas que os afasta, por vezes, do exercício do pensamento.

1789. Paris. A Academia das Ciências reúne-se para ouvir falar da respiração dos animais. Lavoisier e Séguin têm já um conjunto de resultados que querem comunicar. A vida de Lavoisier é muito intensa em termos da variedade de actividades que desenvolve no momento. De entre elas a ciência é objecto de grande investimento. Dedica seis horas por dia à ciência e um dia por semana à realização de experiências no laboratório do Arsenal. Este dia é o mais esperado e é uma honra ser admitido no círculo para assistir às experiências. Antes de comunicar os resultados à Academia, Lavoisier tem o cuidado de convidar cientistas que possam testemunhar aqueles acontecimentos. Contudo, antes da experiência aperfeiçoada, quantas vezes não terá sido realizada! Estamos em plena Revolução Francesa mas neste laboratório o empolgamento centra-se na analogia que recentemente se desenvolveu entre a combustão e a respiração. Ela é inspiradora para Lavoisier e Séguin, tanto do ponto de vista do conhecimento como do ponto de vista da visão da natureza e da sociedade.

M. Séguin disponibilizou-se para um conjunto de experiências, sendo ele uma parte importante do próprio dispositivo experimental. Estamos perante uma bela instalação. Percebemos pela imagem que não terá sido muito confortável para Séguin e que são necessários vários intervenientes. O pulso de M. Séguin é alvo de grande atenção. O que está em causa neste conjunto de experiências é uma comparação entre consumos de ar vital, oxigénio, e diferentes estados e actividades do ser vivo. Tratando-se de experiências difíceis de realizar há que encontrar uma maneira que nos permita comparar esses estados e actividades. Foi para isso que tanto incómodo serviu…

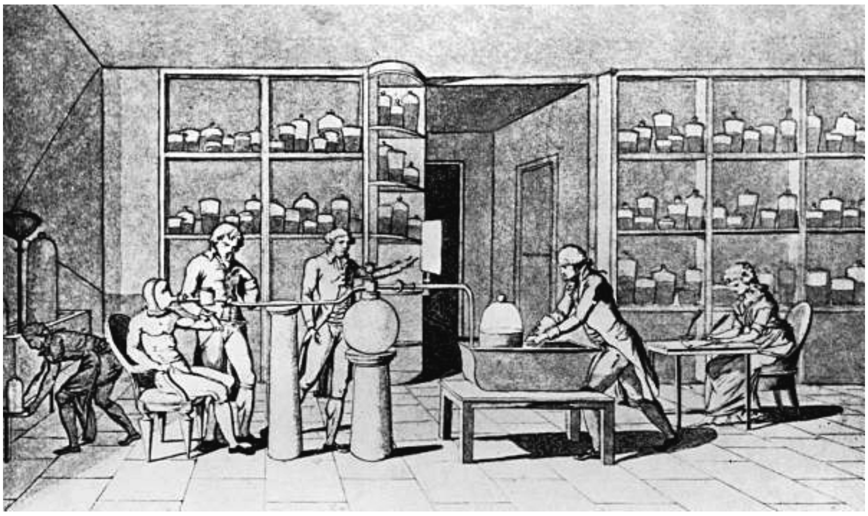

Fig. 1. Experiências sobre a respiração. Sépia de Mme Lavoisier[6]

"Por muito que estas experiências fossem penosas, desagradáveis ou mesmo perigosas, M. Séguin quis que todas elas se realizassem sobre ele"[7], como está escrito no *Mémoire* da Academia. Sigamos, então, os resultados enunciados destas experiência

"Um homem em jejum e num estado de repouso e a uma temperatura ambiente de cerca de 26º, termómetro de mercúrio dividido em 80 partes, consome por hora cerca de 1210 polegadas de ar vital; [que] este consumo aumenta com o frio, o mesmo homem, igualmente em jejum e em repouso mas numa temperatura ambiente de 20º, consome por hora 1344 polegadas de ar vital.

Durante a digestão, este consumo eleva-se a 1800 ou 1900 polegadas.

O movimento e o exercício aumentam consideravelmente todos estes valores. Estando M. Séguin em jejum e tendo elevado um peso de 15 libras, durante um quarto de hora a uma altura de 613 pés, o seu consumo de ar neste tempo foi de 800 polegadas, quer dizer de 3200 polegadas por hora. O mesmo exercício feito durante a digestão levou a um consumo de 4600 polegadas por hora de ar vital. Os esforços que M. Séguin realizou neste intervalo equivalem à elevação do peso de 15 libras a uma altura de 650 pés, durante

6 Retirada da obra *Lavoisier* (1993) de B. Bensaude-Vincent. Esta autora utiliza uma fotografia de J.-L. Charmet

7 p.695

um quarto de hora. Em todas estas experiências a temperatura do sangue permanece quase constante"[8].

Do exposto entrevemos já uma maneira possível de comparar as diferentes actividades realizadas num determinado intervalo de tempo, comparando o ar consumido com a elevação de um determinado peso a diferentes alturas. Comparar, por exemplo, a digestão e o pedalar de uma bicicleta à elevação de um peso a uma determinada altura, permite-nos entrever que algo de comum haverá entre estes dois acontecimentos. Mas há uma dificuldade no exercício desta comparação: será sempre necessário sujeitar o indivíduo a experiências penosas. Procuram-se, então, outros sinais, que se possam relacionar, de forma segura, com a referida elevação do peso. E é aí que é desenvolvida uma lei empírica que estabelece que o aumento do nº de pulsações é directamente proporcional à soma dos pesos elevados a uma determinada altura. Entramos assim na posse de um "instrumento" que nos permite comparar "o uso de forças entre as quais pareceria não existir nenhuma relação". "Podemos, por exemplo, conhecer a quantas libras de peso elevado a uma determinada altura correspondem os esforços de um homem que recita um discurso, de um músico que toca um instrumento. Poderíamos mesmo avaliar o que há de mecânico no trabalho do filósofo que pensa, do homem de letras que escreve, do músico que compõe. Estas realizações, consideradas como puramente morais, têm qualquer coisa de físico e de material que permite, do ponto de vista desta relação, compará-las com as do trabalhador físico (homme de peine). Há, pois, alguma justeza na designação comum, na língua francesa, de trabalho, tanto para os esforços do espírito como para os do corpo, o trabalho de gabinete e o trabalho do assalariado". [9]

Esta entre-medida (nº de pulsações) é comparável ao papel do equivalente mecânico do calor que nos permitirá uma unificação do mundo físico sem a necessidade de reproduzir a célebre experiência de Joule, tão difícil de realizar. O dispositivo de que temos estado a falar põe ainda mais problemas por incluir o humano no próprio dispositivo. Podemos imaginar o nº de pulsações do Sr. Séguin aumentar substancialmente quando pressente que se estão a aproximar de ideias justas. Mas, hoje, que há testemunhas, na realização da experiência, O sr. Séguin terá de evitar que as suas emoções provoquem problemas. Toda esta instalação testemunha o carácter artificial do trabalho de laboratório. Mas é a compreensão da natureza que mobiliza estes trabalho.

[8] p.696
[9] p.697

3. Da natureza à sociedade

"Interest in education is only an expression of our interest in the world and in humanity"
Herbart, citado por Otto Blüh, 1975[10]

"Enquanto considerarmos a respiração apenas do ponto de vista de consumo de ar, a sorte do rico e do pobre é a mesma porque o ar é de todos e nada custa a ninguém. *L'homme de peine* que exerce mais esforço físico frui mais completamente deste benefício da natureza. Mas agora que a experiência nos ensina que a respiração é uma verdadeira combustão que consome em cada instante uma porção da substância do indivíduo, que este consumo é tanto maior quanto mais a circulação e a respiração estão aceleradas, que ele aumenta à medida que o indivíduo leva uma vida mais laboriosa e mais activa, uma grande quantidade de considerações morais brota destes resultados da física.

Porque fatalidade injusta o homem pobre, que vive do trabalho dos seus braços, que é obrigado a empregar para a sua subsistência tudo o que a natureza lhe deu em forças, consome mais do que o homem ocioso, pois este último tem menos necessidade de restaurar? Porque é que, num contraste chocante, o homem rico dispõe de uma abundância que não lhe é fisicamente necessária e que parecia destinada para o homem de trabalho? Evitemos caluniar a natureza, e de a acusar de faltas que devem ser atribuídas às nossa instituições sociais. Contentemo-nos em louvar a filosofia e a humanidade, que se unam para nos prometerem instituições sábias, que farão aproximar os destinos na igualdade, a aumentar o preço do trabalho (etc.)"[11].

A balança associada à figura de Lavoisier é uma balança mais conceptual que física e já está em cena em toda esta experiência: mais acontecimentos logo mais pulsações e a "balança" permanece em equilíbrio. Este equilíbrio é o mote para pensar a ordem social.

"A ordem física, decorrente de leis imutáveis, chegou desde há muito a um estado de equilíbrio que nada pode perturbar, não está mais sujeita a estes movimentos tumultuosos que se desenrolam na ordem moral. É uma coisa verdadeiramente admirável este resultado que se observa na economia animal: forças continuamente variáveis e continuamente em equilíbrio permitindo ao indivíduo adaptar-se a todas as circunstâncias em que o acaso o coloca"[12]. Neste ponto do texto poderemos inserir o acaso que leva o jovem médico Mayer em 1840 à ilha de Java e onde acontece um incidente

[10] p.19
[11] p.698
[12] p.699

médico Mayer em 1840 à ilha de Java e onde acontece um incidente que será o ponto inicial de uma aventura intelectual espantosa, que muito contribuiu para o desenvolvimento do conceito de energia.

A ordem da natureza que emerge neste texto já contrasta com a ordem mecânica que é levada ao extremo nos finais do séc. XVIII com as invenções de autómatos que pretendem reproduzir a vida através de uma complexa transmissão de movimentos. A vida, aqui pensada em termos da respiração dos animais, tem uma auto-regulação que faz com que os seres vivos, ao nível físico vivam de forma equilibrada (não é por estarem numa atmosfera mais rica em oxigénio que se consomem mais, como acontece na combustão de uma vela). Como escreve Bensaude-Vincent (1993), "Lavoisier e Séguin não hesitam em colocar a natureza e a sociedade na balança, a fazer reflexões de ordem moral a partir das suas medidas físicas"[13].

Continuando ainda com Bensaude-Vincent "um outro estudo dedicado à transpiração animal em 1790 é a ocasião de atribuir à natureza uma outra virtude, cara aos revolucionários "não podemos deixar de admirar o sistema de liberdade geral que a natureza parece ter querido estabelecer em tudo o que tem a ver com os seres vivos. Dando-lhes a vida, o movimento espontâneo, uma força activa, necessidades, paixões, ela não os impediu de tudo usarem. Ela quis que fossem livres para de tudo poderem abusar; mas prudente e sábia colocou reguladores por todo o lado, fez funcionar a saciedade no seguimento da fruição"[14].

8 de Maio de 1794, Lavoisier "comparece" perante a guilhotina.

4. Breves considerações finais

A frase em epígrafe no ponto 3 traduz bem o conteúdo do texto que temos vindo a explorar, substituindo a palavra educação pela palavra ciência: é o interesse pelo mundo e pela humanidade que mobiliza de forma tão intensa esta procura de conhecimento. A presença da guilhotina permitirá discutir o contraste que estes autores fazem entre as leis da natureza e as leis da sociedade e talvez nessa discussão aconteça algo como preconizado na introdução:"the pupil to uncover a secret".

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La réception française de la mécanique statistique

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Abstract
Au début du XIX^{e} siècle la physique française a connu son âge d'or. Concernant la chaleur deux théories ont été proposées: le calorique (Laplace-Poisson) et la théorie ondulatoire de la chaleur (Ampère). La question de la transition des vieilles théories à la théorie cinétique a reçu très peu d'attention.

En effet, l'histoire usuelle des théories cinétiques de la chaleur est trop linéaire: elle sélectionne les travaux qui fondent la conception moderne (Clausius, Maxwell, Boltzmann et leurs proches) et ignore tout de qui s'en écarte. Il y a eu, dans toute la seconde moitié du XIX^{e}, plusieurs conceptions cinétiques de la chaleur. Cette situation peut être comparée à la multiplicité des théories mécaniques contemporaines de l'éther optique. Dans les années 1870-1890, on constate l'intérêt des Français pour des mémoires de Clausius n'appartenant pas à la théorie cinétique des gaz, lesquelles sont compatibles avec la théorie ondulatoire. Contrairement aux clichés concernant l'absence d'une physique théorique française ou la dominance totale des approches empiriques et phénoménologiques, je constate que, pendant tout le XIX^{e} siècle, la plupart des physiciens français étaient favorables aux vues mécanistes.

1.

En septembre 2008 j'ai soutenu à Paris, devant un jury international, ma thèse de doctorat, dirigée par M. Olivier Darrigol. M. Rui Namorado Rosa a toujours démontré un vif intérêt pour mes travaux et je veux, avec le présent texte, lui rendre hommage. Dans ce qui suit, je résume mon parcours de recherche.

2. Mon hypothèse de départ

Au début de mon travail, après la lecture des mémoires fondamentaux de Maxwell, Boltzmann, Gibbs, et de quelques études sur l'histoire de la théorie cinétique et de la mécanique statistique (Nye, Brush, Truesdell, Klein, Sklar, von Plato et autres), il était clair qu'une bonne partie des auteurs qui avaient touché à mon sujet étaient favorables à l'hypothèse d'un retard français dans la réception des nouvelles idées.

Nye, Brush et Pestre suggéraient que l'intérêt actif pour ces théories commençait avec la génération de Jean Perrin, Paul Langevin et Emile Borel. L'hypothèse initiale pour mes recherches était donc :

> Une microphysique expérimentale a créé au début du XX^{e} siècle (la physique des ions développée par Langevin, Perrin et le mouvement brownien) un climat favorable, en France, à des arguments de mécanique statistique. Mais le contexte français n'était pas favorable à de tels arguments dans le période antérieure.

3. Critique des idées reçues

Cependant, en ce qui concerne mon sujet, Nye, Brush et Pestre avaient esquissé un portrait vague et imprécis (Von Plato, en revanche, s'est intéressé vivement à quelques aspects des mémoires de Poincaré mais sans considérer le contexte de la physique française). Ils avaient noté la marginalité de la théorie cinétique des gaz en France au XIX^{e} siècle et souligné quelques caractéristiques supposées de la physique française compatibles avec la thèse d'un retard : isolement, positivisme, anti-atomisme. Voici quelques exemples :

- Dans son ouvrage, *Molecular theory*, de 1972, Nye met l'accent sur le climat anti-atomiste de la fin de siècle, conséquence en bonne partie des débats sur le statut de l'atome (1877 pour la querelle équivalents-atomes; 1895 pour l'énergétisme) chez les chimistes. Elle souligne le renouveau de l'intérêt pour les théories atomiques en conséquence des travaux de Jean Perrin. Les convictions atomistes des physiciens français post-laplaciens, occupant des positions importantes dans l'hiérarchie scientifique, ont été oublié, comme aussi l'intérêt pour le réductionnisme mécaniste des principes de la Thermodynamique; les références à la réception de la théorie cinétique sont assez schématiques :

Perrin's position in the controversies [sur le statut des hypothèses atomiques] evolved from his education at the Ecole Normale amidst this environment of staunch polemics, and while he found the French physicists and chemists, on the whole, to be only lukewarm about atomic molecular conceptions, his own publications and experiments were later to play a large part in a conversion of their viewpoint…. Almost all of his publications, from the very outset of his career, were aimed at resolving the controversies of the nineteenth century, and he confidently tackled the ideological and experimental positions of some of the most prestigious figures in French science – including M. Berthelot, Henri Le Châtelier, Pierre Duhem and (in a sense) Henri Poincaré – as well as some renowned *étrangères* as Wilhelm Ostwald and Ernst Mach. (Nye, 1972).[1]

Though he disagreed with Ostwald's more extreme pronouncements on energy, Le Châtelier supported the 1895 'Déroute de l'atomisme contemporain' as did other scientists…. This déroute however, excited the ire of the few proponents of the kinetic theory in France and an immediate reply proceeded from the pen of Marcel Brillouin…. Brillouin was among the few professors who taught the kinetic theory from a thoroughly sympathetic point of view at this time… [footnote:] Prior to Brillouin, J. Boussinesq had espoused the mechanical viewpoint in his lectures on mathematical physics at the Sorbonne… [référence à son 'Nouvelle théorie des gaz parfaits' de 1873] ; Lucien Poincaré [*Revue scientifique* 5 (1906) pp. 483-484] also discusses the adherence to the mechanical-kinetic picture by Verdet, Jamin and Violle, p. 40.(Nye, 1972).[2]

- Dans l'ouvrage majeur de Stephen Brush, *The kind of motion we call heat,* les auteurs français méritent très peu d'attention. Il donne des renseignements imprécis sur la réception dans les années 1860 :

In France [vers 1860] there was not much interest in the kinetic theory; I have found a favourable reference by Amagat in 1869, but there is also evidence that the caloric and wave theories of heat had not been completed abandoned [il cite deux traités élémentaires de physique, celui de Daguin de 1855 et celui de Ganot de 1857 et un article de Achille Cazin pour la *Revue scientifique*]. (Brush, 1976). [3]

Brush souligne l'anti-atomisme dominant dans les années 1880-1890:

During the 1880s and 1890s a number of physicists and physical chemists published attacks on the kinetic theory of gases…. Often the critique of kinetic theory was part of a broader attack on atomism or on mechanist hypotheses in general. Among the better-known names were those of Ernst Mach, Pierre Duhem, Wilhelm Ostwald, Henri Poincaré, Gustav-Adolph Hirn, Ernst Zermelo…. The list could be made longer by including more obscure scientists who also attacked the kinetic theory or proposed non-kinetic theories of gas properties [Parmi les mémoires cites par Brush on trouve ceux de Boussinesq de 1873 sur la théorie des gaz]. (Brush, 1976). [4]

Et Brush suggère que le théorème de récurrence de Poincaré montre l'incompatibilité entre le mécanisme et la thermodynamique:

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[1] p. 1.
[2] p. 40.
[3] p. 203.
[4] p. 94.

Poincaré, and later Zermelo (1896) argued that the recurrence theorem makes any mechanical model, such as the kinetic theory, incompatible with the Second law of Thermodynamics ; and since, it was asserted, the second law is a strictly valid induction from experience, one must reject the mechanist viewpoint. (Brush, 1976). [5]

- Dominique Pestre, dans son ouvrage *Physique et physiciens en France 1918-1940* (1984), n'étudie pas attentivement la place de la théorie cinétique des gaz dans les manuels et dans la recherche. Mais il note la prédominance d'une attitude positiviste :

III – L'enseignement de la thermodynamique : la logique positiviste de la fin du XIXe siècle

[après référence aux *Leçons* de Gabriel Lippmann à la Sorbonne et à la *Thermodynamique* de Poincaré l'auteur énonce sa] Première conclusion : avant la guerre de 1914, une très vive résistance pour ne pas dire une occultation règne dans les manuels relativement aux théories statistiques de la thermodynamique. (Pestre, 1984).[6]

Pestre affirme aussi que Poincaré ne s'est pas intéressé à la théorie cinétique du point de vue de la recherche :

Physiciens théoriciens et mathématiciens face aux théories nouvelles

Vis-à-vis des théories statistiques – Maxwell, Boltzmann, Gibbs –…. Nous avons déjà cité Poincaré dans l'édition 'revue et corrigée' de son cours de thermodynamique de 1908 : l'intéresse beaucoup plus la théorie de Helmholtz que celle de Boltzmann. Non qu'il ne connaisse pas la théorie statistique mais cela n'est pas dans ses préoccupations de recherche, cela ne peut constituer un domaine d'élection de ses talents de mathématicien. (Pestre, 1984).[7]

4. La thèse du déclin et la spécificité de la physique française

Bien que ces brèves références s'enchaînent bien avec la thèse du déclin de la physique française dans la seconde moitié du XIXe siècle, j'ai cherché à approfondir mes connaissances sur les propriétés globales de la physique française dans cette période. Je me suis donc immergé dans la littérature concernant les aspects socio-institutionnels. J'ai trouvé, surtout après la lecture des mémoires de Terry Shinn (sur l'évolution du système des facultés des sciences) et de John Davis (sur l'hégémonie de la tradition opticienne vers 1870), que les arguments favorables à l'idée d'un déclin concernaient une échelle sociologique différente de celle qui m'occupait, l'étude d'un sous-domaine disciplinaire. Cette littérature permettait surtout de justifier des

[5] p. 239.
[6] Seconde édition de 1992, p. 47.
[7] p. 113.

études dans un contexte national et montrait nettement la dominance des Grandes Ecoles pour les sciences mathématiques et de la dominance de la science parisienne. Elle permet aussi de connaître l'importance relative des scientifiques dans la hiérarchie et donc d'inférer les domaines d'élection.

L'argument de Davis m'a surtout intéressé par son caractère « internaliste »: Davis explique le manque d'intérêt des physiciens français (dont la carrière a commencé dans les années 1840) pour les domaines de pointe par le fait que les problèmes d'astronomie et d'optique étaient favorisés dans les institutions scientifiques les plus puissantes. En conséquence, pour un jeune chercheur ambitieux venant de finir sa formation dans les Grandes Ecoles et voulant faire une carrière à Paris, il était sage de se consacrer à l'optique.

5. La scène française n'était pas vide

L'étude des tables des matières des *Comptes rendus* et des *Annales de chimie et physique,* m'a montré qu'une vaste littérature existait sur les sujets de la chaleur et des gaz en France. Ce fait et aussi mes souvenirs sur l'importance de la physique moléculaire de Laplace et Poisson ont déplacé mon centre d'intérêt vers la question de la transition des vielles théories (calorique et théorie ondulatoire de la chaleur) à la théorie cinétique. L'idée que la scène n'était pas vide avant l'arrivée de la théorie cinétique a inspiré mes recherches pendant une période que je décrirai, sur le plan émotionnel, comme ma traversée du désert.

La lecture des déclarations de Marcel Brillouin faites en 1925, pour les cinquante ans de la Société Française de Physique, m'a suggéré qu'Emile Verdet, Maître de conférence à l'ENS vers 1860 et traducteur des mémoires de Joule, Krönig et Clausius, serait un personnage clef sur ce chemin :

Seuls, les anciens élèves de Verdet connaissaient les progrès et les développements des théories physiques en Allemagne et en Angleterre, jusqu'à la mort de Verdet ou à peu près. Et comme la guerre était survenue en 1870 et leur avait à tous donné d'autres soucis, il y avait, même pour eux, près de dix ans de retard…. Aussi, les physiciens de cette nouvelle génération, ceux de 1870 à 1890, n'auront jamais assez de reconnaissance pour les anciens élèves de Verdet qui, de 1868 à 1872, menèrent à bien la publication de ses œuvres : Gernez pour les conférences à l'Ecole Normale, Lévistal pour les deux volumes de Leçons d'optique physique, Prudhon et Violle pour les deux volumes de Théorie mécanique de la chaleur. (Brillouin, 1925).[8]

[8] p. 15.

En tombant, avec Olivier Darrigol, dans les greniers de l'ENS, rue d'Ulm, sur le vieux bouquin de Verdet sur la théorie mécanique de la chaleur, j'ai été fort content de découvrir que, contrairement au préjugé courant, la théorie cinétique était enseignée aux Grandes Ecoles et en Sorbonne dès la fin des années 1860.

La présentation par Verdet des idées de Clausius, bien qu'assez détaillée et fidèle, était particulière, dans le sens qu'elle donnait une grande importance à l'interaction entre l'éther et les molécules gazeuses, laquelle a été une anomalie persistante de la théorie :

Outre le mouvement apparent des molécules, nous devrons donc considérer encore ce mouvement intérieur dû aux vibrations de leurs atomes. Enfin, comme les molécules des gaz condensent ou dilatent l'agent lumineux, sur la nature duquel je ne préjuge rien d'ailleurs, la matière pondérable ne peut pas être animée d'un mouvement sensible sans que l'éther y participe.... Le mouvement de l'éther provient des mouvements de translation et de rotation des molécules pondérables, et il consiste lui-même en rotations ou translations très petites. (Verdet, 1872).[9]

Verdet, comme les autres introducteurs de la théorie dans l'enseignement, Charles Briot et Jules Jamin appartiennent à la tradition opticienne issue de Fresnel et de Cauchy.

6. La théorie ondulatoire de la chaleur

Lentement, je me suis aperçu que l'histoire usuelle des théories cinétiques de la chaleur est trop linéaire: elle sélectionne les travaux qui fondent la conception moderne (Clausius, Maxwell, Boltzmann et leurs proches) et ignore tout de qui s'en écarte. Par exemple, Brush a écrit:

Disappearance of the wave theory of heat after 1850…. Many books and papers by minor scientists continued to use or refer to the wave theory of heat [Ampère's] as if it were still acceptable for several decades after 1850. (Brush, 1976).[10]

L'analogie entre chaleur et lumière inspira à Ampère une théorie vibratoire de la chaleur. D'après ses idées les molécules sont composées par des atomes centres-de-force qui vibrent autour d'une position fixe et communiquent leur mouvement à travers des ondulations se propageant dans l'éther. Dans la conception Ampérienne, la chaleur rayonnante s'expliquait naturellement comme un mode de vibration de l'éther. Mais pour la théorie cinétique des gaz qui lui fit bientôt concurrence, le problème de l'éther était une source d'anomalies. Comme l'éther participait sans doute à certains processus dans

[9] §259, p. 21.
[10] p. 330.

les milieux gazeux (échauffement par radiation, décharges électriques dans les gaz, réactions chimiques, etc.), les adeptes de la théorie cinétique comprenaient qu'une théorie générale des phénomènes thermiques devrait donner une place importante à l'éther et aux ondulations. Mais ils ne voyaient pas trop comment.

Conscient de ces difficultés, Clausius s'abstint de condamner la conception vibratoire, même si sa théorie cinétique était supérieure dans le cas des gaz. L'année-même où il publie son premier mémoire sur la théorie cinétique des gaz, en 1857, dans une conférence libre tenue à Zürich, il expose les deux hypothèses, la théorie vibratoire étant mise en relief.

Clausius décrit des expériences et des raisons théoriques et note qu'« il est à peu près impossible de ne pas admettre que la chaleur rayonnante consiste, elle aussi [comme la lumière], en vibrations de l'éther se propageant par ondulations ». La non matérialité de la chaleur rayonnante, nous-dit Clausius, favorise l'hypothèse de la non matérialité de la chaleur qui se trouve dans les corps. Les expériences où il y a échauffement des corps par frottement ne sont explicables que dans l'hypothèse que la chaleur soit un mouvement des parties microscopiques des corps. Se figurer ce mouvement intérieur est une question que Clausius admet ne pas être « encore complètement résolue ».

Clausius résume le noyau de cette discussion sur la nature de la chaleur en affirmant :

Tous les corps de la nature, même ceux qui paraissent complètement en repos, sont soumis à des mouvements intérieurs très violents, et ces mouvements se communiquent à l'éther environnant, de sorte que tout l'espace céleste est traversé continuellement et dans tous les sens par une foule de mouvements ondulatoires, et c'est à l'ensemble de tous ces mouvements que nous donnons le nom de chaleur. (Clausius, 1857).[11]

Avec ces extraits, on voit comment l'un des fondateurs de la théorie cinétique des gaz concède à l'éther un rôle déterminant dans la compréhension de la chaleur.

7. La mécanique physique et la chaleur

La majorité des Français s'intéressant à la nature de la chaleur, opticiens et/ou adeptes de la tradition de mécanique physique partageaient l'ontologie moléculaire de Laplace, Navier, Poisson et Ampère, la conception des atomes comme centres de force.

En 1872 Joseph Boussinesq proposait encore une théorie des gaz inspiré des idées d'Ampère, comme alternative à la théorie de Clausius. Au début de

[11] p. 130.

mes recherches, j'ignorais l'histoire (et les liens) de la théorie de l'élasticité, de l'hydrodynamique et de l'éther mécanique lumineux. Ces domaines étaient au centre des réussites de la physique mathématique française à son âge d'or et cette tradition laplacienne restait vivante vers 1870. La lecture du long mémoire de Boussinesq n'était possible qu'en l'inscrivant dans cette tradition.

Les méthodes utilisées dans la mécanique physique vers 1870 sont assez différentes de celle de Clausius et de Maxwell. Dans les théories concrètes de la mécanique physique, les détails du monde microscopique restent cachés:

Les actions, dites *de pesanteur*, s'exerçant aux distances de grandeur notable, peuvent être regardées comme infiniment petites en comparaison de celles, appelées le plus souvent *actions moléculaires*, qui existent entre points matériels, à ces distances absolument insensibles auxquelles se produit le *contact physique* des corps, et dont même la plus grande, dite *rayon d'activité des actions moléculaires*, échappe complètement à nos mesures. (Boussinesq, 1889).[12]

Comme le calorique chez Laplace et Fourier, l'éther de Boussinesq est responsable de la thermalisation de la matière:

Ce milieu ne peut pas, à cause de sa faible masse, en détenir des quantités sensibles [de l'énergie interne] et il ne fait que la transporter rapidement, par petites charges, d'un corps à l'autre du système, de manière à tendre à établir entre eux et avec lui-même une sorte d'équilibre dynamique appelé *équilibre des températures*.

Cependant, Boussinesq reconnaît que :

Le détail des mouvements calorifiques et leur mode de propagation d'une molécule à l'autre nous est inconnu. (Boussinesq, 1873).[13]

Comme Laplace, Boussinesq définit la température à partir des propriétés du milieu ténu où se propage le rayonnement calorifique. La différence, c'est qu'il la définit cinétiquement comme dans la théorie d'Ampère:

On peut appeler *température absolue* d'un petit volume d'éther la demi-force vive qu'il possède sous l'unité de masse, ou une quantité proportionnelle à cette demi-force. Un corps est dit à une certaine température *T*, lorsque ces vibrations calorifiques n'augmentent ni diminuent si l'on vient à le placer dans l'éther à la même température. (Boussinesq, 1873).[14]

L'intérêt de Marcel Brillouin pour la théorie cinétique est certain (d'après ses propres déclarations de 1925). Mais en 1893 Marcel Brillouin était encore d'accord avec Boussinesq et défendait une position contraire à celle de Maxwell et de Boltzmann:

Pour ma part, je reste convaincu que la définition de la température comme une quantité d'énergie potentielle, ou cinétique, totale ou partielle, de la matière ordinaire seule est une erreur. Assez simplement liée aux propriétés

[12] p. 28.
[13] p. 339.
[14] p. 337.

thermomécaniques des gaz, la température ainsi définie ne paraît avoir aucun lien avec les conditions d'équilibre par rayonnement dans une enceinte vide de matière. Dans ce dernier cas, l'intervention inévitable de l'éther a conduit M. Boussinesq à une définition de la température toute différente, et trop peu connue, qui me paraît beaucoup plus satisfaisante et féconde : « Pour définir la température en un point d'un corps, imaginons qu'on enlève la matière autour de ce point ; la température est la force vive, par unité de volume, de l'éther du vide qui occupe la cavité. » C'est cette définition de la *température*, entièrement satisfaisante au point de vue du rayonnement, qu'il me semblerait important de compléter et de relier au principe de Carnot avec plus de précision que ne l'a fait M. Boussinesq.[15]

Brillouin cite directement le mémoire de Boussinesq de 1873 et ne fait pas la moindre référence à la loi de Stefan-Boltzmann (1879 et 1884), laquelle établit la proportionnalité entre la densité d'énergie du rayonnement noir et la quatrième puissance de la température des parois de la cavité qui est en équilibre thermique avec ce rayonnement. Cela signifie que Brillouin, en 1893, ne connaissait pas ce résultat. Au début du XXème, il notait encore le rôle problématique de l'éther dans le cadre de la théorie cinétique. En discutant le problème des chaleurs spécifiques, il a écrit:

Même en faisant abstraction du nombre considérable de libertés que révèle l'analyse spectrale dans un seul atome, traitant chaque atome comme un point matériel, le nombre de libertés semble trop grand par comparaison avec le rapport des chaleurs spécifiques ; le rapport 1,4…conduit à traiter la molécule comme un système dans lequel existe un certain nombre de liaisons rigides. Or, la rigidité absolue n'est pas dans la nature, et la question se pose de savoir par quelle circonstance certaines libertés restent sans influence sur le rapport des chaleurs spécifiques. *C'est bien évidemment aux réactions entre l'éther et la molécule qu'il faut demander cette cause.* Les molécules d'un gaz enfermé dans une enceinte à température constante subissent en effet des influences de deux sortes : 1° celles des autres molécules et des parois, pendant les chocs, *seules considérées par la théorie cinétique* ; 2° celles de la radiation noire qui circule incessamment dans l'enceinte, sans interruption. Les règles de la théorie cinétique ne peuvent évidemment pas s'appliquer qu'aux libertés qui ne subissent pas d'une manière appréciable l'influence de l'éther.[16]

Le plus remarquable est le rapport causal établi entre les degrés de libertés mécaniques « congelés », associées à l'idée macroscopique de rigidité, et l'interaction avec l'éther qui en est la justification. Cette idée ne se trouve pas chez Boltzmann, qui considère que la thermalisation de l'éther doit être infiniment lente, notamment dans ses textes en anglais publiés dans *Nature* en 1895.

[15] Brillouin dans une note à (Thomson, 1891), p. 357.
[16] Brillouin dans une note dans (Boltzmann, 1905), pp. 270-271. Les italiques sont de ma responsabilité.

8. Mécanismes à la française

Une de mes grandes surprises a été la persistance des convictions favorables à la théorie ondulatoire de la chaleur. Vers 1885, la version ampérienne du programme de la physique moléculaire était encore vivante. Elle garantissait encore une vision unificatrice des phénomènes, une cosmovision. Donnons un exemple assez significatif de cet état des choses. Jules Violle est le disciple de Verdet qui s'est le plus distingué par ses travaux sur la chaleur. Verdet et Violle appartenaient à la tradition opticienne et ils avaient néanmoins un intérêt réel pour la théorie cinétique. Les deux faisaient partie de l'élite de la physique française. Dans la préface du traité de physique moléculaire de Violle, publié en 1884, on trouve l'essence de cet engagement thématique commun à beaucoup de physiciens français dans la seconde moitié du XIX^e^ siècle:

Rien dans l'immensité de l'univers n'est immobile. Déplacement de mondes, frémissement d'atomes, tout est agitation et mouvement. La science de la nature tend vers la mécanique par une évolution nécessaire, le physicien ne pouvant établir de théories solides que sur les lois du mouvement. Ces lois deviennent aussi la préface obligée d'un cours de physique. Les phénomènes de la pesanteur en fournissent immédiatement une application simple et grandiose. A l'examen des propriétés générales des corps succède l'étude des mouvements vibratoires qui constituent à proprement parler le véritable champ de la physique. Par un enchaînement rationnel, l'acoustique où ces mouvements sont nettement perceptibles prépare l'optique qui conduit elle-même à la chaleur. En dernier lieu viendra l'électricité, que les connaissances acquises jusqu'à ce jour ne permettent pas de rattacher directement à ces conceptions, bien qu'il soit possible dès maintenant d'y appliquer sans conteste le grand principe de la conservation de l'énergie. (Violle, 1884).[17]

La mécanique est donc le pilier de la physique ; la majesté de la mécanique céleste démontre sa supériorité; la physique moléculaire a comme théorie fondamentale et unifiante la théorie vibratoire, laquelle permet de comprendre le son, la lumière et la chaleur.

Que la théorie ondulatoire (ou vibratoire) de la chaleur ait été en faveur pendant les deux derniers tiers du siècle en France n'implique pas que beaucoup de physiciens y aient vraiment travaillé. La physique théorique était peu pratiquée (en France comme ailleurs) et la théorie mécanique de la chaleur n'était pas le domaine d'élection pour les théoriciens français. Vers 1875, la tradition laplacienne de physique moléculaire, ou mécanique physique à laquelle se rattache la théorie vibratoire de la chaleur, est représentée par des chercheurs comme Saint-Venant ou Boussinesq. Dans l'Académie des

[17] pp. V-VI.

Sciences, ils sont surtout cantonnés dans la section de mécanique. Ces savants se sentent menacés et se plaignent du manque de soutien institutionnel. Citons Boussinesq :

L'hydrodynamique est la branche de la mécanique physique la plus avancée…. Elle a, d'ailleurs, sur la mécanique céleste, l'avantage d'être encore neuve dans un grand nombre de ses chapitres et d'offrir ainsi un champ des plus vastes aux recherches originales…. Et, cependant, aucune chaire, aucun cours, même accessoire, ne lui est consacré dans aucun de nos principaux établissements d'enseignement supérieur ! (Boussinesq, 1879).[18]

Mon travail montre qu'il y a eu, dans toute la seconde moitié du XIX^e^, plusieurs conceptions cinétiques de la chaleur. Cette situation peut être comparée à la multiplicité des théories mécaniques contemporaines de l'éther optique. Dans les années 1870-1890, on constate l'intérêt pour des mémoires de Clausius n'appartenant pas à la théorie cinétique des gaz. Certains de ces mémoires concernent la réduction mécaniste du deuxième principe par analogie avec les systèmes périodiques; d'autres concernent le théorème du viriel.

Contrairement aux clichés concernant l'absence d'une physique théorique française ou la dominance totale des approches empiriques et phénoménologiques, j'ai constaté que, pendant tout le XIX^e^ siècle, la plupart des physiciens français étaient favorables aux vues mécanistes. Illustrons ce point par un exemple significatif.

Le 15 novembre 1895, la *Revue générale des sciences* publie la traduction d'un article d'Ostwald sur la déroute du matérialisme dans les sciences. Les traducteurs l'ont intitulé « La déroute de l'atomisme contemporain ». C'est d'abord le réductionnisme mécaniste (matière et mouvement) qu'Ostwald critique, partant de sa vision de la thermodynamique. Réponse d'Alfred Cornu, vice-président de L'Académie des Sciences :

Le grand obstacle auquel on vient se heurter est l'ignorance où nous sommes de la structure intime des corps pondérables et du milieu impondérable existant jusque dans le vide [l'éther]. Dans quelle mesure la connaissance exacte de cette constitution est-elle nécessaire pour expliquer mécaniquement les phénomènes physiques ? C'est là le grand problème : pourquoi désespérer de le résoudre et le déclarer absurde *a priori ?* Comme les géomètres, les physiciens y travaillent avec ardeur…. Bien des résultats partiels sont déjà acquis et toujours dans le sens d'une réduction aux lois ordinaires de la mécanique.… Si l'on doit s'étonner d'une chose, c'est de voir la mécanique rationnelle, avec des éléments si restreints et si simples – points matériels, actions réciproques – arriver à rendre un compte si fidèle de tant de phénomènes divers et compliqués. (Cornu, 1895).[19]

[18] pp. 51 et 56.
[19] p. 227.

9. Freins à la réception de la théorie cinétique de Clausius et Maxwell

La mécanique physique est sur le déclin dans la seconde moitié du siècle même si elle reste active. Ce déclin explique en partie le peu d'intérêt des Français pour la théorie cinétique des gaz. En même temps (et paradoxalement), il est vrai que le maintien de cette tradition sous une forme toujours ampérienne est une autre cause de ce manque d'intérêt.

Une autre cause pour ce manque d'intérêt a été l'influence de Victor Regnault. Regnault et ses disciples avaient montré que le modèle unifiant du gaz parfait ne reflétait que grossièrement le comportement réel des gaz. En conséquence, les Français furent plus sensibles que d'autres aux anomalies de la jeune théorie cinétique des gaz (chaleurs spécifiques, équation d'état des gaz réels).

Dans la seconde moitié du siècle, les utilisateurs français de la théorie mécanique de la chaleur s'intéressaient aux analogies mécaniques du deuxième principe indépendantes de modèles concrets. Cette préférence venait sans doute d'une certaine méfiance à l'égard de modèles mécaniques particuliers de la chaleur, ou de la volonté de laisser le champ libre à la théorie vibratoire de la matière.

L'enseignement des Grandes Ecoles avait certes introduit la théorie cinétique élémentaire. Mais en ce qui concerne la recherche, des idées de la théorie cinétique moléculaire, les Français ne retiennent guère que celles qui se passent de considérations probabilistes et qui ne dépendent pas du modèle particulier de la théorie cinétique des gaz (viriel, analogie avec les systèmes périodiques). Malgré la forte tradition probabiliste dans les mathématiques françaises, les raisonnements probabilistes paraissaient suspects dans le domaine de la théorie mécanique de la chaleur. Il est vrai que cette méfiance n'était pas l'apanage des Français.

En 1903, Pierre Duhem relevait la difficulté présentée par les raisonnements probabilistes de la nouvelle théorie cinétique:

Selon l'heureuse expression de Maxwell, l'équilibre d'une masse gazeuse est un *équilibre statistique.* Ces simples indications annoncent suffisamment les difficultés extrêmes que vont rencontrer les physiciens lorsqu'ils voudront prendre les hypothèses cinétiques pour point de départ de déductions rigoureuses ; ces difficultés se résument en ces deux mots : *approximation, probabilité*.… C'est cette égalité approchée, c'est ce balancement entre les chances qu'ont les molécules d'être lancées dans une direction et les chances qu'elles ont d'être rejetées dans la direction opposée, qui constitue l'état d'équilibre d'un gaz…. Lors donc que nous voudrons savoir si une certaine distribution d'atomes et de mouvements représente un état d'équilibre apparent…, nous devrons supputer les chances qui sont en faveur de chacune des causes capables de le troubler. Dès lors, nous voici obligés de recourir au *Calcul des probabilités*, en dépit des hésitations et des doutes qui semblent inhérents à cet ordre de raisonnements. (Duhem, 1903).[20]

Duhem écrit ces mots à une époque un peu tardive, pour laquelle on peut déjà signaler une contribution française à la théorie cinétique et la mécanique statistique. Mais ce point de vue était probablement assez répandu chez les physiciens français actifs dans les quatre dernières décennies du XIX^e siècle.

Dans l'introduction de ses leçons sur la théorie de Maxwell, Poincaré établit un rapport étroit entre la tradition de physique mathématique française et quelques difficultés dans la compréhension des ouvrages de Maxwell:

La première fois qu'un lecteur français ouvre le livre de Maxwell [*A treatise on electricity and magnetism*], un sentiment de malaise, et souvent même de défiance se mêle d'abord à son admiration.… Pourquoi les idées du savant anglais ont-elles tant de peine à s'acclimater chez nous ? C'est sans doute que l'éducation reçue par la plupart des Français éclairés les dispose à goûter la précision et la logique avant toute autre qualité.

Les anciennes théories de la Physique mathématique nous donnaient à cet égard une satisfaction complète. Tous nos maîtres, depuis Laplace jusqu'à Cauchy, ont procédé de la même manière. Partant d'hypothèses nettement énoncées, ils en ont déduit toutes les conséquences avec une rigueur mathématique, et les ont comparées ensuite avec l'expérience. *Ils semblent vouloir donner à chacune des branches la même précision qu'à la Mécanique céleste.*

Pour un esprit accoutumé à admirer de tels modèles, une théorie est difficilement satisfaisante. Non seulement il n'y tolérera pas la moindre apparence de contradiction, mais il exigera que les diverses parties en soient logiquement reliées les unes aux autres et que le nombre des hypothèses distinctes soit réduit au minimum. (Poincaré, 1890).[21]

Poincaré insiste ici sur le style de présentation, sur la logique et la précision favorisée par la formation des physiciens français. Puis il passe à un aspect plus contestable :

Ce n'est pas tout, il [le savant français] aura encore d'autres exigences qui me paraissent moins raisonnables. Derrière la matière qu'atteignent nos sens et que l'expérience nous fait connaître, il voit une autre matière, la seule véritable à ses yeux, qui n'aura plus que des qualités purement géométriques et dont les atomes ne seront plus que des points mathématiques soumis aux seules lois de la dynamique. Et pourtant il cherchera, par une inconsciente contradiction, à se les représenter et par conséquent à les rapprocher le plus

[20] pp. 95-97.

[21] Ce texte reprend celui de l'*Introduction* du premier tome du traité (1890) *Electricité et Optique*. (Poincaré, 1902), chap. XII, section « La théorie de Maxwell ».

possible de la matière vulgaire. C'est alors [en trouvant ces représentations atomiques] seulement qu'il sera pleinement satisfait et s'imaginera avoir pénétré le secret de l'univers. Si cette satisfaction est trompeuse, il n'en est pas moins pénible d'y renoncer. (Poincaré, 1890).[22]

Poincaré affirme donc que la tradition de la physique laplacienne est encore très vivante et que son ontologie inconsciente constitue un obstacle épistémologique dans l'acceptation de nouvelles approches.

10. Epilogue

L'intérêt actif des Français pour la théorie cinétique commence avec les travaux de Marcel Brillouin et de Henri Poincaré. Brillouin s'est surtout intéressé à la seconde théorie de Maxwell et aux phénomènes de transport. Poincaré s'est intéressé d'abord à la thermodynamique et à son rapport avec la mécanique. Après une période de scepticisme à l'égard de la théorie cinétique, il a lu très attentivement quelques uns des mémoires de Maxwell et il a contribué aux fondements de la mécanique statistique.

Ces deux savants font preuve d'une grande ouverture envers la physique étrangère. Ils s'inscrivent pourtant dans la grande tradition des mathématiques françaises. En particulier, Poincaré s'inspire de la tradition probabiliste et de la mécanique céleste issue de Laplace; et Brillouin s'inspire de la tradition hydrodynamicienne. Leurs apports à la théorie cinétique des gaz, ainsi que ceux d'Emile Borel, sont étudiés de façon détaillée dans la troisième partie de ma thèse, dont je ne m'occupe pas dans cette courte présentation. Rétrospectivement, il ne fait pas de doute que ces trois savants sont les seuls Français à avoir contribué de manière significative au progrès global de la mécanique statistique. Il reste cependant vrai que la persistance de la physique moléculaire ampérienne a auparavant permis le développement d'une théorie cinétique française hétérodoxe de la chaleur et aussi une diffusion limitée mais certaine des idées de Clausius et de Maxwell.

[22] Idem.

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O Universo Invisível

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Abstract
Era muito difícil, antes dos anos 20 do século passado, inventar modelos para o nosso Universo: nunca se tinha realmente olhado para além da nossa simpática galáxia, a Via Láctea, e tudo o que se sabia com alguma segurança era afinal àcerca de um ponto perdido entre milhões e milhões de outros pontos, de outras galáxias. Hoje, menos de cem anos depois, sabemos que vivemos num universo em expansão, que essa expansão é acelerada, e que há relíquias do passado que dão pistas para o futuro. E também sabemos que para lá de uma grande descoberta há sempre um grande mistério: porque é que 95% do Universo que sabemos existir é escuro e invisível?

Os fenómenos abordados pela Física ocorrem nas mais variadas escalas, podendo estar ligados à evolução do próprio Universo no seu todo – ou do que pensamos ser o Universo no seu todo –, o que envolve distâncias da ordem de 10^{22} metros, ou às dimensões das partículas elementares em interacção, com escalas $\lesssim 10^{-22}$ m. Mas, naturalmente que há muitas outras escalas intermédias, das galáxias (10^{18} m), das estrelas (10^{13} m), dos elefantes e das formigas, incluíndo o ser humano (~ 1 m), dos átomos e das moléculas (10^{-8} m), do núcleo atómico (10^{-15} m). A Física sendo sempre a mesma, adquire formulações próprias, adequadas às diferentes escalas.

Como é que foi possível chegar a todas estas escalas? Naturalmente que o homem primitivo só conhecia como escala mínima a espessura do cabelo que conseguia ver ($\sim 10^{-4}$ m) e como escala máxima a distância correspondendo a uma caminhada de dezenas de quilómetros ($\sim 10^{5}$ m). Os limites naturais, dos 10^{-4} m aos 10^{5} m, só foram ultrapassados com desenvolvimentos tecnológicos no campo da visão: os telesópios, que começaram a ser utilizados em 1609, para as grandes distâncias, e os microcópios, de 1677, para as distâncias mais pequenas. Num caso como no outro, o meio de obter a informação reside na utilização da luz, isto é, ondas electromagnéticas, isto é, fotões. Note que o homem primitivo via o Sol e as estrelas, mas não fazia ídeia a que distância estavam. Via a diferença entre a água e a terra, mas não fazia ídeia da escala das moléculas e dos agregados moleculares.

Com Galileu – e também Kepler e Newton –, graças à curiosidade e a aperfeiçoamentos ópticos, deu-se um renascimento da astronomia com a observação de montanhas na Lua, fases de Vénus, satélites de Júpiter e, sobretudo, com a resolução de nebulosas em amontoados de estrelas distantes. Era a conquista de novas escalas. Os astros que povoavam os céus tornavam-se mais físicos e sujeitavam-se afinal às leis da Terra – como Newton terá sentido na sua cabeça... Com a entrada do laboratório de física no observatório – fotografias e análise espectroescópica – até foi possível descobrir o elemento hélio (He) no Sol, antes de ser detectado na Terra.

Também no olhar para coisas cada vez mais pequenas não se ficou parado. Com Huygens (1680) e a teoria ondulatória da luz percebeu-se que, para tornar perceptível uma coisa muito pequena era preciso iluminar o objecto em estudo com luz de comprimento de onda pequeno, da ordem do tamanho da escala do objecto. Se para pintar uma mancha grande de céu azul um pincel grosso serve bem, para pintar os caracóis delicados de um anjo tem que se usar um pincel fino. O mesmo se passa com a luz que ilumina: tem de ser o pequeno comprimento de onda para evidenciar os pormenores.

Com Louis de Broglie, em 1924, a óptica deixou de ser um sub-capítulo do capítulo Luz: se as ondas de luz eram afinal partículas (fotões) então as partículas (electrões, protões, etc.) eram também ondas: ondas de matéria. E daí vem a sua célebre relação de onda-partícula,

$$\lambda = h / p \,,$$

onde o comprimento de onda λ se associa ao inverso do momento linear p da partícula. Donde se conclui que as leis da óptica se aplicam a todos os feixes – de partículas de luz ou de partículas de matéria – e que para observar com feixes de partículas – de luz ou de matéria – as estruturas mais íntimas da matéria é preciso cada vez mais momento linear, cada vez mais energia. Daí a obsessão dos físicos de partículas com as energias sempre cada vez mais altas.

A pergunta que naturalmente se pode colocar é a seguinte: porque é que os físicos querem compreender ao mesmo tempo o “infinitamente” grande e o "infinitamente" pequeno? Porque vivemos, ao que tudo leva a crer, num Universo em expansão, que evolui do pequeno para o grande, que parte de campos e partículas fundamentais para estruturas elaboradas de grande complexidade, onde se inclui o fenómeno da vida e, em especial, o fenómeno da vida inteligente.

A expansão do Universo, a partir do chamado “Big-Bang”, pode ser vista muito simplesmente como uma solução possível ds equações de Einstein da Relatividade Geral – George LeMaitre deixou desenhados nos seus cadernos

(1927) universos em expansão e mesmo acelerados -- mas também como o resultado das observações de Hubble (1928) relativamente ao desvio para o vermelho da luz das galàxias distantes. Quer dizer, quanto mais distante de nós està uma galàxia, mais efeito tipo efeito de Doppler existe, sendo maior o desvio para o vermelho e maior, portanto, sendo a sua velocidade de afastamento. é esse afastamento que legitimamente se interpreta como expansão.

Do ponto de vista geométrico o passado e o futuro ficam então ligados por relações de semelhança – introduzidas por Tales (séc. VI, a.C.) – que nos dão a possibilidade de prever o passado – ir no sentido do "Big-Bang" – e de prever o futuro. é assim que se pode estimar a idade do Universo (cerca de 13 mil milhões de anos, e antecipar um futuro desertificado de galáxias).

Em resumo. No modelo cosmológico "standard" no começo do Universo hà um concentrado de massa-energia, correspondendo a temperaturas extremamente elevadas. Com a expansão do Espaço-Tempo dá-se a diminuição da temperatura e a intervenção cada vez mais relevantes das forças fundamentais. é a tensão sempre presente entre a desordem (temperatura) e a ordem (forças e energias de ligação) que determina o modo como se dá a evolução.

Um ponto de referência – cerca de 300 mil anos depois do "Big-Bang" – é o da neutralização das cargas eléctricas no Universo, com a passagem dos núcleos atómicos (com cargas eléctricas +) captando electrões (cargas eléctricas -) produzindo átomos neutros. Porque é que a neutralização é perfeita, isto é, com a carga eléctrica do protão sendo, em módulo, igual à carga eléctrica do electrão, ninguém sabe bem porquê!

O que fica da neutralização é um gás livre de fotõeses – que interagiam antes com as cargas eléctricas -- que foi detectado em 1964, por Pengias e Wilson, e que constitui o melhor exemplo para ilustrar a lei de Planck (1900),

$$E \sim \frac{h\nu}{e^{h\nu/kT}+1} \quad , \quad T = 2.73K \, ,$$

para a chamada radiação de fundo do Universo. A existência desta relíquia fotónica, satisfazendo a lei de Planck, é a prova mais convincente da existência do "Big-Bang".

Não é difícil contar uma história breve do Universo. Há a grande explosão inicial, com densidades de massa-energia e temperaturas elevadíssimas onde as estruturas do nosso tempo – das galáxias ao átomo, passando pelos seres vivos – estão necessariamente ausentes. Só subsistem os campos fundamentais - unificados? - e as partículas (mais) elementares. O Espaço-Tempo desenvolve-se aí exponencialmente no tempo - inflacção - o que explica a grande isotropia, homogeneidade e "planitude" do Universo em grande escalas. Com o correr do tempo cosmológico vão surgindo as estruturas –

núcleos atómicos, átomos, moléculas, etc., até chegarmos a todas as estruturas que conhecemos.

Contada assim a história, parece que tudo está esclarecido quanto à evolução do Universo. Na verdade não é bem assim – aliás em ciência normalmente por cada resposta encontrada levantam-se novas perguntas.

De facto, desde meados do século passado que apareceu o problema da massa ou *matéria escura*. Ninguém duvida que a interacção dominante entre planetas, no saistema solar (ou em sistemas solares), entre galáxias, entre enxames de galáxias é a interacção universal da gravitação de Newton na versão de Einstein. Ora quando se fazem as contas verifica-se que não há matéria que chegue para explicar o ovimento. Imaginemos então um corpo de massa M (um sol, uma galáxia) e outro corpo de massa $m \leq M$ (um planeta, poeiras, uma estrela). No centro de massa do sistema o corpo de massa m descreve uma curva - elipse - em torno de corpo de massa M, e a condição de estabilidade da órbita – supondo ser circular, para simplificar – é a de que a força radial de atracção gravitacional seja exactamente compensada pela força centrífuga:

$$\frac{GMm}{r^2} = \frac{mv^2}{r},$$

sendo G a constante universal, r o raio da órbita e v a velocidade orbital. Da equação acima vem

$$v = \sqrt{\frac{GM}{r}}.$$

Suponhamos que o corpo pesado ocupa uma esfera de raio R e tem uma densidade média ρ de matéria, isto é,

$$M = \frac{4}{3}\pi\rho R^3 .$$

A velocidade orbital do corpo de massa m no campo do corpo de massa M será – lembrar o teorema de Gauss –

$$\begin{cases} v \sim r & ,0 \le r \le R \\ \\ v \sim 1/r^{1/2} & ,r > R \end{cases}.$$

Zwicky (anos 30-40 do século passado) estudando galáxias no campo de enxames de galáxias, e observou que o decréscimo com $1/r^{1/2}$ para distâncias grandes não ocorria: a velocidade era praticamente constante, decrescendo muito lentamente. Ora as distribuições das massas, as estimativas das massas de galàxias são obtidas a partir do que se observa em telescópios, isto é, dependem do que se "vê" – em qualquer frequência de luz ou de partículas, usando-se neste caso, detectores apropriados. A única forma, sem mudar a lei da gravitação universal, de explicar o que se passa é supor que há mais matéria, que se estende para além de $r = R$, só que não é detectada pela luz – por isso se chama *escura*. Quer dizer que a matéria escura está sujeita à gravitação universal, mas não tem interacções electromagnética, fraca e forte, pelo menos com as intensidades habituais.

Mas a história não acaba aqui. Na última década do século passado dois grupos de investigação (um dirigido por Saul Perlmutter e o outro por Alan Ries) procuraram verificar a lei de Hubble para estrelas em galàxias muito mais longe do que o que se tinha conseguido até aí, para isso seguindo o rasto de explosões de estrelas em supernovas. E a conclusão a que os dois grupos chegaram é que a expansão do Universo é *acelerada*. Isto quer dizer que a recta de Hubble, com velocidade de afastamento da galàxia proporcional à distância, não é uma recta: a velocidade cresce mais depressa que a distância.

De facto, a distância em cada instante ser proporcional à velocidade é uma característica do movimento uniforme: $d = vt$. Na presença da gravidade hà necessariamente uma *desaceleração*. Uma pedra atirada ao ar vai constantemente desacelerando: acaba por parar de subir, depois inverte o sinal da velocidade e cai. Um foguetão, que parte com uma velocidade inicial maior que a velocidade de escape não acaba por cair na Terra, mas vai sempre desacelerando. No afastamento das galàxias não é isso o que se passa: à medida que o tempo passa a velocidade aumenta, há *aceleração* (note que, em cada instante, a velocidade é dada pela tangente à curva). Dir-se-ia que hà uma anti-gravidade, uma força repulsiva em acção. Por outras palavras, hà uma energia repulsiva não detectada directamente em acção: é a *energia escura*.

A história da anti-gravidade ou da energia escura é uma história muito antiga. Aristóteles (séc. VI a.C.) desenvolveu um modelo para o Universo que era um modelo de esferas dentro de esferas. No baixo nível tinhamos a Terra, a Lua e pouco mais: aí dominavam as 4 substâncias terrestres (terra, água, ar e fogo) e o movimento natural era o da queda. Mas nas altas esferas, onde actuavam anjos e deuses, não havia a queda, o tombar na Terra. Porquê? Porque nas altas esferas a natureza das coisas era diferente, havia uma outra substância, mais imaterial, que era a *quinta-essência*. Numa linguagem mais física: havia a Terra que era o centro do mundo e era o centro do campo da gravidade, por causa disso as coisas caíam. Mas nas altas esferas havia a quinta-essência que impedia a queda. Realmente a quinta-essência pode ser vista como equivalente a uma anti-gravidade: os objectos e seres das altas esferas não vinham a cair aos trambolhões até à vil e pecaminosa Terra – por acção da enigmática gravidade...

A cosmologia de Newton depende de uma maneira essencial da presença da gravidade. Mas prescinde completamente da anti-gravidade. Um planeta do sistema solar não cai no Sol não por graças duma anti-gravidade mas porque – como já vimos – a força atractiva da gravidade é compensada pela força repulsiva centrífuga. E desta maneira simples foi ditada a morte da quinta-essência.

Mas a quinta-essência renasceu pela mão de Einstein. Em meados do século passado Einstein via o Universo como algo estático, sem evolução, com o futuro igual ao passado. Mas, já se sabia, o Universo era constituído por concentrados massivos de estrelas e galáxias. Ora essas massas, devido à gravidade, teriam tendência a colapsar umas nas outras, formando uma única grande massa. Um Universo estático, em que actue a força da gravidade não é, portanto, estruturalmente estável. Einstein para dar estabilidade ao modelo estàtico decidiu introduzir uma anti-gravidade a que chamou *constante cosmológica* Λ. Onde houvesse uma força da gravidade havia também uma força igual, de sentido oposto, de anti-gravidade. E estava assim assegurada a estabiliade do Universo estático.

Mas nos finais dos anos vinte do século passado estava Hubble a descobrir que o Universo era tudo menos estático: era um Universo evolutivo, em expansão. Einstein em visita à Califórnia toma conhecimento dos resultados de Hubble e abandona de imediato o seu modelo estático, que considerou ser: "o maior erro da minha vida!".

A verdade, porém, é que a energia escura parece mesmo existir, não correspondendo à força que anula a gravidade, mas, mais do que isso, à força que é responsável pela aceleração.

Estamos perante um problema muito complicado. Por um lado as trajectórias em campos gravitacionais exigem que haja matéria escura, invisível. Talvez que as partículas para além das anti-partículas associadas tenham também partículas super-simétricas, mais pesadas, associadas a elas. Cada bosão teria um fermião associado e vice-versa. Até agora não há convincente evidência experimental disso.

Por outro lado, há a energia invisível, a energia escura, comportando-se como um campo, que parece existir por todo o Universo que poderá, ou não, perpetuar-se.

Mas o mais grave é que o Universo invisível é muito mais importante do que o Universo visível. Galáxias visíveis, estrelas, planetas, poeiras, átomos ionizados ou não, luz, isto é, o Universo visível, no balanço de massa-energia representa só 5% da massa-energia do Universo. À matéria escura cabem cerca de 25% e à energia escura 70%.

Como sempre, a Física depara-se com grandes desafios na sua frente!

The study of aerosols and other atmospheric constituents at Évora University: start and development since 1993

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Abstract

The interest on aerosol studies at the CGE was first prompted by Rui Namorado Rosa, in the framework of his interest in the role of aerosols on cloud formation and more generally on the climate system. The first steps were done about seventeen years ago with an application for the establishment of a Research Centre in Climate Change, which counted with the participation of four Portuguese universities, under the leadership of the CGE aerosol initial team. A few years later the activities were definitely launched with the involvement of the team in the CLEARCOLUMN-ACE2 European project, part of the IGAC-IGBP International Program, where apart from being responsible for the local organization in Sagres, Portugal, the CGE participated scientifically moving to the place scientific instrumentation dedicated to aerosol studies.

Since then the research continued to develop in the frame of several scientific project and the initial objectives have been greatly broaden. The CGE aerosol monitoring is included in some International Networks (AERONET, EARLINET, SPALINET) and the number of people involved has greatly increased with the integration of several PhD and MSc students, Post-Doc researchers and more recently, with the incorporation of Science Program researchers.

1. Introduction

In 1993, the interest in aerosols and in the fundamental physical mechanisms such as aggregation, nucleation and cloud formation, as well as the radiative impact on climate were first brought to the Physics Department by Rui Rosa. At the same time Évora Geophysics Centre, created two years before under the framework of Programa Ciência, was just starting its scientific activities, scientifically oriented to classic research fields of the atmospheric and earth sciences.

In 1994/95 there was the first opportunity to set up a research infrastructure in the fields of Atmospheric Sciences and Climate, due to the Proposal coordinated by Évora University (Évora Geophysics Centre) in collaboration with other 4 Institutions to PRAXIS Program, for setting up a Research Centre on Global Change. Unfortunately this proposal as well as another one made later to the Scientific Re-equipment National Program, also coordinated by Évora University in collaboration with other six Institutions, were not successful and the set up of a research program on atmospheric aerosols had to wait some years for a better opportunity, which appeared in 1995/96 when Évora Geophysics Centre was invited, together with the Institute of Meteorology, to participate in the International Project CLEARCOLUMN-ACE2 (Raes et al., 2000) sponsored by the International Global Atmospheric Chemistry (IGAC) Project, a core project of the International Geosphere-Biosphere Program (IGBP).This project aimed at studying the column integrated radiative effect of aerosols in the cloud free atmosphere making use of different observational platforms (surface based stations, aircraft and satellites), being Sagres, in Portugal one of the two sites where CLEARCOLUMN Project, in 1997, was set up as one of the two main surface based stations; Évora Geophysics Centre (CGE) was the scientific coordinator entity from Portugal, which included three Portuguese institutions. Besides the fact of being the responsible for the local organization and set up of this Project at Sagres, where a multinational team of about 60 persons remained for almost three months, the CGE has also deployed its own scientific instruments and in this way the team of the University of Évora was finally starting the research on atmospheric aerosols (Silva et al., 2002). The main direction of this research was first oriented towards the characterization of the impact of the aerosols on the climate, rather than on the study of the fundamental physical mechanisms such as aggregation, nucleation of atmospheric aerosols and cloud formation.

Hence, after having approved a FCT project in 2002 and a European Project in 2003 and having acquired and set up some in situ as well as passive remote sensing instruments, which became part of the AERONET (Aerosol Robotic NETwork) network, the research on atmospheric aerosols kept on. First, on the characterization of the in situ and columnar optical aerosol properties over Évora and Cabo da Roca, aiming at establishing an aerosol climatology and assessment of the direct effects of aerosols upon the climate (at a local and regional scales)(Silva et al., 2003; Elias et al., 2006); later, as the research team was growing and the set up of the Évora atmospheric sciences observatory proceeded, the indirect effects of atmospheric aerosols were also investigated(Costa et al., 2006; Santos et al., 2008). Different approaches and methodologies, besides the ground-based observational component, were used in the aerosol studies and the extension of the investigation to clouds and cloud-aerosol interactions (Costa et al., 2002, Cattani et al., 2006), as well as to climate relevant trace gases (Bortoli et al., 2009a) was also initiated. In this last topic the quantification of the total column and of the vertical profiles of optically and chemically active atmospheric species relevant to climate studies started in middle 2004 due to the development, by the team in cooperation with the Institute of Atmospheric Sciences and Climate (ISAC-CNR) at Bologna, of the necessary ground based passive remote sensing instruments to measure the spectral radiative quantities, from which the gas column contents and vertical profiles could be derived (Bortoli et al., 2009b; Bortoli et al., 2010). Advanced radiative and atmospheric models, numerical simulations techniques, statistical and analytical studies making use of combined observational platforms (satellite as well as ground based observations) are currently used by the team aiming at fully characterizing and modeling atmospheric aerosols and gases and its multiple impacts on local and regional climate and on air quality (Costa et al., 2004; Palazzi et al., 2008; Wagner et al., 2009; Potes et al., 2010; Salgado and Le Moigne, 2010).

As a consequence of the development of the research on climate relevant atmospheric constituents, the advanced training activities have regularly increased since the start of the research activities and a significant number of Master and Ph.D Students as well as pos-doc positions and more recently Ciência 2007 and 2008 senior researchers have been integrated in the group.

The present paper is organized as follows: in Section 2 a description of the scientific objectives concerning aerosol, cloud and gases studies is presented; section 3 presents the atmospheric physics observatory and the quantities that can be obtained from the different instruments; section 4 exhibits some results achieved by the team concerning atmospheric aerosols, gases and cloud-aerosol interactions; section 5 presents the evolution and trend of the research that is being developed within the group.

2. Scientific objectives

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.

Since they have normally short residence time, except the ones reaching the stratosphere where they can stay for some years, their characterization and modeling is very complex and their impacts on the climate and on the environment are quite difficult to quantify both in space and time. At the same time, due to different origins and mechanisms of formation and transformation during the transport form the sources, they have a variety of physical and chemical characteristics, changing with time and space and their effects on climate are thus highly uncertain.

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.

From the point of view of the interaction of atmospheric aerosols with the climate system the **main climate relevant aerosol properties** are, for the atmospheric column, the following optical properties: spectral aerosol optical thickness **,** related to the aerosol load in the atmospheric column, the aerosol phase function **,** the radiation scattering pattern due to aerosols, related with their size and shape, and the single scattering albedo **,** relative scattering to extinction in a single scattering event related to the absorption properties of aerosols. These columnar **optical properties** must be linked properly to their **physical and chemical properties** like the size distribution, shape , the complex refractive index **,** directly linked to the shape and to the chemical composition if the mixture state of the various aerosol components are known, through an appropriate scattering theory. 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 the 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 most of its studies by using the inverse approach, which is being also applied to gases and to cloud studies, varying the type and amount of the optical information (spectral extinction, sky radiance or irradiance field, spectral radiances and others) and the inversion techniques used optimal estimation, radiative transfer inversions, etc) depending whether one is deriving aerosols, gases or cloud properties.

Because the aerosol properties are space and time dependent, they have to be obtained not only at the ground surface at a particular site (*in situ* properties at ground surface or at different altitudes), but also on the column (vertical profile and total atmospheric column) as well as at different places covering a given area/region (satellite imaging and/or a network of ground-based observations).

Taking into consideration what was explained above, the Group has defined the **following scientific objectives** concerning aerosol, gases and cloud studies:

- Set-up of an **atmospheric observatory at Évora**, where i) in-situ and remote sensing measurements of aerosol optical properties are made at the surface and in the atmospheric column (integral or vertically resolved measurements); ii) remote sensing measurements of spectral diffuse radiation from different geometrical configurations are also made for deriving the column content and vertical profiles of atmospheric trace gases; passive and active remote sensing measurements of cloud properties;

- Set-up of an atmospheric observatory at the Atlantic Coast northern Lisbon (Cabo da Roca) where measurements of the columnar aerosol optical properties are made;

- Combination of aerosol measurements from different observational platforms, for **aerosol studies** (optical and microphysical properties and dynamics) and assessment of the *climate direct effects*, both at local and regional scales.

- Combination of aerosol and cloud measurements from different observational platforms, for **aerosol-cloud interaction studies** and assessment of the *climate indirect effects,* both at local and regional scales.

- Combination of aerosol measurements at Évora from different platforms and **mesoscale modelling** to constrain model calculations of spatial and temporal distribution and variability of aerosol and cloud microphysical properties;

- Development of **optical instrumentation** for the monitoring of atmospheric trace gases and air quality;

- Investigation of the **spatial–temporal structure of total ozone and total NO_2** variations in the atmosphere over Portugal and comparison with satellite data;

- Integration in international observational networks like: AERONET (Aerosol Robotic NETwork), EARLINET (European Aerosol Research LIdar NETwork) and SPALINET (Spanish and Portuguese Aerosol LIdar NETwork);

- **Advanced training** of graduate and pos-graduate students and lecturing in the graduation and pos graduation cycles of the University of Évora on *Earth and Atmospheric Sciences*, *Energy and Environment*, *Air Quality Management*; host of pos-doc positions and senior researchers from Ciência 2007 and 2008 Programs.

3. Atmospheric Physics Observatory

The Observatory of Atmospheric Physics of the Geophysics Centre, which is being set up since 2002, is a Research Infrastructure that is integrated in-AERONET network with NASA and is operating at two different locations: Évora (city) and at Cabo da Roca, 30km northeast of Lisbon in the installations of Cabo da Roca lighthouse. In addition, it is also integrated in EARLINET and SPALINET with the Lidar instrument since 2009.

The majority of the instruments set up at the Observatory are based on passive and/or active remote sensing techniques, providing information on the radiative field measured from the surface (direct solar spectral radiance or spectral angular sky radiance or irradiance in different observational configurations, or vertical profiles of spectral lidar backscattered signals). In all cases the columnar microphysical properties of aerosols and/ or content (columnar /vertical profile) of gases or cloud properties may be derived by numerical inversion procedures with different inversion techniques; other instruments measure directly the volumetric aerosol optical and physical properties at the surface, making possible the evaluation of air quality at Évora as far as aerosols are concerned. At the website

http://www.cge.uevora.pt/en/lab/observatory/physics-of-atmosphere.html it is possible to have an overview of all the instruments operating at the Observatory.

4. Main Results

In this section the most significant and representative results of the research on aerosols, clouds and gases will be present. Concerning aerosols, the following results are presented, illustrating in situ and columnar aerosol characterization in different sites at different atmospheric conditions, by means of ground-based measurements as shown in Figs 1-2, and of satellite data as shown in the upper panels of Fig.4:

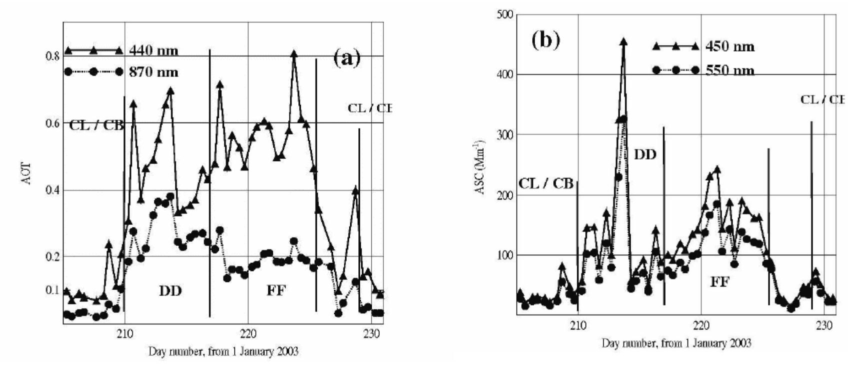

Fig. 1. Examples of aerosol types (desert dust, DD and forest fire, FF) derived from columnar aerosol optical properties (left) and from in situ local measurements of aerosol optical properties (right) in Évora during the heat wave episode of summer 2003.

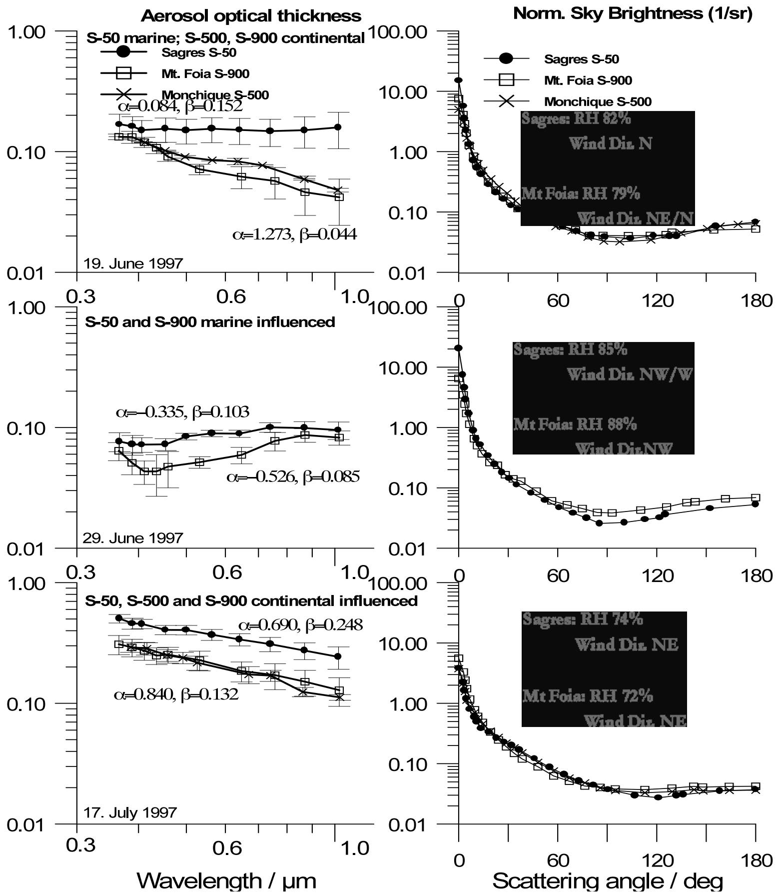

Fig. 2. Examples of aerosol optical conditions over two sites at different altitudes in the southern part of Portugal (Sagres (50m) and Mt Foia(900m)) for three typical cases: (top) :Sagres is within the marine boundary layer (MBL) and Foia is above; (middle): both sites are within the MBL; (bottom): both sites are influenced by continental air mass. The average relative and wind direction observed in each case is also indicated in red colour.

Concerning the local and the regional *climate direct effects* induced by different aerosol types at different sites, the following results are presented in Fig.3. and in the lower panels of Fig.4, respectively:

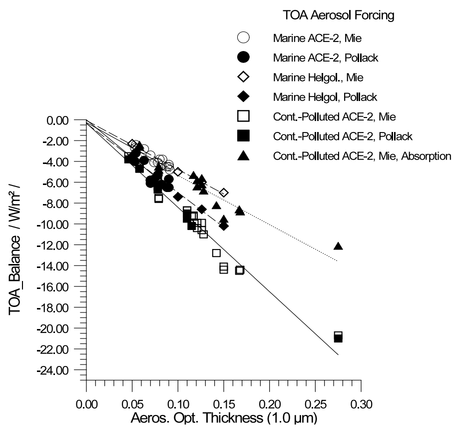

Fig. 3. Aerosol contribution to the short-wave Top of the Atmosphere (TOA) aerosol forcing (W/m2) for the main optical aerosol types found during CLEARCOLUMN ACE-2 in Portugal in comparison with results of a previous campaign at the island of Helgoland

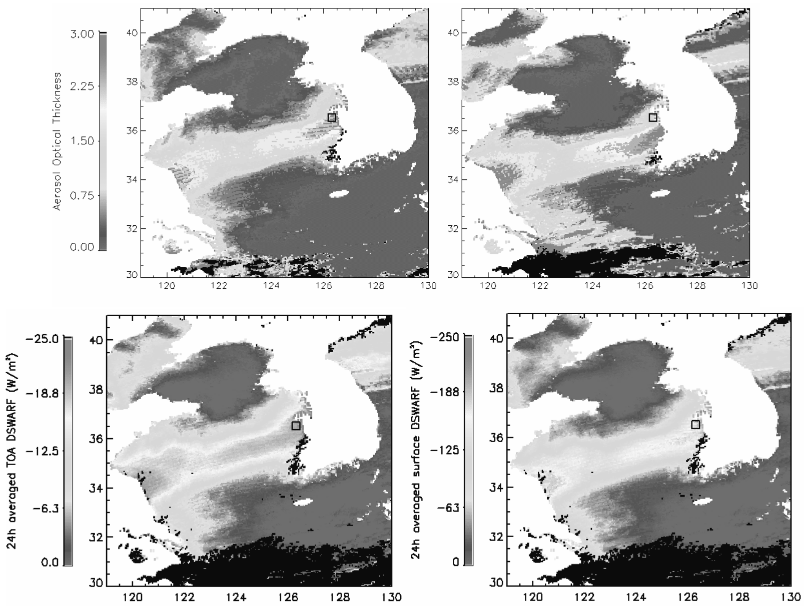

Fig. 4. Aerosol optical thickness derived from GMS-5 satellite visible reflectance for 7 April 2000 over the Yellow Sea at 02:30 and 04:30 UTC (upper panels) and daily mean direct SW aerosol radiative forcing at the TOA and surface (lower panels).

Concerning cloud studies the following results are presented in Fig.5, illustrating the cloud microphysical properties derived from satellite remote sensing over Portugal and adjacent Atlantic Ocean:

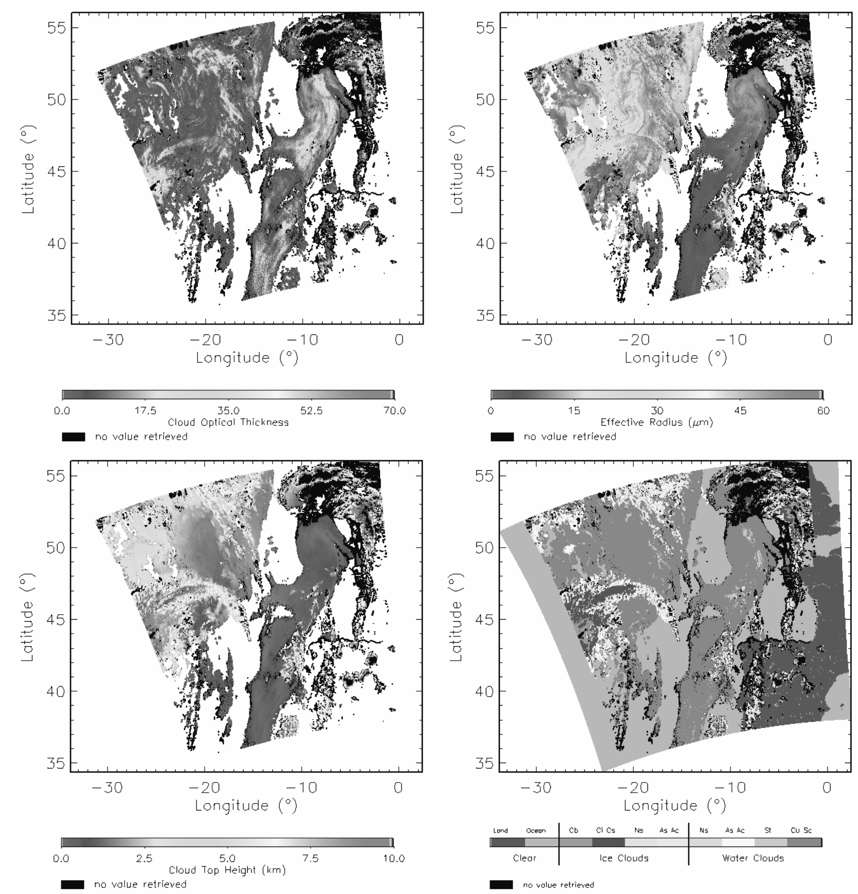

Fig. 5. Maps of the cloud optical thickness, effective radius, top height and type retrieved from MODIS – Terra satellite data on 5 August 2003 at 1350UTC.

The use of atmospheric models has been used to model the aerosol optical thickness (related with aerosol load) and the climate direct effects at regional scales over Portugal and adjacent ocean as shown in **Fig.6:**

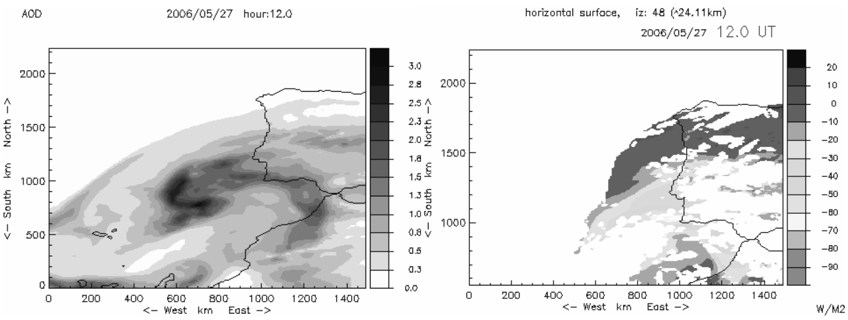

Fig. 6. Modelled aerosol optical thickness and top of the atmosphere SW radiative forcing for 27 May 2006, 12:00 UTC

The development of optical instrumentation leads to construction of the SPATRAM UV-Vis spectrometer in cooperation with the ISAC-CNR Institute at Bologna shown in **Fig. 7** and set up at CGE Observatory.

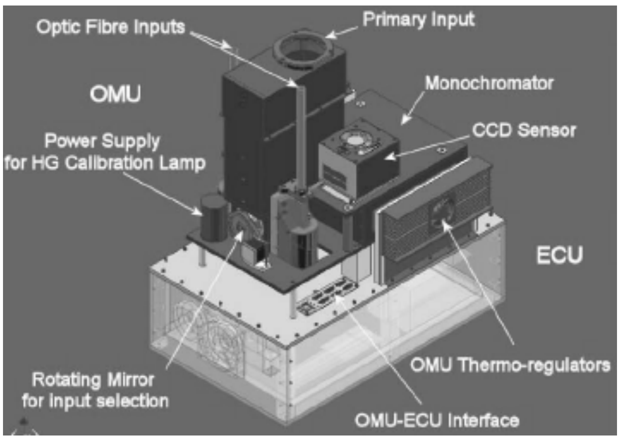

Fig. 7 Schematic view of the SPATRAM instrument installed at CGE Observatory since April 2004.

leading to the monitoring the atmospheric column content over Évora which can be compared with the correspondent satellite data, as shown in **Fig.8.**

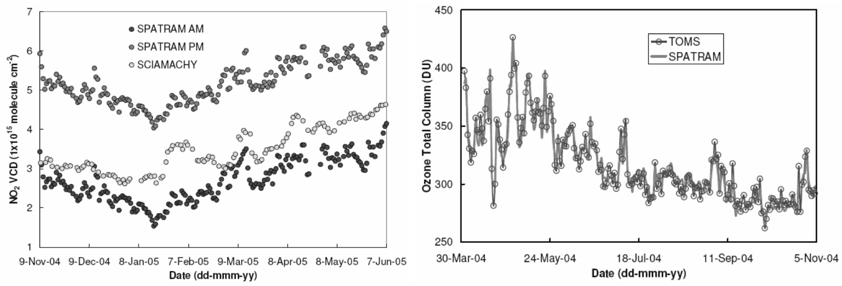

Fig.8. Time series of the NO2 Vertical Column Densities and ozone total column obtained with the SPATRAM equipment installed at the CGE observatory and comparison with satellite data (SCIAMACHY and TOMS).

Concerning the ground-based active remote sensing measurements of cloud and aerosol optical properties at different altitudes aiming at assessing the direct and indirect climate effects due to aerosols and clouds, the next Figure, shows the CGE LIDAR system **(Fig 9a)** set up at Évora Observatory, which performs the measurements and the identification of aerosols and cirrus clouds over Évora (**Fig.9b),** respectively at about 2km and 12km heights.

Fig. 9a. View of the open LIDAR System set up at Évora.

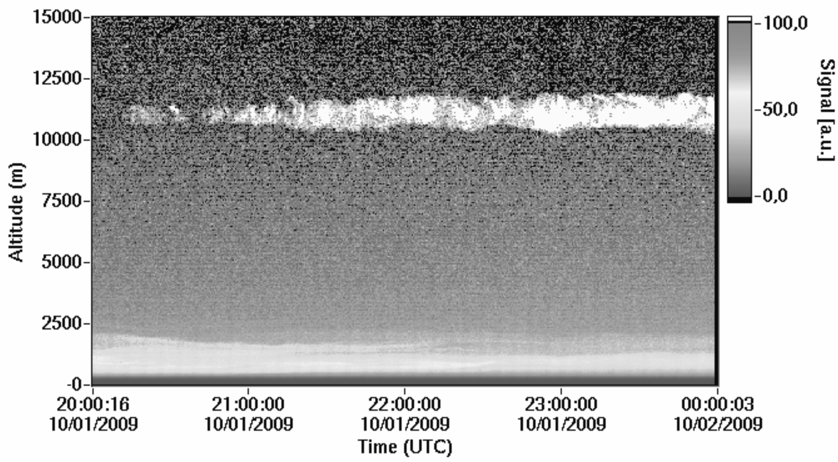

Fig.9b. Range corrected LIDAR signal for 532 nm. Measurements were taken on 1st October 2009 at Évora. The colour scale corresponds to the intensity of the signal. Clearly visible are aerosols in the boundary layer between ground and about 2000m height, as well as cirrus clouds between 10 and 12 km height.

5. Final remarks

As demonstrated by the results presented, the group has considerably evolved since the early 1990s, when the basic ideas were launched. Scientific achievements were reached in the studies carried out on aerosol, gases and clouds by the team in the last 15 years.

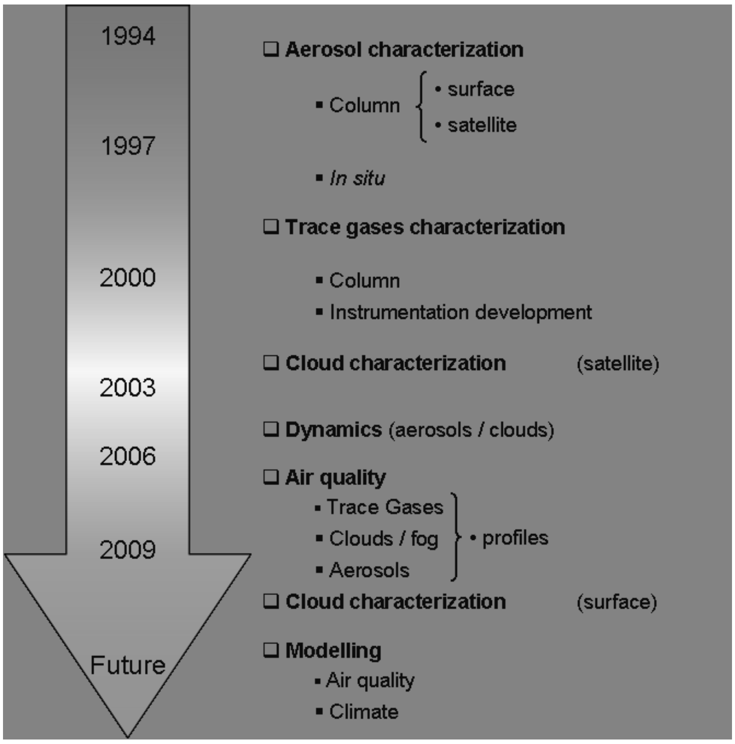

Fig. 10 Temporal evolution of the research activities

The academic progressions of the members of the team as well as the advanced training activities have regularly increased since the start of the group. Initially the team had five members, three of which starting their academic progression, we are presently a team with 11 researchers (including 3 pos-doc positions and two senior researchers from Program "Ciência") and 6 Ph.D students. Since the early 1990s five members of the group have concluded their Ph.D thesis and nine Master theses were supervised by the members of the team, under the Master Course on Climate and Atmospheric Environment of the University of Évora. The high rate of publications in international peer reviewed journals and the fact that the Observatory conditions are quite unique in Portugal have contributed for the strong internationalization of the team and for the high demand from students looking for Ph.D or Master Supervisons.

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Probing the Sun's Interior: Neutrino Spectroscopy and Helioseismology – Searching for Dark Matter

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Abstract
During the last half a century, helioseismology had been the preferential probe of the Sun's interior. In the beginning of this new century, several solar neutrino experiments will reveal which physical processes are occurring in the deepest layers of the Sun's core. Borexino and SNO+, a new generation of ongoing solar neutrino experiments, will unlock the power of solar neutrino spectroscopy to probe the Sun's central temperature profile. Here, I show how different physical processes, occurring inside the Sun, will produce a unique neutrino flux distribution in 7Be-ν and 8B-ν, as well as 13N-ν, 15O-ν and 17F-ν. This new generation of neutrino experiments will be able to confirm or rule out the existence of several physical processes in the Sun's interior, and thereby complement the findings of helioseismology. Furthermore, in my presentation I will focus on my latest research on dark matter in the solar interior, namely, to discuss the impact of the new dark matter candidates proposed by current new theories of particle physics.

1. Probing the Universe: The Observational Tools

During the last centuries, scientists have developed sophisticated theories in an attempt to rationally explain our Universe. More remarkably, scientists have also been able to develop sophisticated instruments that have allowed humans to extend our natural abilities to see and listen to the Universe around us.

The theories of classical mechanics developed mostly in the 19^{th} century, have allowed us to understand the way that mechanical perturbations propagate through different mediums, and today not only can we listen to the sound, but also can make accurate measurements of propagating sound waves in the different mediums. More significantly, we have been using this technology to probe the interior of many different subjects, from the human body (ecography), to the Earth (seismology) and the Sun (heliseismology).

The same century gave us a modern account of the way light propagates through the different material mediums and the vacuum: Electromagnetism. The technological developments achieved up to now on this topic have been remarkable, as with modern telescopes and satellite missions we have been able to observe our universe almost in the entirety of the electromagnetic spectrum, from the radio waves to gamma rays. This is far beyond what our eyes can see. And if the reader has the opportunity to talk with my Observational Astronomer colleagues, they will tell you that this is simply the beginning of what future technology can bring.

In the 20th century, following on the same footpath, but by taking a radical view of the world, the modern theories of General Relativity and Quantum Mechanics lead us to develop a fundamental theory of particles physics and interactions. These remarkable achievements have come together with the discovery of new forces in Nature as well as of new fundamental particles. From the latter, there is a particle in particular that we are now able to start to understand and use to probe the Universe: the neutrino.

What makes the neutrino of interest for this talk is the fact that, for the first time, we are able to understand the basic laws that regulate their behaviour, and, more remarkably, that neutrinos are produced in locations in the Universe from where we cannot obtain information otherwise, namely, at the innermost core of stars, including our Sun.

A new generation of neutrino telescopes is being built to observe the Sun, and some occasional supernova explosions but, in the future, technology will give us the ability to observe the remaining of the Universe. Indeed neutrinos have the fantastic potential to reveal to us a *new, undiscovered Universe*, similarly to what the photon has done for us (from radio waves up to the gamma rays) in the previous centuries.

The existence of the neutrino was first postulated by Wolfgang Pauli in 1930. In 1963, John Bahcall and Raymond Davis proposed an experiment to measure the neutrino fluxes coming from the nuclear reactions occurring in the Sun's core. Unexpectedly, the neutrino flux measured was 1/3 of the predicted by the solar standard model. In the following decades, this disagreement became known as the "solar neutrino problem". Two types of solutions where proposed: (1) some scientists, most of them Astrophysicists, believed that physical process still unknown in the Sun's interior were responsible for the observed neutrino deficit; (2) other scientists, mostly Particles Physicists, suggested that there was a fundamental problem in particle physics theories.

During the following decades the problem was the subject of vivid discussions between the particle physics and astrophysics research communities. In a seminal paper with Sylvaine Turck-Chièze, we proposed the use of Helioseismolgy as a tool to probe the physics of the solar core. At first, John

Bahcall has dismissed this proposal. Nevertheless, soon after he[1] realized that helioseismology was a powerful tool to probe the physics of the Sun's interior as well as the physical mechanisms responsible for the production of the neutrinos. Finally, on a paper published by J. Bahcall and collaborators in astro-ph and Physics review letters B, he wrote "Helioseismological measurements indicate [Turck-Chièze and Lopez (1993) – Lopez, with a z because John at first thought that I was Spanish] that the solar sound velocity does not differ significantly from the standard model profile, as far as the helioseismological measurements have probed ". Since then, astrophysics have started to model the Sun using helioseimology as a diagnostic tool, and particle physicists and astrophysicists have worked together towards the resolution of the neutrino problem.

The particle physics proposed solution has prevailed: neutrinos once produced in the Sun's core, change flavor soon after. Neutrinos are produced with an electronic flavor, i.e., electron-neutrinos. In their journey towards the Earth, some of them will change to muon-neutrinos or tau-neutrinos. This fundamental process is known as neutrino oscillations.

Indeed, in August 2001, the SNO experiment has measured for the first time the solar neutrino fluxes of more than one neutrino species. The once famous solar neutrino problem was finally resolved. Surprisingly, the values obtained were in agreement with the predictions of the solar standard model. The exceptional agreement obtained was a clear result of the high quality of the solar standard model developed during the previous decades, which was greatly improved due the accurate measurements provided by the new field of helioseismology. One year later, Raymond Davis received the Nobel Prize of Physics for his discovery in the sixties, i.e., for measuring for the first times the integrated neutrino flux coming from the Sun. In the Nobel Lecture, he acknowledged the contribution of helioseismolgy to the resolution of such fundamental problem in Particle Physics. The neutrino, once a problem, has now become the new probe, a source of solutions. A new generation of instruments are now being used to measure the solar neutrino spectrum, i.e., to measure the neutrino flux in frequency rather than the total integrated spec-

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[1] In a meeting in Paris, I had the pleasure to meet John Bahcall for the first time. At the time already converted to the importance of Helioseismolgy for the Sun, he gave a seminar in Particles Physics. He told to an educated audience that the way to progress in Helioseismology, should be done through a numerical approach, rather than an analytical one! On the talk presentation, he commented further, "I disagree with the approach made by Prof. Douglas Gough (Institute of Astronomy, University of Cambridge) by insisting in using an analytical methods to progress in the understanding of the physical mechanism of propagation of waves in the Sun (Helioseismology)". I told him at that time that I strongly disagreed with his comments and that both methods should be considered.

trum, as was done in the pioneering experiments proposed by John Bahcall and Raymond Davis.

This new generation of neutrino telescopes is of fundamental importance for all fields of astrophysics, in particular for the search of dark matter inside the Sun, a research field in which I am very much involved.

2. Probing the Universe: Searching for Dark Matter

Evidence for the existence of dark matter in the Universe is well established by cosmological observations, and its influence is also necessary in order to explain the formation of the structure of the current epoch Universe. Various studies suggest that dark matter should be constituted by massive, neutral, non-baryonic particles. Furthermore, independent considerations from particle physics, also propose the existence of such particles.

Recently, several particle physics detection experiments have suggested that weakly interacting massive dark matter particles (WIMPs) could have a mass smaller than 10 GeV, and have spin-dependent elastic scattering cross-sections with baryons as large as 10^{-32} cm^2 or spin-independent elastic scattering cross-section with baryons of the order of 10^{-40} cm^2. This last cross-section is negligible when compared with the spin-dependent cross-section. The relatively weak experimental limits on spin-independent interactions of dark matter particles are especially of interest for the Sun with its large abundance of protons. In some particle physics formation scenarios, cold dark matter particles are non-annihilating particles, on other scenarios they are self-annihilating particles.

Study of the effects of the accumulation of dark matter particles by the Sun may therefore, be an important complement to direct detection searches for light WIMPs.

2. The Dark Matter and the Evolution of Stars

High resolution simulations indicated that our own Galaxy is immersed in a halo of cold dark matter particles. Furthermore, studies on the solar neighbourhood suggest that a dark matter component is needed in order to explain the motion of stars. There is evidence that dark matter particles have a local density of 0.3 GeV/cm^3 and velocity dispersion of the Galactic Halo of 270 km/s, therefore, providing the necessary mass required for holding the observed stars within the galactic halo. The rotation velocity of our own Sun around the Galactic center is of the order of 220 Km/s. Throughout its continuous motion in the Milky Way, and with its intense gravitational field, the

Sun captures a significant amount of the dark matter particles that passes through it. These particles are trapped in the Sun's interior when they collide with the nuclei and lose (linear) momentum, ending up by drifting into the Sun's core. The collision of captured particles with the local baryons, lowers the central temperature by a few percent. The final temperature profile of the core depends on the properties of the dark matter particles: mass, elastic scattering cross section and annihilation cross section, among other parameters. Helioseismology and neutrino spectroscopy are powerful probes of such dark matter inside the Sun.

3. Helioseismology: Probing the Sun's Envelope

The Sun shows a complex pattern of surface oscillations whose restoring forces are produced either by compressibility or buoyancy. The pressure perturbations give rise to acoustic sound waves in the high-frequency part of the spectrum, and buoyancy variations drive gravity waves in the low-frequency range of the spectrum.

The small amplitude surface perturbations observed in the Sun can be described as a sum of eigenstates. Each eigenstate has a spatial counterpart that is defined by a spatial eigenfunction that depends on the thermodynamical structure of the background state (the sun's internal structure), and a time-dependent eigenfunction that is characterized by the frequency $\nu_{l,n}$. The numbers l and n are positive integers, known as the degree and radial order of the mode.

During the last 50 years accurate measurements of frequency values were obtained for more than 7 thousand acoustic mode frequencies, $\nu_{l,n}$. This achievement is the result of the combined efforts of several observational networks, such as BISON and GONG, followed by the helioseismic experiments from the SoHO mission: GOLF, VIRGO and MDI-SOI. Figure 1 shows the power spectrum of acoustic oscillations. Seismology has provided the most powerful tool to probe the Sun's interior. Accurate frequency measurements of large numbers acoustic modes were made, including the radial and dipole global acoustic modes, which are the ones that penetrate more deeply into the core.

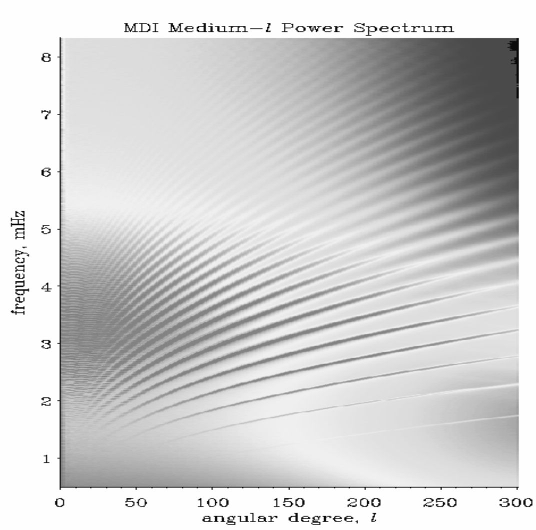

Fig. 1: Power spectrum: $\nu=\nu(l)$ [or $\omega=\omega(k)$] diagram from MDI/SOHO high-cadence full disk data. It shows acoustic mode frequencies from a few Hz up to 10 mHz and from modes of degree l=0 up to l=1000. MDI/SOHO measures Dopplergrams every minute since 1996. These modes are excited by turbulent convection beneath the surface. Acoustic modes with similar wave speeds probe similar depths. The maximum amplitude occurs for the 5-minute (3 mHz) p-modes or acoustic oscillations. This corresponds to an amplitude velocity of the order of 10 cm/s, or luminosity variations of the order of 10^{-6}.

Figure 2 shows the difference between the sound speed inverted from the acoustic power spectrum and the square sound speed of the present Sun as predicted by the solar standard model. The difference is less than 2%. Unfortunately, the diagnostics of the Sun's core provided by these acoustic modes are still insufficient. Inversions of the sound speed for the inner Sun's core are not reliable. However, the possible accurate measurement of neutrino fluxes by current ongoing experiments or future ones could be a breakthrough to understand the physics of the Sun's core and establish the possible existence of dark matter.

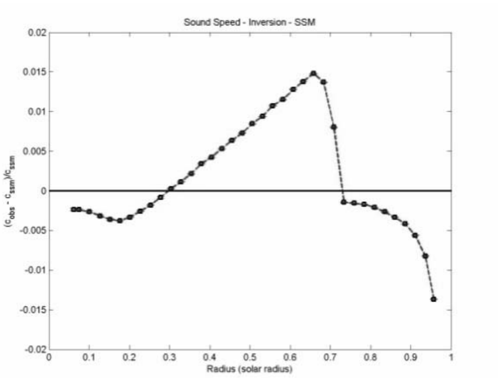

Fig. 2: The red dotted curve corresponds to the difference between inverted profiles and our solar standard model (see text).

4. Neutrino Spectroscopy: Probing the Sun's Core

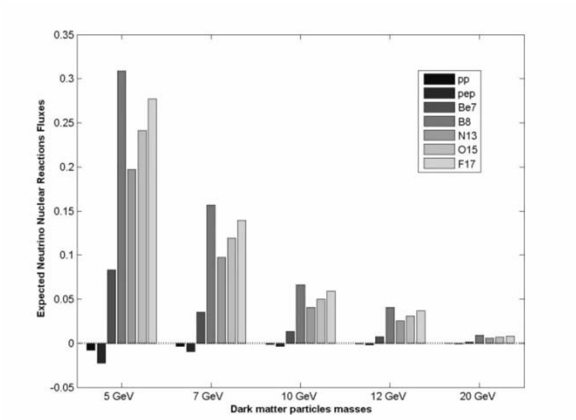

Fig. 3. Estimates of solar neutrino fluxes for the pp-chain (pp-ν, pep-ν, ^{7}Be-ν and ^{8}B-ν) and CNO cycle (^{13}N-ν, ^{15}O-ν and ^{17}F-ν). The different bars show the relative neutrino flux variations, relatively to current neutrino flux values predicted by the solar standard model. The dark matter haloes are composed by self-annihilating massive particles, with dependent and independent scattering cross-sections with baryons of the order of $2.0\text{x}10^{-36}$ cm^2 and $4.0\text{x}10^{-40}$ cm^2. The product of the self-annihilation cross section and the relative velocity of colliding particles at freeze-out is of order $1.0\text{x}10^{-36}$ cm^3 s^{-1}. The Sun's dark matter models were computed in a similar way to the solar standard model.

Neutrinos are produced by the nuclear reactions in the solar core. They leave the Sun, traveling to Earth in less than 8 minutes. These neutrinos stream freely to Earth, subject only to nuclear forces with baryons at the weak scale with scattering cross section interactions of the order of 10^{-44} cm^2, and hence are natural probes of the Sun's core structure. In recent years, the determination of the neutrino particle properties, as well as the establishment of the mechanism responsible for neutrino oscillations, has refocused the scientific community towards the primordial goal of using solar neutrinos to probe the physics of the Sun's core, as initially proposed by John Bahcall and Raymond Davis about 50 years ago.

With recent technological developments, a new generation of instruments is starting to measure the neutrino fluxes produced in the different nuclear reactions of the pp-chain and the CNO cycle. In order to infer the structure of the solar core, the new neutrino spectroscopy can be used in two ways: (1) as a probe of the local temperature profile, by measuring the total number of electron neutrinos produced for each nuclear reaction, and (2) as a probe of the local electron density profile, by determining the amount of electron neutrinos converted into other neutrino flavors. The high precision of such neutrino experiments will be an excellent tool for probing the physical mechanisms occurring inside the Sun, and to test the existence of dark matter in the Sun's core.

In the near future, the measurements of pep and CNO neutrino fluxes will be greatly refined through the Borexino detector or through one of the upcoming experiments SNO+ or LENA- although for LENA we will have to wait a full decade. Using the neutrino fluxes of the present solar standard model as a reference, in Figure 3 we show the neutrino flux variations for a range of solar models evolving in halos of dark matter in the cases of annihilating and non-annihilating low mass particles. The variations can be as much as 90% in the case of non-annihilating particles. The possible existence of a dark matter core will produce a distinct signature for several neutrino flux measurements that will distinguish dark matter modulation of the solar core from other possible astrophysical sources.

Our star, the Sun, can still be keeping in its interior the most exciting discovery yet of modern Cosmology. Although, myself being a septic about such exceptional possibility, I will try not to commit the same mistake as did a previous well-know physicist of the beginning of the 20^{th} century. Famously, Lord Kelvin[2] has stated "There is nothing new to be discovered in Physics now. All that remains is more and more precise measurements" (circa 1900). Ever since, physicists avoid making the same mistake.

[2] This quotation has also been attributed to other scientists, and the fact that Lord Kelvin has indeed said that, is still a matter of debate. Albert Michelson and William Thomson are also considered to have made similar remarks.

Acknowledgments

I would like to acknowledge my Ph.D. students: Dario Passos, Jordi Casanellas, Elisa Cardoso and Ana Brito for their support to my research work. Furthermore, and in particular, I would like to thank Prof. Joseph Silk (FRS) with whom I have done some of the unpublished research discussed in this communication.

I would like to thank the Organising Committee for giving me the opportunity to participate in this Conference.

Finally, I would like to congratulate Prof. Rui Namorado Rosa, to whom this Conference is dedicated, for being one of the inspiring academics of this University.

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Electric properties of granitic rocks

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Abstract
The objective of this work is to clarify the role of water content on the charge transport mechanisms of different granitic rocks. The mineralogical content of the rocks will also be taken into account. From the electrical point of view these materials are rather insulating porous media where charge injection creates different phenomena like build-up charges, space charge limited currents, surface effects and other behaviors that resemble much a variety of oxides, like AlO.

1. Introduction

Interesting electric properties of rocks are a result of their behaviour as both conductor and dielectric. In fact, dielectric behaviour of rocks is being used for decades in different logging tools, Garrouch *et al.* (2009), to determine the water content in oil and gas wells, Kenyon *et al.* (1994). Additionally, these properties can also be used in rock-type classification, Garrouch *et al.* (2009). Moreover, recently these properties have become of capital importance in lithosphere exploration using electromagnetic techniques like ground-penetrating radar (GPR), Reppert *et al.* (2000). Furthermore present investigations, Freund *et al.* (2006), have shown interesting pressure stimulated currents, Vallianatos *et al.* (2008), and voltages, Aydin *et al.* (2009), that could have some implications in the so called seismo-electromagnetic phenomena, Uyeda *et al.* (2009). For that reason electric properties of rocks are now receiving a highly relevant research effort.

The earlier studies in this area were done by P. Sen and co-works, Sen (1981) and Chew and Sen (1982), who gave a very important contribution to it. These works were focused in the anomalously high values of the real part of the dielectric constant, □', at low frequencies and authors presented different models to explain such behaviour. Later studies have considered the effect of water in porous media like calcite rocks, Kenyon *et al.* (1994), and artificial porous glass specimen, Haslund *et al.* (1994). In this work we will follow this perspective by measuring the electrical properties of different granitic rock types (initially there types will be considered, presented in Fig. 1) varying the content of water in four samples of the same rock class. The simplified classification of the different rocks is as follows: 1) the left most rock of Fig. 1 is a coarse grained biotitic granite, yellow coloured and characterized by an abundance of large feldspar megacrystals usually showing poorly defined shapes (abbreviated to Yellow Coarse, YC); 2) the middle one is a quartz diorite grey coloured and medium grained rock with homogeneous appearance, dominantly biotitic (reduced in waht follows to Grey Medium, GM); 3) the right one is a medium grained homogeneous granite, with light rosy colour determined by the tonality of the feldspar crystals that stand out from a greyish with matrix containing dark grains (condensed to Rose Medium, RM). The results will be discussed in terms of local porosity, Kenyon *et al.* (1994) and Haslund *et al.* (1994), and fractal geometry of the fissures network, Miguel *et al.* (2000).

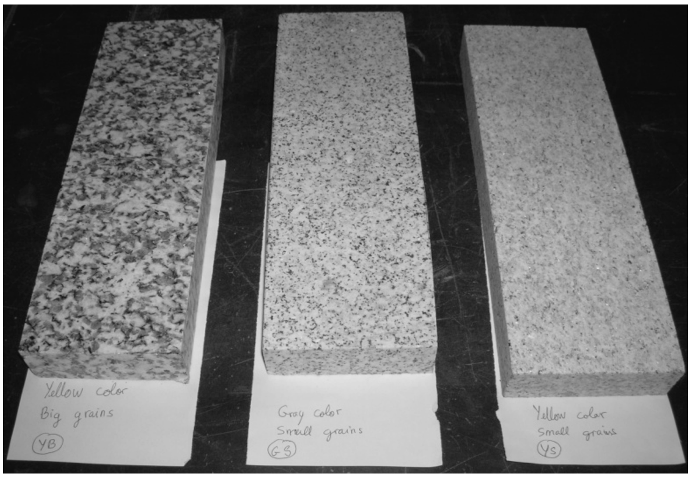

Fig. 1. Picture of the three granitic rock types considered in this work.

In addition, the measurements will be done using a recent digital-signal processing algorithms based on Personal Computer and analog to digital converters. The algorithms are based on ellipse fitting for the extraction of the acquired sine signal parameters so that the impedance magnitude and phase can be determined, Ramos *et al.* (2009).

2. Experimental

The experimental work is divided in two parts, first the samples will be prepared with different water contents and then different electrical measurements are preformed in order to clarify the charge transport measurements.

2.1. Rock samples preparation

Granitic rock samples are prepared with geometry 9×9×3 cm3. Figure 2 shows a photograph of a typical sample. The top and down squared sides of the samples, after the preparation process (described below), will be covered with conductive silver paint to act as electrodes. With this method it is expected that we could reduce the low-frequency electrode polarization effect.

Fig.2. Photograph of a typical sample used in the research process.

The preparation process is as follows, after being cut all samples are heated up from room-temperature (RT) in low vacuum to 150 ºC and then they are cooled down to RT to the effect of being completely dried. The samples are then left in a desiccator containing dry silica gel. Afterwards, the samples are subjected at a fixed RT to isothermal adsorption of water. One sample from each lot is not subjected to this process to be left completely dry for comparison.

Isothermic adsorption equilibrium curves for water vapor in the rock samples is obtained by placing the samples in different ambient conditions with variable relative humidity (RH) and monitoring the samples weight (using a precision balance with 1 mg resolution) and the dielectric constant until no further changes were detected on both, this process takes approximately one to two weeks. Once the samples are saturated with a given content of water (depending on the RH that the adsorption process occurred) the following measurements are performed.

2.2. Measurements

Based on our previous work in rather insulating materials, Silva *et al.* (2009a,b), we have elaborated the following set of measurements:

Current-Voltage characteristics (I-V): it is planned that this measurements will be done at fixed (stabilized) temperatures ranging from −60 ºC, below the common fusion point of water and near its supercooled state transition, Gomes *et al.* (2006), to 150 ºC, above its evaporation point. Due to the high resistance of the samples, low-current/high-resistance picoammeter/voltage source equipments are required. The voltage ramps are expected to be controlled automatically by a program with several parameters: voltage step typically $\Delta V \sim 0.1$ V, trigger time $\Delta t \sim 100$ ms, maximum, V_{max}, and minimum voltages, V_{min}, and initial voltage, V_I, normally set to zero. The voltage cycles will be as follows: starting from V_I up to V_{max}, then down to V_{min} and finally to V_I again. The current passing through the samples is expected to vary strongly with the water content.

Current versus Temperature (I-T): it is expected to be obtained by continuously changing the temperature at a typical rate of ~1 ºC/min from −60 ºC to 150 ºC. Both current measurement and DC voltage biasing, typically V = 20 V, can be made with the use of a picoammeter/voltage source instrument.

Impedance spectroscopy (ε-f): it is projected to be done with the application of a stabilizing (fixed throughout the measurement) DC bias input signal, up to ~50 V, modulated by an AC test signal. The test signal level typically varies between 10 mV to ~2 V. The frequency is varied in the range of interest from 1 Hz to 1 MHz. The temperature conditions are the same as the I-V measurements. The measured samples are modeled through a capacitance (*C*) and resistance (*R*) parallel association, Fig. 3, so that the real and imaginary parts of the complex dielectric constant:

$$\varepsilon^*(\omega) = \varepsilon'(\omega) + i\varepsilon''(\omega), \tag{1}$$

can be written, defining $\varepsilon' = d/A \times C$, $\varepsilon'' = \sigma/\omega$ and normalizing them to the permittivity of vacuum $K^* = \varepsilon^*/\varepsilon_0$, through simplified expressions:

$$K'(\omega) = \frac{\varepsilon'}{\varepsilon_0} = \frac{d}{\varepsilon_0 A}\frac{\sin|\varphi(\omega)|}{|Z(\omega)|\omega} \tag{2a}$$

$$K''(\omega) = \frac{\varepsilon''}{\varepsilon_0} = \frac{d}{\varepsilon_0 A} \frac{\cos|\varphi(\omega)|}{|Z(\omega)|\omega}, \tag{2b}$$

here Z is the complex impedance, □ is its phase, □ the angular frequency, *A* the electrodes area, and *d* the distance between them. Please notice that the dielectric constant is the result of the measurements, not of a model. The *R* and *C* association model is useful only if the results prove *R* and *C* to be constants within the measuring ranges.

Fig.3. Schematic diagram that represents the model used in the present work.

Impedance-Voltage characteristics (□-V): it is planned to be performed in a similar away as □-f curves, but with given fixed frequencies and varying the DC voltage with the same voltage ramp protocol used in the I-V characteristics. Additionally, the temperature settings are the same as for I-V and □-f measurements.

2.3. First results

We have successfully obtained impedance results for a dry GM sample applying V_{AC}=1V at $T \approx 20$ ºC and in ambient air conditions. Such results are presented in Fig.4 (a,b). Capacitance shows the expected decrease with the frequency and apparently no anomaly at low frequencies exists consistent with dry samples. On the other hand, the dissipation factor (*D*) besides the normal decrease with frequency also presents a small anomaly in the 0.5 MHz region that could be related with a Maxwell-Wagner relaxation, Maxwell (1892) and Wagner (1914), caused by the rock plus air system. This anomaly requires a better study in future measurements, in particular it is important to analyse its behaviour with temperature.

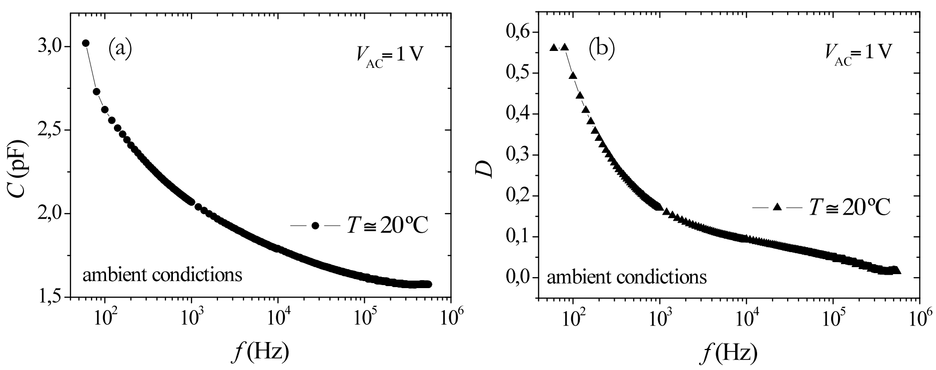

Fig.4. First impedance spectrum for GM sample applying V_{AC}=1V at T ≈ 20 ºC and in ambient air conditions: a) Capacitance (*C*); b) Dissipation factor (*D*).

3. Expected results and Future work

The main results coming out from this research plan are the understanding of charge transport mechanisms in different granitic rock types with distinct water content, mineralogical composition, and porosity. Ultimately, these studies will give an indication of the materials porosity and composition through their electrical response, Garrouch *et al.* (2009) and Haslund *et al.* (1994). Future studies could involve the analysis of pressure stimulated currents, Freund *et al.* (2006) and Vallianatos *et al.* (2008), and voltages, Aydin *et al.* (2009), near fracture and other extreme conditions like the study of the electric response of samples submitted to drastic temperature changes or internal gradients.

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Heat transfer in the thermal entry region of single-connected tubes with uniform wall temperature

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Abstract
In this work we address the problem of laminar flow characteristics in the thermal entry region of single-connected circular tubes with uniform wall temperature. The velocity profile is considered to be fully developed and the thermal and transport properties of the fluid are assumed to be constant. By invoking the heat transfer and fluid flow similarity solutions for the case of a flat plate, from analogy between heat and momentum transfer a new relation was established and compared with the Graetz and Lévêque solutions for the thermally developing region in circular tubes. An asymptotic method is used to obtain the overall Nusselt number in the entire range of the dimensionless thermal length of the flow. Results are compared with data and a very good agreement is observed.

1. Introduction

The determination of the heat transfer in the thermal entrance region of forced convection in ducts is a basic issue of the heat and mass transfer theory. Heat transfer in laminar flow in circular tubes with uniform wall temperature and constant fluid properties was one of the cases first studied (Bejan, 1995). Although this problem is well characterized and the exact solution is known in the form of an infinity series (Graetz solution), attempts always existed to find simpler solutions that could be easier used in calculations. One of such attempts is known as the Lévêque solution (Bird et al., 1960) which describes the overall Nusselt number in the thermal entrance region. Additionally, several correlations or empirical formulas either based on the values of the Graetz solution or on experimental data have been proposed by several authors in the last decades (see Incropera and DeWitt, 1996).

In this work we present an approximate formula for determining the overall Nusselt number in the thermal entry region of internal laminar fluid flow in circular tubes with uniform wall temperature. The approximation is based in the similarity solutions of the boundary layer development over a flat plate. An asymptotic method is then used to obtain the overall Nusselt number in the entire range of the dimensionless thermal length of the flow.

2. Heat transfer in the thermal entry of laminar flow in ducts

For fully developed laminar flow in a circular duct of constant cross-sectional area the governing equation in cylindrical coordinates reads:

$$\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} = \frac{1}{\mu}\frac{dp}{dx}, \qquad (1)$$

which represents balance between viscous and pressure forces. The velocity profile of a constant-property fluid is obtained by solving this equation subjected to $u = 0$ at the wall $(r = D/2)$, yielding the known Hagen-Poiseuille solution

$$u = 2U_0\left[1 - \left(\frac{r}{D/2}\right)^2\right], \qquad (2)$$

where U_0 is mean velocity and D is diameter. One of the parameters most commonly used in practice to characterize the flow is the Fanning friction factor which is defined for an arbitrary duct shape as follows:

$$f = \frac{\bar{\tau}_w}{\frac{1}{2}\rho U_0^2}. \qquad (3)$$

The average wall shear stress $\bar{\tau}_w = \mu\overline{(\partial u/\partial n)}_w$ is representative of the average velocity gradient at the wall. However, the friction factor appears usually associated with Reynolds number in the form:

$$f\,\mathrm{Re} = 2D_h\frac{\overline{(\partial u/\partial n)}_w}{U_0}, \qquad (4)$$

where $D_h = 4A/P$ is hydraulic diameter of the duct. For fully developed flow in a circular duct ($D_h = D$), $f\,\mathrm{Re}$ is found to be constant (eqs. (2) and (4)) and takes the value

$$f \, \mathrm{Re} = 16 \,. \tag{5}$$

The energy equation in cylindrical coordinates for thermally developing flow in tubes of constant cross-sectional area reads

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{u(r)}{\alpha}\frac{\partial T}{\partial x} \,, \tag{6}$$

where $u(r)$ represents the fully developed velocity profile, T the temperature and α the thermal diffusivity of the fluid. The heat transfer process in a tube of total length L is characterized by the overall Nusselt number Nu_{0-L} which is related with the average circumferential and axial heat transfer coefficient h_{0-L} through

$$\mathrm{Nu}_{0-L} = \frac{D h_{0-L}}{k} \,, \tag{7}$$

where k is the thermal conductivity of the fluid. Two dimensionless axial distances are used to describe the velocity and temperature boundary layers development: $x_+ = (L/D)/\mathrm{Re}$, which stands for hydrodynamically developing flow; and x_* that stands for thermally and simultaneously developing flows, which is defined as

$$x_* = \frac{L/D}{\mathrm{Re}\,\mathrm{Pr}} \,. \tag{8}$$

Note that the relation between these two dimensionless distances is $x_+ = x_* \,\mathrm{Pr}$.

For a particular duct shape Nusselt number is usually expressed in terms of x_* and of Prandtl number. In the case of fully developed velocity profile the Nusselt number is independent on Pr. The $\mathrm{Nu}_{0-L}\,(x_*)$ relationship has two asymptotic limits: the thermally developing limit ($x_* \to 0$), in which the overall Nusselt number increases with decreasing values of x_*; and the fully developed flow limit ($x_* \to \infty$), in which Nusselt number becomes constant, its value depending on duct shape only.

The problem of heat transfer in a flow with fully developed velocity profile in a circular duct and uniform wall temperature was firstly treated by Graetz and is recognized as the Graetz problem, which is formulated by using the Hagen-Poiseuille solution of Equation (2) in the Equation (6). The solution is known as the Graetz series (Bejan, 1995). For decreasing values of dimensionless thermal length ($x_* < 10^{-4}$) the Graetz solution converges to the asymptotic solution obtained by Lévêque (1928) as $\mathrm{Nu}_{0-L} = 1.615 x_*^{-1/3}$ (Bird et al., 1960). This solution is valid when the thermal boundary layer thickness is very small as compared with the tube diameter, i.e. when it develops only in the region near the wall where the velocity profile is approximately linear. The Nusselt number is a weak function of duct shape in the thermal entrance region, and the Lévêque solution can be generalized as follows

$$\mathrm{Nu}_{0-L} = 0.641 \left(\frac{f\,\mathrm{Re}}{x_*} \right)^{1/3} . \tag{9}$$

There are several proposals to correct the Lévêque solution in order to obtain a more accurate expression in the practical range: $10^{-4} < x_* < 10^{-2}$. As an example, Shah and London (1978) recommended the use of $1.615 x_*^{-1/3} - 0.2$ in the range $0.005 < x_* < 0.03$ for circular tubes, and Muzychka (2004) modified the constant in the right hand side of Equation (9) to 0.614, in order to provide a model for predicting the results of different duct shapes. On the other hand, several correlation expressions have been obtained from the Graetz solution or from experimental data and, as a reference, it must be mentioned that of Hausen (1943) developed one of the firsts and most known compact correlation for the overall Nusselt number in circular tubes (see Incropera and DeWitt, 1996) in the form:

$$\mathrm{Nu}_{0-L} = 3.657 + \frac{0.0668 / x_*}{1 + 0.04 / x_*^{2/3}} . \tag{10}$$

3. Approximation based on the boundary layer solution over a flat plate

The derivation of the present approximation starts by considering that in a thermally developing flow: (i) the thermal boundary layer thickness is very small as compared with the tube diameter; (ii) the overall Nusselt number is a weak function of the duct shape; (iii) the heat transfer rate may be adequately approximated by the boundary layer theory, in particular, by the boundary layer solution of a flow over a flat plate. The first two assumptions were already discussed in the previous section. The third assumption arises from considering that, from the point of view of an element of fluid near the wall, which is the part that is affected by the thermal boundary layer development at low values of x_* (corresponding to large values of Re and/or D/L ratio), the wall may be considered as a flat plate.

We start by invoking the similarity solution for the thermal boundary layer development over a flat plate (Bejan, 1995)

$$\frac{L\,h_{0-L}}{k} = 0.664\,\mathrm{Re}_L^{1/2}\,\mathrm{Pr}^{1/3}, \tag{11}$$

where $\mathrm{Re}_L = U_\infty L/\upsilon$ is Reynolds number based on total length *L*, and U_∞ is free steam velocity. This approximation allows to determine the mean heat transfer coefficient h_{0-L}, of dimensions $\mathrm{Wm^{-2}K^{-1}}$, and was also used by Muzychka (2005) for optimizing a compact heat sink of parallel ducts through the method of the intersection of asymptotes. Additionally, the similarity solution for fluid flow over a flat plate is (Bejan, 1995)

$$\frac{(\overline{\tau}_w)_{plate}}{\frac{1}{2}\rho U_\infty^2} = 1.328\,\mathrm{Re}_L^{-1/2}. \tag{12}$$

The only condition for using the solution of Equation (11) in thermally developing flow in circular tubes is that the average velocity gradient at the plate surface is the same as the velocity gradient at the tube wall, i.e. if the plate has the same length of the tube we must find a value of Re_L such that,

$$\overline{(\partial u/\partial y)}_{y=0,\,plate} = (\partial u/\partial r)_{r=D/2,\,tube}. \tag{13}$$

Note that the velocity gradient at the wall of the tube is uniform due to the fully developed velocity profile and due to tube symmetry, as all the points on the wall are at the same distance from the axis. By combining Equations (4) and (12) one obtains:

$$\mathrm{Re}_L^{1/2} = \left(\frac{f\,\mathrm{Re}}{1.328}\right)^{1/3} (L/D)^{2/3}\,\mathrm{Re}^{1/3}, \tag{14}$$

where $\mathrm{Re} = U_0 D / \upsilon$ is Reynolds number based on tube diameter D and mean velocity U_0. The square root of Re_L is a measure of the boundary layer slenderness ratio, as noted by Bejan (1995). Now, by combining Equations (11) and (14) for the overall Nusselt number of a thermally developing flow in circular tubes we obtain the following expression

$$\mathrm{Nu}_{0-L} = \frac{D h_{0-L}}{k} = 0.604 (f\,\mathrm{Re})^{1/3} x_*^{-1/3}, \tag{15}$$

which, by using $f\,\mathrm{Re} = 16$, reduces to

$$\mathrm{Nu}_{0-L} = 1.522 x_*^{-1/3}. \tag{16}$$

This expression has the same form of the Lévêque's asymptotic solution with a constant factor of 1.522 in the right hand side instead of 1.615 (see §2), thus allowing for a much better accuracy in the practical range of $10^{-4} < x_* < 10^{-2}$. For comparison, Figure 1 shows Graetz series, Lévêque's solution and the present result, where Graetz series was determined using twenty terms. A very good agreement is obtained between the values of Equation (15) or (16) and Graetz series for thermally developing flow, whereas the Lévêque's asymptotic solution overestimates the exact values.

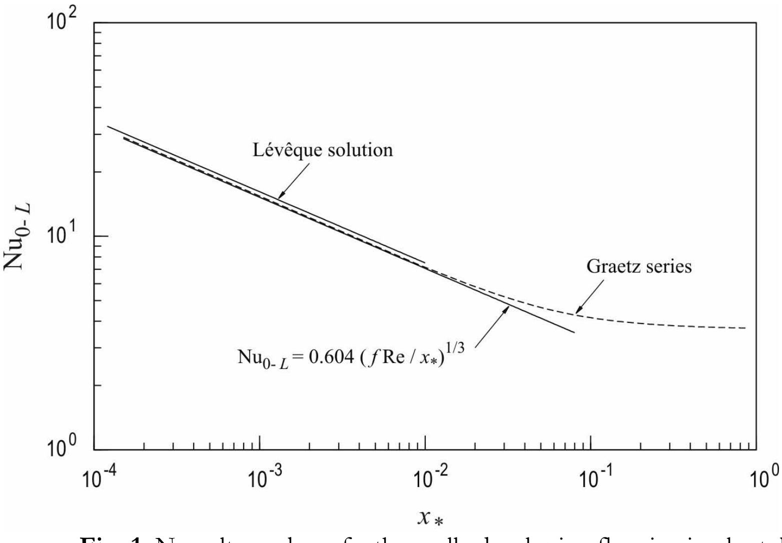

Fig. 1. Nusselt number of a thermally developing flow in circular tubes: a) Graetz series; b) Lévêque solution; and c) present result.

4. Model for the overall Nusselt number in the entire range of x_*

The overall Nusselt number in the entire range of x_* is modelled through the method of superposition of asymptotic solutions of Churchill and Usagi (1972) as follows

$$\mathrm{Nu}_{0-L} = \left[\mathrm{Nu}_{fd}^{n} + \left(0.604\,(f\,\mathrm{Re})^{1/3} x_*^{-1/3}\right)^{n}\right]^{1/n}, \tag{17}$$

where Nu_{fd} is Nusselt number for thermally fully developed flow, which in the case of circular tubes is 3.66. This method assumes that smooth transition exists between developing and developed flow asymptotes, and thus the parameter n is important only for defining this transition region. A value of $n = 4$ was found adequate in the present case.

Figure 2 shows the comparison between the values predicted by Equation (17) and the data from Shah and London (1978). Figure 3 shows the absolute difference in percentage of the data to predictions of the present model, the correlation of Hausen and the Lévêque's asymptotic solution. Equation (17) fits the data with a maximum absolute error of 3% within the range $10^{-4} < x_* < 1$. This error decreases to values lower than 1% in the range $10^{-3} < x_* < 1$.

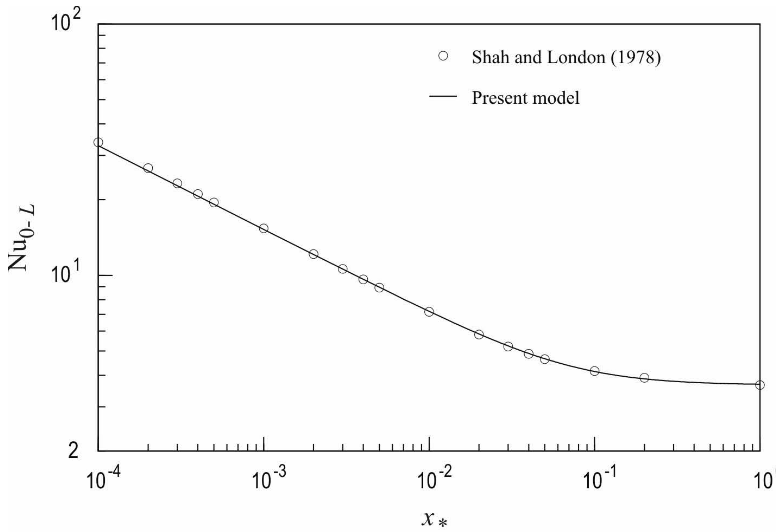

Fig. 2. Overall Nusselt number of a thermally developing flow in circular tubes: comparison of the present model with data.

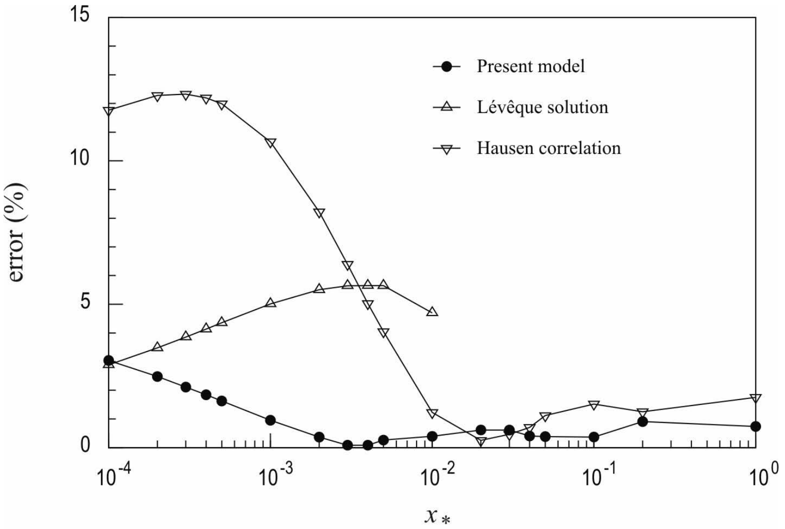

Fig. 3. Absolute error in comparison with data of: a) the present model; b) the Lévêque solution; and c) the Hausen correlation.

5. Conclusions

By invoking the similarity solutions for the boundary layer development over a flat plate, in this work we put forward an approximate solution for the overall Nesselt number in the thermal entry region of laminar fluid flow in circular tubes with uniform wall temperature. The velocity profile is assumed fully developed and the fluid properties are assumed constant. Very good agreement was found with the Gratez solution in the practical range of $10^{-4} < x_* < 10^{-2}$. A method of superposition of asymptotic solutions was used thus providing an expression for the Nusselt number in the entire range of x_*. The resulting expression predicts the available data with a maximum absolute error of 3% for $x_* > 10^{-4}$. For $x_* > 10^{-3}$ the error decreases to values lower than 1%.

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Ductile fracture: nonlocal modeling

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Abstract
Damage-induced ductile crack initiation and propagation is modeled by using tip remeshing and mapping of historical variables combined with a nonlocal strain technique. Finite strain plasticity is used with smoothing of the complementarity condition and the prototype constitutive laws include pressure sensitivity and the Lode angle influence. The plane stress idealization is considered: thickness variation in plane stress is included by imposing a null out-of-plane stress. The nonlocal approach is applied to strains so that the damage value evolves up to close to one and this is verified numerically. Two verification examples are proposed and one validation example are shown, both sets illustrating the excellent results of the proposed method.

1. Introduction

All metals in Engineering applications contain volumetric defects in their crystalline structure. These are micro-voids and micro-cracks, as well as foreign atom inclusions and secondary phases. Mechanical loads increase the severity of these defects, in particular for ductile metals (such as low-Carbon steel). The ductile degradation of solids is a process comprised of three main stages: i) Void nucleation and growth, ii) Void coalescence and crack initiation, iii) Crack propagation (Lemaitre [17] presents a comprehensive description of this process). The numerical solution of ductile damage problems poses problems both from the physical modeling and the discretization perspectives. By physical modeling we understand the governing equations of equilibrium and the constitutive representations. The equilibrium equations (see the treatise by Ogden [21]) must be complemented, in the plane stress case, by a null normal stress in the thickness direction (see [3]); for the general finite strain case this must be imposed by an iterative procedure. Material degradation in tension is accompanied by a strong necking which should be represented by an appropriate softening mechanism and sufficient geometrical resolution [4]. The constitutive modeling is more challenging: many elasto-plastic laws do not include the necessary ingredients for the representation of ductile cracking. Shrinking of the yield surface must be represented, as well as separation, in the yield function, of tension and compression which becomes more important as degradation progresses (see, for example [17]). Besides the shrinking yield surface, an additional law must appear to relate the degradation (damage variable or void fraction) with the strain (or stress) history. If the complete degradation process is to be represented with the same constitutive model, then the strain localization must be contained (or, using the nomenclature of Lasry and Belytschko [16], limited) so that the constitutive model remains valid. The nonlocal models (in the sense of Bazant and co-workers [9]) are a solution to ensure that localization is limited. This is here assessed by the strong ellipticity condition; we show that the ellipticity indicator remains positive at all instants.

2. Introduction

The problem under study is stable fracture caused by void growth, of both plane stress and plane strain problems. Conceptually, we partition time according to propagation instances; only a small amount of crack growth occurs during each time interval and therefore classical finite-strain analysis are interleaved with propagation steps. Since each time instance corresponds to a certain fractured configuration, the only remaining difficulty is the constitutive history transference between configuration changes and subsequent equilibrium iteration convergence. The problem is solved by restarting at each change and adequately mapping the history; a stabilization step follows the mesh modification and hence rather large deformations are feasible. Mapping constitutive history provides an opportunity to introduce a decoupled nonlocal constitutive model; it is well known that this decoupling solves the ill-posedness of the local strain-softening model [9]. In terms of solution, since a time-step freeze of the constitutive history and the crack advance is performed, the problem becomes a standard finite-strain plasticity. The non-smoothness caused by the complementarity condition is smoothed by the Chen-Mangasarian function [4]. We show the problem statement in weak form, both for the plane stress (displacement as unknown) and plane strain (displacement and pressure as unknowns), the latter being an application of the MINI [5] element.

3. Plane stress formulation

Plane stress low-order displacement-based elements do not lock with incompressible or quasi-incompressible constitutive laws. Thickness variation compensates the change in planar area. In the following derivations, τ_c represents the Kirchhoff stress, which is equal to the Cauchy stress multiplied by the determinant of the deformation gradient ($J = \det F$): $\tau_c = J\sigma$. Here we denote the deformation gradient as F. This allows the use of integration in the undeformed configuration since $\int_\Omega ...\sigma d\Omega = \int_{\Omega_0} ...\tau_c d\Omega_0$. However, gradients are still taken with respect to the *deformed* configuration. This procedure was used by Simo and co-workers [28,25,27] and is now reasonably standard. Body forces are here identified as b, surface pressure as t and the reference integration volume at time t (note that due to crack evolution, the reference integration volume changes) is denoted by Ω_{0t}. The boundary of Ω_{0t} is denoted Γ_0 and has an outer normal as n. The initial thickness is written as H and the deformed thickness as h. The remaining nomenclature is standard (both the one of continuum mechanics [12] and finite element formulation [14])

For plane stress, the equilibrium problem in the weak form is stated in terms of the displacement field only. Given $t \in R_0^+ \; t$, $b \in [L_2(\Omega_0)]^{n_{sd}}$ and $\lambda_t \in R_0^+$, find $u \in D$, such that $\forall \tilde{u} \in V$ and $e(u) > 0$:

$$\int_{\Omega_{0t}} \tau_c[F(u), t] : \nabla \tilde{u} \, d\Omega_0 = \int_{\Gamma_{0ct}} \lambda_t t \cdot n \tilde{u} \, d\Gamma_{0c} + \int_{\Omega_{0t}} \lambda_t b \cdot \tilde{u} \, d\Omega_0 \qquad (1)$$

with λ_t, the load parameter, being a function of t. Changes in Ω_0 occur whenever one crack advances. We restart the problem by updating Ω_{0t}: $\Omega_{0t_{n+1}}$ succeeds Ω_{0t_n}. Thickness variation is caused by the condition $\tau_{c33} = 0$. Call to the constitutive library (see, e.g. [1]) makes use of four components (since $\tau_{c13} = \tau_{c23}$ are identically zero). For τ_{c33} we use the Newton method to obtain:

$$\tau_{c33}(h) = 0 \qquad (2)$$

which reads (it is the iteration counter):

$$\frac{\partial \tau_{c33}}{\partial \varepsilon_{33}} \Delta h = -\tau_{c33} H \qquad (3)$$

$$h_{it+1} \leftarrow h_{it} + \Delta h \tag{4}$$

with $h_0 = H$. Convergence of this iteration is usually achieved, for $\Delta h \leq 1\times 10^{-8} H$, after six or seven iterations. After convergence, we can calculate the tangent modulus as:

$$C = \frac{\partial \tau_c}{\partial \varepsilon} - \left(\frac{\partial \tau_{c33}}{\partial \varepsilon_{33}}\right)^{-1} \frac{\partial \tau_c}{\partial \varepsilon_{33}} \otimes \frac{\partial \tau_{c33}}{\partial \varepsilon} \tag{5}$$

with τ_c including only the non-null stress components. The definition of ε is given by equation (24). The strong ellipticity condition (35) uses this modulus C instead of the classical $\frac{\partial \tau_c}{\partial \varepsilon}$.

4. Plane strain formulation

Convergent low order plane strain and 3D elements for incompressible and quasi-incompressible constitutive laws are usually based on mixed pressure-displacement interpolations. Of these, the MINI element ([5,14]) is probably the better studied and theoretically sound. No equivalent proofs were presented for "enhanced strain" and other related techniques. We make an extension of the MINI element for finite strains which is, to the Author's knowledge, completely new. The fundamental derivations are presented here and the implementation made use of Mathematica [23] with the Acegen add-on.

The constitutive pressure is a function of the deformation gradient determinant, $J = \det F$, and therefore of u. Since this can be either undefined (in the case of pure incompressibility) or have a preponderant slope resulting in over-constrained kinematics (see, e.g. [14]). Pressure is here an independent field, tied to the constitutive law by a (weak) equation. We introduce the deviatoric projection $P = I - \frac{1}{3} I \otimes I$, with I being the symmetric fourth order identity. With this, the mixed $u - p$ form (a two field formulation by substitution of the independent test function) of equilibrium is given by: Given $t \in R_0^+$ $t \in [L_2(\Gamma_{0t})]^{n_{sd}}$, $b \in [L_2(\Omega_{0t})]^{n_{sd}}$ and $\lambda_t \in R_0^+$, find $u \in D$ and $p \in L_2(\Omega_{0t})$ such that $\forall \tilde{u} \in V$ and $\forall \tilde{\theta} \in L_2(\Omega_{0t})$ with $e(u) > 0$:

$$\int_{\Omega_{0t}} \left\{P : \tau_c\left[F(u), t\right] + pI\right\} : \nabla \tilde{u} d\Omega_{0t} = \tag{6}$$

$$\lambda_t \int_{\Gamma_{0t}} t \cdot \tilde{u}\, d\Gamma_{0c} + \lambda_t \int_{\Omega_{0t}} b \cdot \tilde{u}\, d\Omega_{0t} \tag{7}$$

$$\int_{\Omega_{0t}} \left\{ \frac{1}{n_{sd}} \tau_c : I - p \right\} \tilde{\theta}\, d\Omega_{0t} = 0 \tag{8}$$

or, succinctly, in terms of virtual work (displacement- u, external- e and pressure- p):

$$\tilde{W}_{ut} = \tilde{W}_{et} \tag{9}$$

$$\tilde{W}_{pt} = 0 \tag{10}$$

In contrast with the stable Petrov-Galerkin formulation [15], there is no specific requirement concerning the pressure space other than to be a subspace of $L_2(\Omega_{0t})$ and there are no user-attributable parameters. Note that we designate the pressure as the mean stress, instead of its symmetric, for clarity in reading the equations (the projection filters p_c which is then replaced by p). The kinematical *variable* conjugate to the independent pressure field (p) is here denominated dilatation field and denoted $\tilde{\theta}$. Its only role is to ensure unit consistency between equations (6) and (8). The linearization makes use of the time-derivative and the notion of upper-Oldroyd stress rate:

$$\int_{\Omega_{0t}} \left\{ \left[P : \left(C : \nabla \dot{u} + \nabla \dot{u} \tau_c + \tau_c \nabla \dot{u}^T \right) \right] : \nabla \tilde{u} - \right.$$

$$\left. \left(P : \tau_c + pI \right) : \left(\nabla \tilde{u} \nabla \dot{u} \right) \right\} d\Omega_{0t} +$$

$$\int_{\Omega_{0t}} \dot{p} I : \nabla \tilde{u}\, d\Omega_{0t} = \delta \dot{W}_{ut} \tag{11}$$

$$\int_{\Omega_{0t}} \left[\frac{1}{n_{sd}} I : \left(C : \nabla \dot{u} + \tau_c \nabla \dot{u}^T + \nabla \dot{u} \tau_c \right) - \dot{p} \right] \tilde{\theta} d\Omega_{0t} = \delta W_{pt} \tag{12}$$

where the following properties were employed (see, e.g. [12]):

$$\dot{\tau}_c = C : \nabla \dot{u} + \tau_c \nabla \dot{u}^T + \nabla \dot{u} \tau_c \tag{13}$$

$$\frac{d\nabla\tilde{u}}{dt} = -\nabla\tilde{u}\nabla\dot{u} \tag{14}$$

An overlooked aspect in expression (11) is that $P:(\tau_c\nabla\dot{u}^T):\nabla\tilde{u} \neq (P:\tau_c):\left(\nabla\tilde{u}\nabla\dot{u}\right)$ unless $P = I$. It is worth noting that the forms above are distinct from the classical ones of Simo Taylor and Pister [28] and Moran, Ortiz and Shih [20] because we do not replace the pressure-dilatation relation by an elastic one. In addition, τ_c is a function of the displacement-based deformation gradient, F and does not include θ as an ingredient. This is essential for ductile damage, since void growth representation must include the pressure term and this should be independent of the particular element formulation. Note that exact linearization with the upper Oldroyd rate was used, but any alternative rate could be used with the same exact result (see, e.g. [12,29]). The implementation of linearization was found to be fundamental for convergence (we have performed it with Mathematica [23] and the Acegen add-on). We could not find these linearization expressions anywhere in the literature.

4. Discretization

Discretization consists of the replacement of the unknown displacement and pressure fields replaced by discrete ones. Since the discretization rate of convergence (for a fixed interpolant) is characterized by the mesh size suppremum, h (see, e.g. [14]), we use this as a superscript in the discrete displacement field. The discrete displacement vector and the displacement test function are written as:

$$u^h = \sum_{K=1}^{N_n} N_K(\xi)u_K + N_{N_n+1}(\xi)\alpha_K \tag{15}$$

$$\tilde{u}^h = \sum_{K=1}^{N_n} N_K(\xi)\tilde{u}_K + N_{N_n+1}(\xi)\tilde{\alpha}_K \tag{16}$$

following standard notation in the subject (e.g. [11,14]). The functions $N_K(\xi), K = 1,\ldots,N_n$ are also given in standard FE literature [14]. The pressure field and the dilatation test functions are simply written using the same shape functions:

$$p^h = \sum_{K=1}^{N_n} N_K(\xi) p_K \tag{17}$$

$$\tilde{\theta}^h = \sum_{K=1}^{N_n} N_K(\xi) \tilde{\theta}_K \tag{18}$$

with N_n being the number of (outer) nodes in each element, ξ is the set of parent-domain coordinates (specifically area coordinates), N_K is the node K shape function. The $N_{N_n}(\xi)$ shape function is the bubble; its support is the interior of each element. In $2D$ it is given by:

$$N_{N_n}(\xi) = \xi_1 \xi_2 (1 - \xi_1 - \xi_2) \tag{19}$$

We use three Gauss points for quadrature of the plane strain triangle and one for the plane stress triangle. This is required to ensure that, in the plane strain case, the displacement gradient arising from the bubble enrichment is well represented. The n_{sd} bubble degrees of freedom are condensed out using the null bubble residual. A similar procedure was used for enhanced strains by Simo, Armero and Taylor [26]. A stable alternative to this interpolation scheme is the Petrov-Galerkin formulation of Hughes, Franca and Balestra [15] where the pressure gradient is included to spread the pressure field.

5. Constitutive law and fracture algorithm

This work is concerned with metal plasticity and therefore the use of corotational stress rates is pragmatically justified. Note that this is standard in metal plasticity, although more accurate methods are available. Of course, for large compressive states it may produce some spurious shift in the strains, but those situations are here ruled out. The Jaummann rate [29] is employed with a complete rotationally neutralized approach. This is slightly different from the standard incremental method, but works for anisotropic problems. The velocity gradient is decomposed as usual into a symmetric ($\dot{\varepsilon}$) and a skew symmetric (ω) part:

$$l = \dot{\varepsilon} + \omega \tag{20}$$

The rotation tensor arising from ω is obtained using the well known relation first order ODE:

$$\dot{R}_\omega = \omega R_\omega \tag{21}$$

$$R_\omega |_{t=0} = I \tag{22}$$

The customary definition of "strain" in the sense of objective rates is simply given as:

$$\varepsilon = \int_0^t R_\omega^T \dot{\varepsilon} R_\omega dt_* \tag{23}$$

the rotated stress can be written analogously, but has a closed-form:

$$\boldsymbol{\tau}_R = R_\omega^T \boldsymbol{\tau} R_\omega \tag{24}$$

Since we here are concerned with the effective modeling of the problem, a simplified constitutive law is used. Omitting the dependencies, the general statement is shown as:

$$\boldsymbol{\tau}_R = 2\mu P : \varepsilon^e + 3\kappa I e^e \tag{25}$$

$$\dot{\varepsilon} = \dot{\varepsilon}^e + \dot{\varepsilon}^p \tag{26}$$

$$\varphi\dot{\gamma} = 0 \tag{27}$$

$$\varphi \leq 0 \tag{28}$$

$$\dot{\gamma} \geq 0 \tag{29}$$

$$\dot{\varepsilon} = \dot{\gamma} \frac{\partial \varphi}{\partial \boldsymbol{\tau}_R} \tag{30}$$

with $\dot{\varepsilon}$ being the strain rate, which is the symmetric part of the velocity gradient (l). The mean elastic strain is $e^e = \frac{1}{n_{sd}} tr(\varepsilon^e)$. These must be related with the quantities required in the weak form, namely $\boldsymbol{\tau}$ and C. It is obvious that to rotationally neutralize $\boldsymbol{\tau}_R$ the expression for the stress must be:

$$\boldsymbol{\tau} = R_\omega \boldsymbol{\tau}_R R_\omega^T \tag{31}$$

The encapsulated small-strain problem will result in a stress tensor which we identify as the small strain stress, and the small consistent modulus, which is identified as E. It is written as a derivative of $\boldsymbol{\tau}_R$ with respect to ε:

$$E = \frac{\partial \boldsymbol{\tau}_R}{\partial \varepsilon} \tag{32}$$

we rotate this modulus to give:

$$[E_R]_{ijkl} = [R_\omega]_{im} [R_\omega]_{jn} [R_\omega]_{kp} [R_\omega]_{lq} [E]_{mnpq} \tag{33}$$

The use of a consistent modulus requires not only the transformation of E but the stress state. By using Mathematica [23] and the definition of Jaumann rate [27], it is straightforward to show that:

$$[C]_{ijkl} = [E_R]_{ijkl} - \frac{1}{2}\left([I]_{ik}[\tau]_{jl} + [I]_{il}[\tau]_{jk} + [I]_{jl}[\tau]_{ik} + [I]_{jk}[\tau]_{il}\right) \tag{34}$$

Although this expression follows from direct manipulation of the upper-Oldroyd rate and the Jaumann rates, *we could not find it in the literature*. This is implemented, along with the standard multiplicative decomposition, in the first Author's code [1]. Additionally, the strong ellipticity condition (cf. [29], first part of eq. 45.14, after substitution by the spatial modulus in their equation 45.6) is stated as:

$$e > 0$$

$$e = \inf_{n_1 \| \|n_1\|_2 = 1} \; \inf_{n_2 \| \|n_2\|_2 = 1} n_{1i} n_{1k} n_{2j} n_{2l} \left([C]_{ijkl} + [I]_{ik}[\tau]_{jl}\right) \tag{35}$$

Since the term $n_{2j} n_{2l} \left([C]_{ijkl} + [I]_{ik}[\tau]_{jl}\right)$ is traditionally called the acoustic tensor and its components are denoted $[Q]_{ik}$, we can write e as follows:

$$e = \inf_{n_1 \| \|n_1\|_2 = 1} \; \inf_{n_2 \| \|n_2\|_2 = 1} n_{1i} n_{1k} [Q]_{ik} \tag{36}$$

note that Q depends on n_2. For each unit n_2, problem (36) consists of an eigenvalue problem with each root n_1 being an eigenvector. Since the value e itself has a difficult interpretation, we normalize it by the isotropic Hookean value to establish our " normalized ellipticity indicator" $e^{\text{å}}$:

$$e^{\text{å}} = e / \mu \tag{37}$$

with μ being the shear modulus. We now construct a constitutive law for ductile damage that satisfies the following requirements:

- Pressure dependence of both the damage law and the yield function
- Yield surface contraction
- Effect of the Lode angle

Since no experiments were carried out by the Author to verify the proposed law, at least the aforementioned essential ingredients for the correct modeling of ductile fracture are included. The yield function is the difference between the equivalent stress (σ_{eq}) and the hardening function:

$$\varphi = \sigma_{eq} - (1 - f)\sigma_y \tag{38}$$

The hardening function is obtained by pre-multiplying the pristine yield stress by $1 - f$, where f is the void fraction. It is well known that the yield function is pressure-sensitive: pressure sensitivity increases with the void fraction (e.g. [18]) and only tension pressures contribute; an affine function is used here:

$$\sigma_{eq} = \sqrt{\frac{3}{2}\left(\tau' : \tau'\right)} + f\, c_1 < p > \tag{39}$$

where use of the Macaulay brackets was made: $< p > \equiv \max(0, p)$. Also, $\tau' = \tau - pI$ is the deviatoric Kirchhoff stress. The hardening function depends on the equivalent plastic strain, $\overline{\varepsilon}_p$ and is given by the following relation (see, e.g. [6]):

$$\sigma_y = (1-f)\sigma_0 \left[1 + \left(\frac{E\overline{\varepsilon}_p}{\sigma_0} \right) \right]^{1/n} \tag{40}$$

where σ_0 is the initial tensile stress, E is the elasticity modulus and n is the hardening exponent. The yield function requires the following constitutive parameters:

- σ_0 initial tensile stress
- c_1 pressure parameter
- $1/n$ is the hardening exponent

Since usually strains are measured, we can relate these to the situation where the difference between the tensile and compressive yielding is the largest: $f = 1$. Denoting the compressive yield strain as ε_c and the tensile yield strain as ε_t we can write σ_0 and c_1 as:

$$c_1 = 3\left(\frac{\overline{\varepsilon}_c}{\overline{\varepsilon}_t} - 1 \right) \tag{41}$$

$$\sigma_0 = E\varepsilon_c \tag{42}$$

The exponent $1/n$ is obtained by measuring the strain and stress (under compression). For unit uniaxial compressive strain (σ_1), we can estimate, for $f = 0$ that the compressive stress is given by:

$$n = \frac{\log(3)}{\log(r)} \tag{43}$$

with r being the ratio between the yield stress for $\overline{\varepsilon}_p = 1$ and the yield stress for $\overline{\varepsilon}_p = 0$.

Remark 1. We tested the pristine von-Mises equivalent strain and failed to capture the material stretching precluding opening at before crack initiation. It is known that only fracture modes II and III will occur from localization of incompressible yield functions [22]. Our modification allows the opening to progressively occur as it is observed in many experiments, for example fig. 15 of Bao and Wierzbicki [8]. Note that this conclusion is *independent* of the particular damage law.

The damage evolution law follows recent developments of Tomasz Wierzbicki group [32], based on previous experiments [8], that are very complete in representing ductile fracture. These incorporate known facts from experimental observation, such as dependence of the fracture strain on the Lode parameter, which are often not included in the classical ductile damage constitutive laws (e.g. Rousselier [24], Lemaitre [17], Gurson-Tvergaard-Needleman [30]). However, we try to avoid models with many parameters (for example the recent Mohr-Coulomb version of Bai and Wierzbicki [7]), since determination of many of the parameters requires extensive experimental study. The void fraction variable is a function of the equivalent fracture strain $\bar{\varepsilon}_f$ and the equivalent plastic strain $\bar{\varepsilon}_p$:

$$f = \left(\frac{\bar{\varepsilon}_p}{\bar{\varepsilon}_f}\right)^m \tag{44}$$

this agrees with the manuscript [31] where the derivation followed low cycle fatigue tests. The fracture strain, $\bar{\varepsilon}_f$ is obtained by multiplying a function of the pressure, $f_p(p)$ and a function of the Lode angle $f_\chi(\chi)$:

$$\bar{\varepsilon}_f = \bar{\varepsilon}_{f0} f_p(p) f_\chi(\chi) \tag{45}$$

These functions are here defined as (a simplification of what was proposed in reference [13]):

$$f_p(p) = 1 - q\log\left(1 - \frac{p}{p_{lim}}\right), p < p_{lim} \tag{46}$$

$$f_\chi(\chi) = \begin{cases} \dfrac{\sqrt{\chi^2 - \chi + 1}}{1 + \left(\frac{\sqrt{3}}{\gamma} - 2\right)\chi} & , \quad 0 \le \chi \le \frac{1}{2}(27) \\ \dfrac{\sqrt{\chi^2 - \chi + 1}}{1 + \left(\frac{\sqrt{3}}{\gamma} - 2\right)(1 - \chi)} & , \quad \frac{1}{2} \le \chi \le 1 \end{cases} \tag{47}$$

with p_{lim} being the pressure beyond which constitutive failure ceases. Of course, μ_p could be non-positive and it must be set to a small value when it does:

$$p = -\left(e^{\frac{1}{q}} - 1\right)p_{lim} \tag{48}$$

In alternative, we employ the simplified law:

$$f = 1 - \exp(-c\overline{\varepsilon}_f) \tag{49}$$

with $\overline{\varepsilon}_f$ being the maximum principal strain attained. This only requires one property (c), which can be estimated by using the strain for 90% of void fraction:

$$c = \frac{2.306}{\overline{\varepsilon}_{f0.9}} \tag{50}$$

A form of nonlocality must be included to maintain strong ellipticity: either explicit, such as in Ba□ant and Jirasek [9], a cohesive law [2] or a rate (or gradient) dependent continuum law (e.g. [10]). We opt for full nonlocality, but also including the mesh topology. The weight function has support 1 and is given by:

$$w(\zeta) = \begin{cases} \frac{2}{3} - 4\zeta^2 + 4\zeta^3, & \zeta \leq \frac{1}{2} \\ \frac{4}{3} - 4\zeta + 4\zeta^2 - \frac{4}{3}\zeta^3, & \frac{1}{2} < \zeta \leq 1 \\ 0, & \zeta > 1 \end{cases} \tag{51}$$

with ζ being the ratio between the distance and the characteristic length:

$$\zeta = \frac{\| x - x_n \|_2}{c_l} \tag{52}$$

Only points which can be reached by edge neighborhood are considered candidates for x_n. The denominator in the right-hand-side of (52) is the characteristic length, and must be estimated for each material. The historical variable chosen for nonlocality is the fracture strain. The nonlocal fracture strain is calculated as:

$$\overline{\varepsilon}_f = \int_{\Omega_0} w(\zeta)\overline{\varepsilon}_f d\Omega_0 \tag{53}$$

Further information concerning nonlocal models of softening can be obtained in reference [9].

Our new fracture algorithm is based on tip remeshing. A sequence of steps is performed (figure 1 illustrates these steps). For propagation:

1. Identification of tips where void fraction reaches the critical value
2. Determination of the intersection of the estimated crack path direction with the opposing edge
3. Classification of edges according to the clockwise (cw) or counter-clockwise (ccw) orientations. New tip elements (ET1 and ET2) are introduced and, if they exist, two back elements are introduced (identified as EB1 and EB2)
4. Node splitting according to the case (see figure 1)

For crack initiation, the algorithm selects, from the elements sharing an outer edge, the most critical (in terms of void fraction) and that arising crack intersects the outer boundary as figure 2 depicts. Since the crack must grow step-by-step, the Newton-Raphson solution method must keep the value of the critical void fraction. We use the false-position method to ensure that each analysis step halts either below the critical value or trigger a new crack advance. This is significantly different from the brittle case where control equations should explicitly be used [2]. The crack path is obtained using Ma and Sutton criterion [19]. This was found, in previous tests, to reproduce with a high degree of accuracy the experimental crack paths.

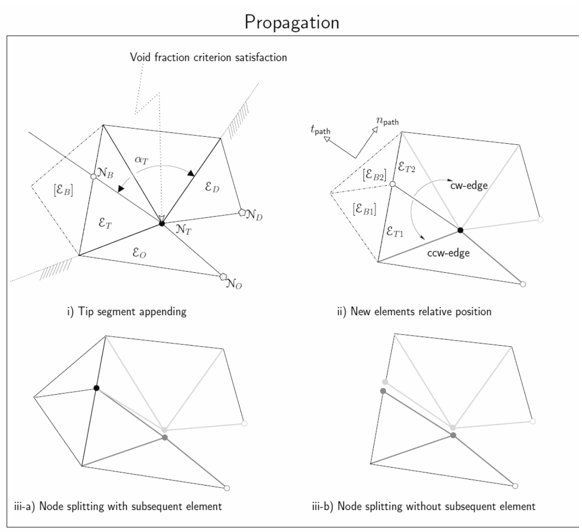


Fig. 1. Fracture algorithm: propagation

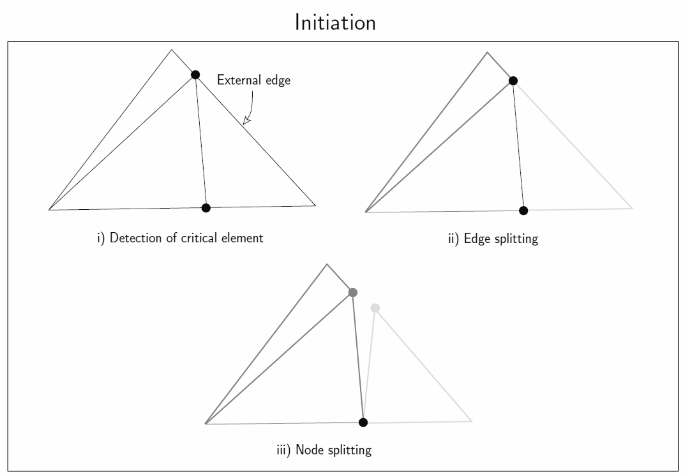
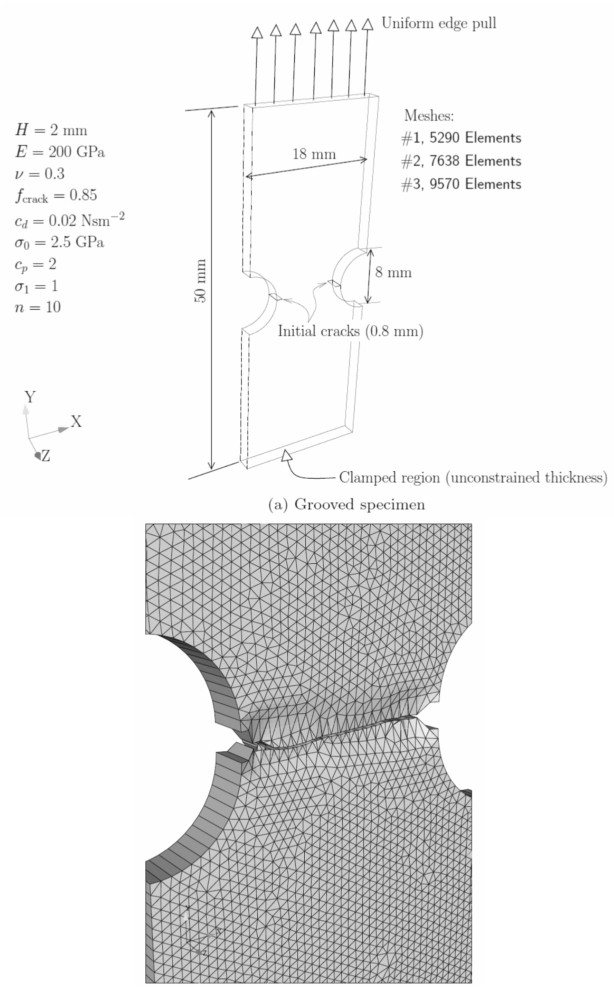


Fig. 2. Fracture algorithm: initiation

6. Numerical examples

Three numerical examples are shown: the grooved specimen, the beams with crack initiation and the Compact Tension specimen.



(a) Grooved specimen

Fig. 3. Grooved specimen geometry and complete crack detail

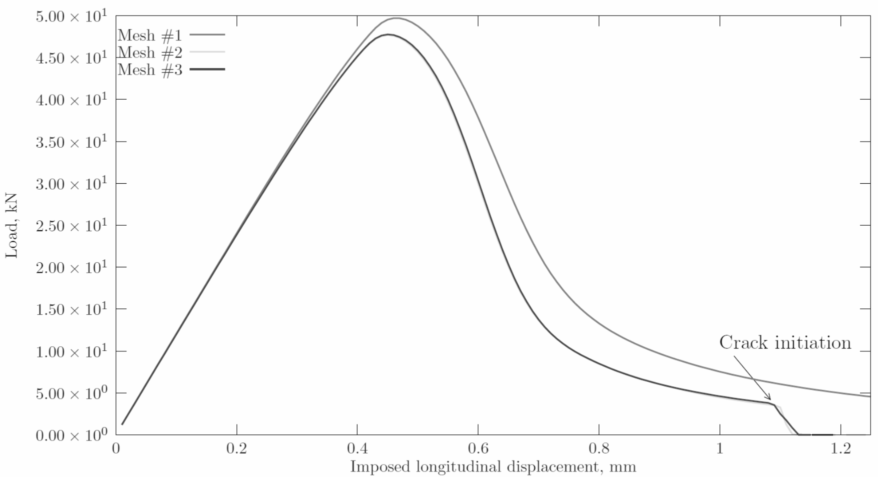


Fig. 4. Grooved specimen: load / displacement result

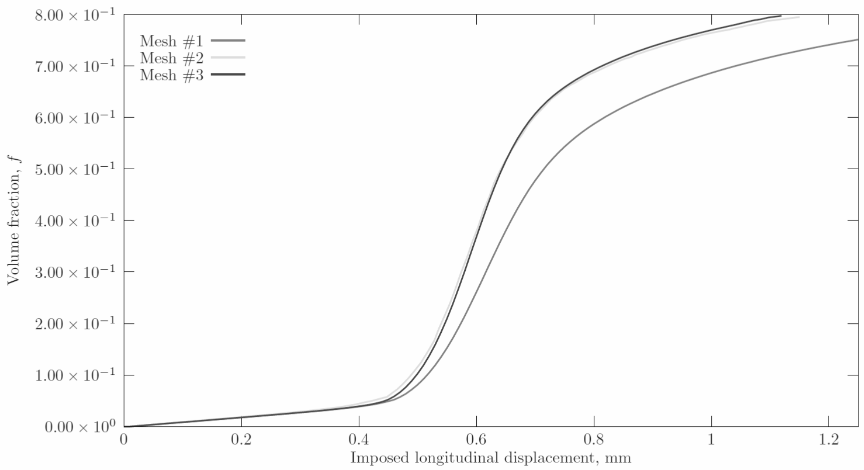


Fig. 5. Grooved specimen: void fraction

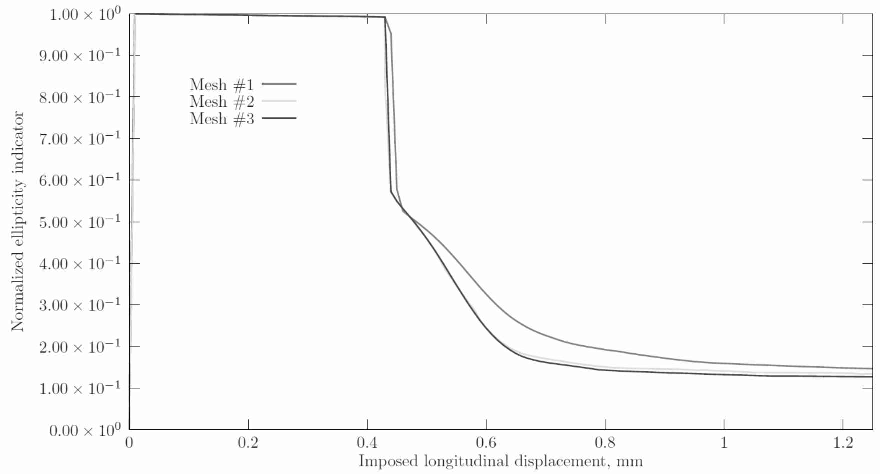


Fig. 6. Grooved specimen: normalized ellipticity

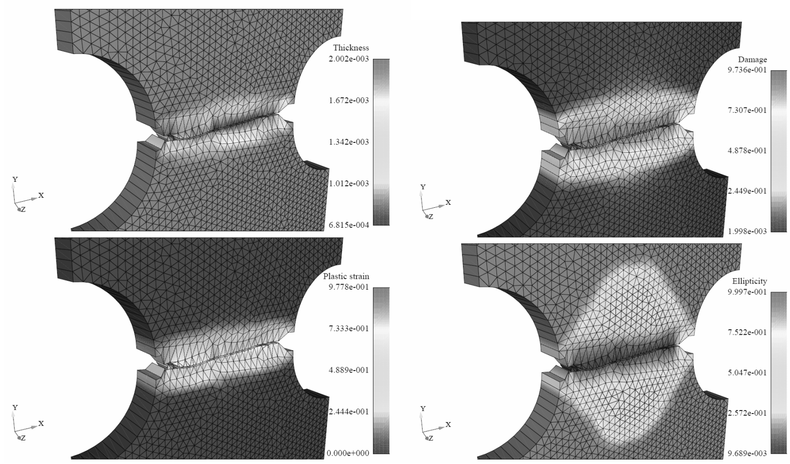


Fig. 7. Grooved specimen: relevant contour plots

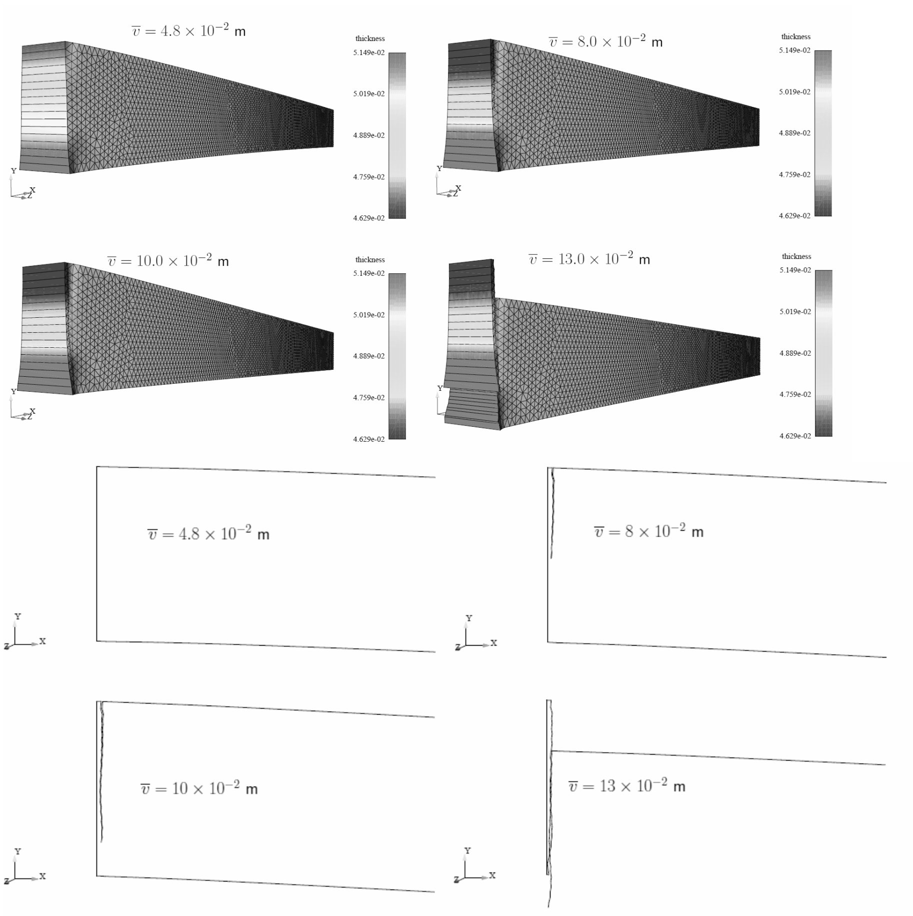
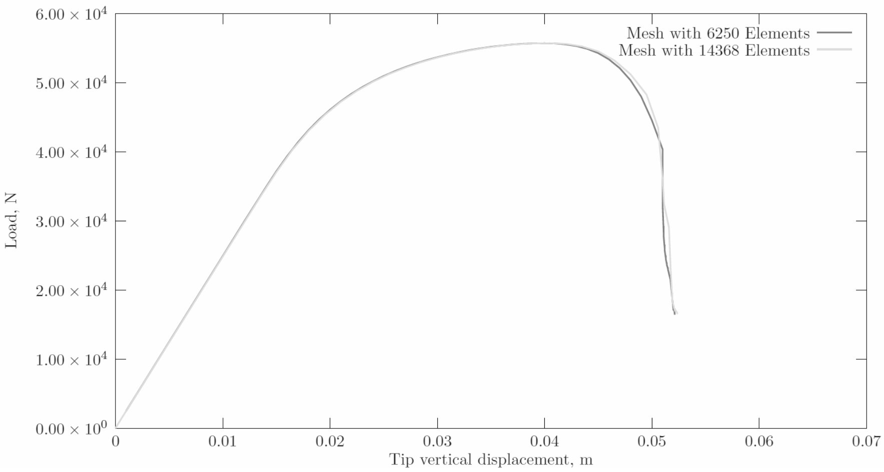


Fig. 8. Cantilever beam: sequence of fracture stages



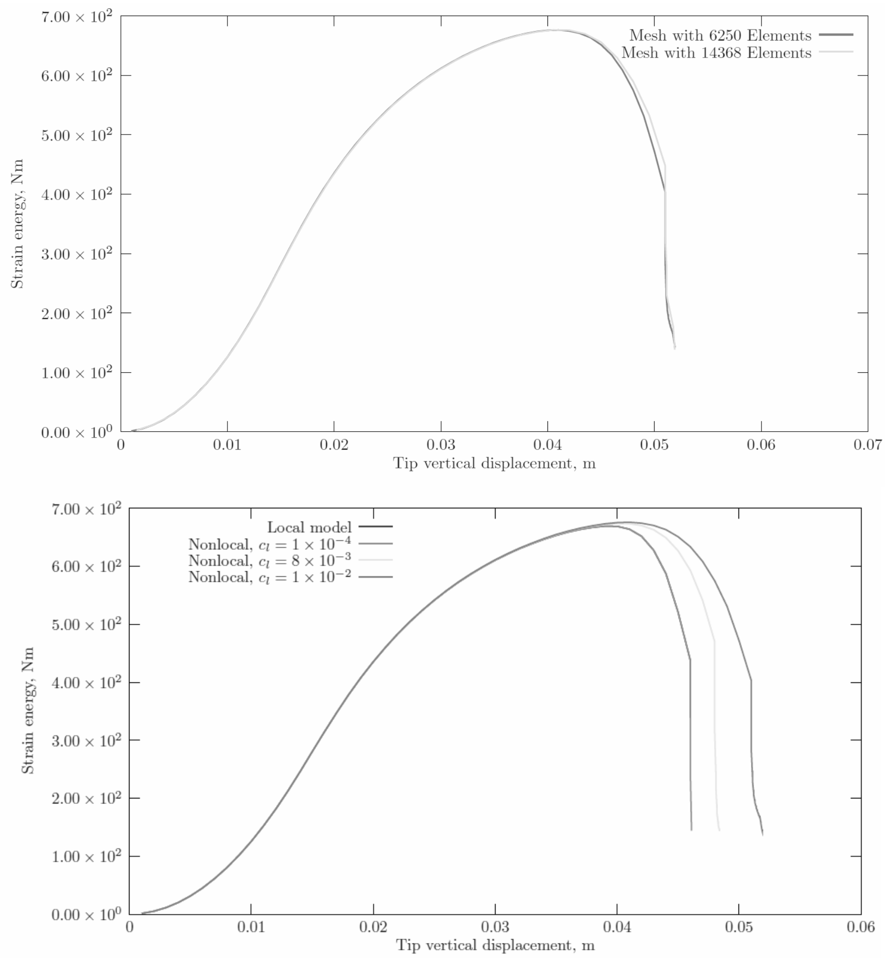


Fig. 9. Cantilever beam: Load-deflection curve

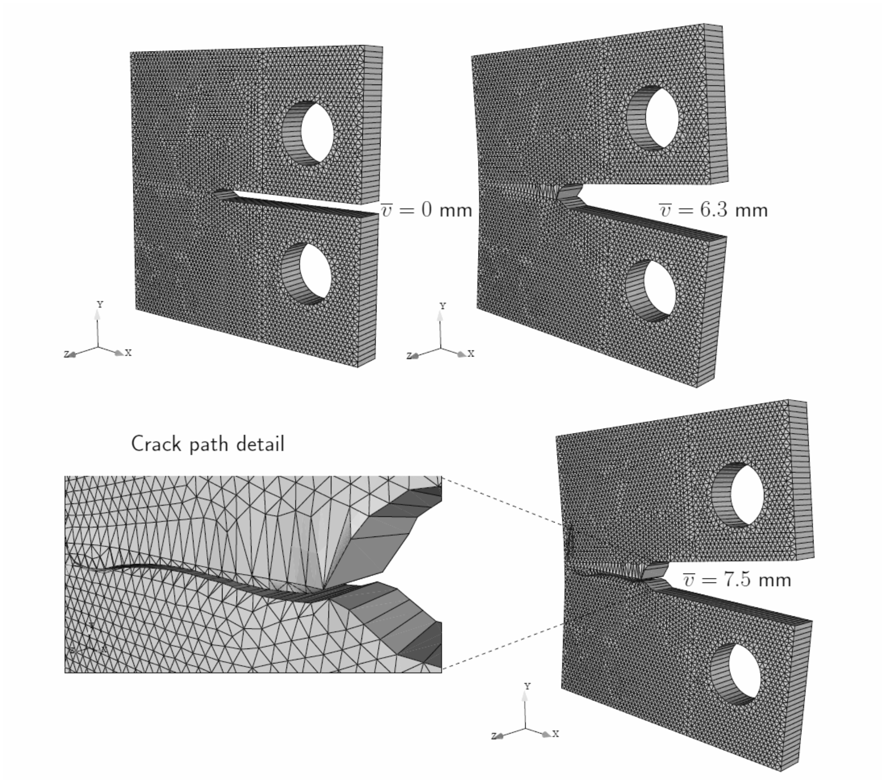


Fig. 10. Double-cantilever beam: sequence of steps

7. Final remarks

We developed a specific constitutive model (although inspired by previous works), a new fracture algorithm which is general and encompasses initiation and propagation, and an appropriate finite element technology for simulation of finite strain elasto-plastic damage and fracture in plane strain and plane stress problems. Since finite strains effects on the thickness are non-negligible, an algorithm to incorporate thickness variation in plane stress is shown and the strong ellipticity condition is altered by the thickness change. For plane strain, a new *general* mixed method is derived that allows pressure softening and does not filter the constitutive laws, as was the case in references [28, 20]. A nonlocal model is applied to the strain tensor to ensure that strain softening does not make the ellipticity indicator negative. Two verification tests were ran with success and one validation tests were performed with very good results both from mesh size independence and accuracy perspectives.

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A New Solar Tracker Approach

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Abstract
This work implements a supervisory control to a solar tracker prototype with two degrees of freedom (DOF). The tracker is motorized by two step motors controlled automatically by a PLC (*Programmable Logic Controller*). Specific function modules are used to communicate with the step motors, as well as with the encoders. The communication between the tracker and the users are performed on two levels: i) Local control implemented by means of an industrial Operator Panel, and ii) Remote Control implemented on a SCADA system (*Supervisory Control And Data Acquisition*). The system supervision and control can be performed remotely through internet as the developed SCADA application is web enabled. This paper describes the methodology used to implement the supervisory control to the tracker prototype. This solar-tracker shows great advantages when compared to other similar devices as the control variable is exactly the measured variable. In fact the sensor used to measure the solar radiation is a PV-cell supplying directly the electric power produced (VxI). The electric power is therefore exactly the control variable to be maximized in a traditional Solar-PV tracking system. The laboratorial prototype structure was developed in collaboration with the Mechatronics Engineering Centre from the University of Évora.

1. Introduction

The search for alternative energies to the oil and its derivatives has known in the last few years a major growth (Khan et al., 2007). The high frequency of energetic crisis and the growing environment sensibility in the world has largely contributed to better thinking in the usage and application of Earth's natural resources in benefit of societies (Denhold and Kulcinski, 2004). The photovoltaic solar energy (PV) as a clean and economical viable alternative has been recently an increasing investment choice from governments and companies, therefore the construction of solar PV-plants has become an indisputable reality, allowing the use of known technology as well as the exploitation of the major potential associated to the generation of electricity from the solar radiation.

Being Portugal one of the countries in Europe with more hours of Sun in the year (European Commission – Joint Research Centre) it becomes clear the great motivation of the country to focus research on this field.

Nowadays photovoltaic energy has a low efficiency ratio concerning the complete distribution chain from production to consumption (ca. 12%). In optimized environments (materials, electric inverters, tracking systems, etc) an input of 1000W of solar incident energy can bring ca. 190W in electricity (efficiency of 19%). This low performance ratio implies big Earth surface consumption when it is intended to install industrial photovoltaic units with significant production impact (50MW – 100MW).

The more relevant side effect of the low efficiency of photovoltaic systems is its poor competition related to traditional fossil combustibles in both economical and financial aspects.

Owing to changes in the solar radiation energy and in the cell operating temperature, the output power of a solar array is not constant at all times. Consequently, a maximum solar power tracking controller is always needed in any scheme with solar cell arrays to ensure maximum utilization. Therefore, research works to solve the problems on Maximum Power Point Tracking (MPPT) have always been a hot topic for the utilization of photovoltaic-array systems. Figure 1 shows the typical variations of the current-voltage characteristic of a PV module, respectively for different values of irradiance and working temperature. A MPPT algorithm must operate in real-time in PV generation systems. The ideal MPPT algorithm sets the operating point of a PV panel, usually forcing the panel voltage at the Maximum Power Point.

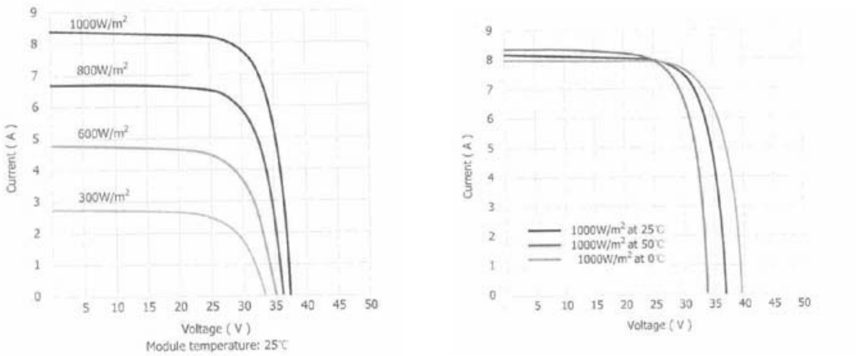


Fig. 1. Current-Voltage characteristic of common PV Panels (influences on irradiation and Temperature)

A logical MPPT search algorithm using normalized current, voltage and power at the working points, for different operating conditions was early tested (Atlas and Sharaf, 1992, 1996). An on-line controller to track the MPPs under changing illumination was described in (Hua and Lin, 2003). An optimization approach using fuzzy logic was given in (Benlarbi et al., 2004) for PV water pumping systems. Other MPP tracking controllers can be found in (Hua and Lin, 2004) and (Chen et al., 2004).

This paper focuses on the optimization of the electric energy production by photovoltaic cells through the development of an intelligent sun-tracking system. The developed tracking system is innovative in relation to the usual sun tracking systems available in the market (Figueiredo and Lobo, 2007).

The usual available solutions for tracking systems rely on the knowledge of the geographical position of the solar panel on the earth surface. With this knowledge it is possible to know the relative position of the sun, on a time basis, according to the well known solar tables (http://solardat.uoregon.edu/SolarPositionCalculatorhtml). Modern solutions incorporate a GPS system to calculate the position of the solar panel on the Earth surface. The orientations to be followed by the photovoltaic panel, on a regular time-base, are then pre-programmed, on an open loop approach.

There are significant efforts on the optimization of sun tracking systems as it is documented by several registered international patents. These solutions are based either on the above described principle either on the quantification of the received solar energy, either on the maximization of the solar incident radiation through the use of light concentration lens or mirrors (Biee and Chace, 2009), (Rubio et al., 2007). The solution here developed is innovative in relation to the above referred approaches as this system is autonomous regarding the information needed to process the optimal orientation and it is intelligent in a way that it monitors, on a real-time base, the photovoltaic energy production and it avoids systematic failures coming from changes on the assumed blind values (position, initial infrastructure orientation, cleanness of the photovoltaic cells, etc.). Finally this system has a competitive advantage, as it measures exactly the controlled variables to be optimized – the actual PV-power generation.

2. System Description

A. General Presentation

The developed sun tracker system is composed by a main mechanical structure with two DOF, motorized by stepper motors with incorporated encoders. The mechanical system was designed using standard industrial Aluminium profiles in order to obtain a simple and economic structure.

The two motorized axis are composed by Step-motors assembled to Aluminium shafts. Both the step-motors and the encoders are wired directly to specific control modules integrated in the Siemens S7-300 PLC. The tracker main structure is presented in fig 2. This electro-mechanical structure is composed by: PV-Cell, two motorized axis with step-motors and encoders, several proximity sensors to indicate the system hard-home.

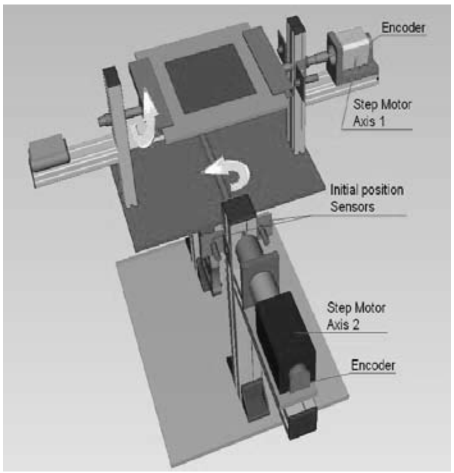


Fig. 2. Electro-mechanical structure

Two user interfaces were developed: Local and Remote. The Local interface was developed over an industrial Operator Panel – Human Machine Interface (HMI). The Remote Interface was developed over a SCADA system. Figure 3 shows an over view of the complete set of components that integrate the developed solar tracker system.

The system operation has two main modes: manual and automatic. In the manual mode the operator (local or remote) supplies the system the target orientations for both axis of the PV-Cell and the tracker develops the actions to achieve the required orientation. In the automatic mode, pre-programmed search directions and amplitudes are defined and the system scans all the predefined searching points, comparing the electric power produced by the photovoltaic cell (PV-panel) in each correspondent orientation. Both the maximal power value and the correspondent orientations on both motorized axis are stored. The system integrates two industrial communication networks: i) ProfiBus DP for local control and monitoring; ii) Ethernet for remote users.

B. Global Technical Characterization

The System control unit is composed by a Siemens S7-300 PLC, with specific modules for: Communications, Digital inputs/outputs, analogue inputs/outputs, Counter modules for encoders and control modules for step-motors.

Table 1 shows the hardware characteristics considered for the developed Prototype: PLC, Motors and Encoders.

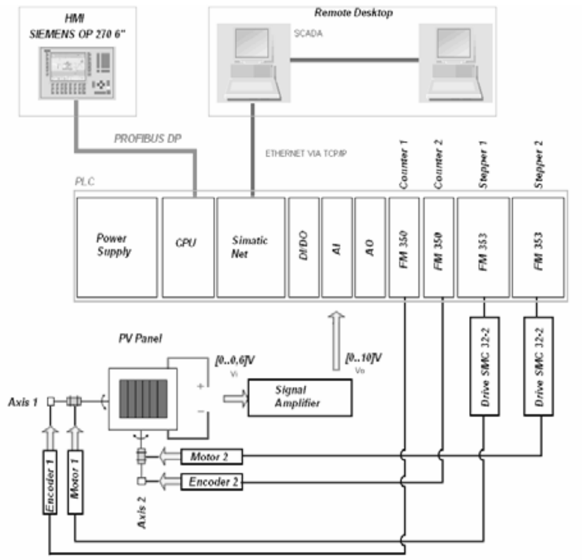


Fig. 3. Overview of all interconnected components

Table 1. Hardware Prototype Characteristics: PLC, Motors, Encoders

Control Unit: Siemens S7-300 hardware configuration		
Slot	**Description**	**Reference**
2	CPU module	Siemens CPU 315-2 DP
4	Ethernet module	Siemens CP 343 Advanced-IT
5	Digital input and output module	Siemens DI8/DO8Xdc24V/0,5A
6	Analogue input module	Siemens AI8x12Bit
7	Analogue output module	Siemens A04x12Bit
8	Function Module for Counters	Siemens FM350 Counter
9	Function Module for Counters	Siemens FM350 Counter
10	Function Module for Step Motors	Siemens FM 353 Stepper
11	Function Module for Step Motors	Siemens FM 353 Stepper
Motors		
Axis	**Description**	**Reference**
1	Step Motor	Nanotec ST4118L0804-B
2	Step Motor + Gear box	Nanotec ST5918L1008-B
Encoders		
Axis	**Description**	**Reference**
1	Encoder 500 pulses	HP HEDS-5540-A14
2	Encoder 500 pulses	HP HEDS-5540-H06

C. PLC Control Application

The control unit is composed by a PLC system (Programmable Logic Controller). This control system has the complete operational management of the tracking system.

The main tasks performed by the system are:

- Control of the two step motors;
- Processing the data from both encoders;
- Processing the voltage signal coming from the PV-Cell;
- Processing the data from the external proximity sensors to inform the system about the hard-home position reference.

As it was described earlier in *A. General Presentation*, the system operation has two main modes: Manual and Automatic. The Manual mode moves the PV-Cell of the tracker to the user specified position. The Automatic mode searches continuously the optimal orientation of the PV-Cell, that corresponds to the maximization of the electric power generated (VxA). Figure 4 shows the flux diagram of the PLC-application developed. The application was implemented using the Statement List programming language (STL) due to the requirements of the cycle-time (Siemens, 2000).

D. User-Interfaces

Two user interfaces were developed for the Tracker system: Local and Remote. The Local interface was developed using an HMI-Operator panel connected to the PLC control unit via a ProfiBus network (Siemens, 2001). The Remote interface was developed over a SCADA system, using the Ethernet TCP/IP protocol to communicate with the PLC control unit (Siemens, 2003). The developed SCADA application is web-enabled, allowing the internet connection through common remote desktop software.

3. Implementation

A. Local Control

The developed local control mode was implemented over an industrial operator panel (Siemens HMI OP 270). Figure 5 shows an overview of the Solar-Tracker Prototype. The local user interface was developed with four main commands/windows: 1) *Command window*, 2) *Define position*, 3) *Define velocity* and 4) *Checkback signals*.

The main structure of the developed Local User Interface is shown in fig. 6. This interface allows the user to navigate among five main menus: *Home*

Menu; *Command Window*; *Define Position*; *Define Velocity* and *Checkback Signals*. The *Command Window* is the main operation menu. Here the user can select between Automatic mode and Manual mode. When Manual mode is selected (default mode) it is possible to define a position and moving the PV-cell, step by step, until the final position is reached. When Automatic mode is selected the tracker movement is autonomous, although the buttons Start, Reset and Stop remain always active for emergency purposes.

In the menus: *Define Position* and *Define Velocity*, the operator can define the target orientation and the working velocity of the PV Panel, respectively.

Finally the Menu *Checkback Signals* allows the system to inform the operator if the system is/is not synchronized. When the origin of the referential is known for both axis - hard-home – (signals supplied from proximity sensors assembled in each axis) the user receives the information: *System Synchronized – YES*. Until this message is not available to the user, the system doesn´t operate in neither Manual nor Automatic modes.

B. Remote Control

The developed remote control mode was implemented over the Siemens SCADA WinCC (Siemens, 2005). The communication between the SCADA system and the PLC control unit was assured by a TCP/IP Industrial communication Module (Siemens CP 343 Advanced-IT). The implemented SCADA system permits a user- selective access to the application, depending on the user's responsibility degree. Three user levels were defined: Operators, Supervisors and Administrators.

Several SCADA menus were built. The main characteristic of a SCADA Menu is to be simple, explicit and quick on transmitting the information to the user. One of the developed Graphical User Interfaces (GUI) is shown in fig 7. In this Menu the remote user can access the total available data characterizing the operation status of the solar-tracker prototype (actual position for both axis, actual PV-power generated, etc.). Additionally all the system commands available locally are also remotely available (mode selection Manual/Automatic; Start and Stop Operations, etc...).

It was defined a hierarchy between the Local and the Remote users. The Remote user (SCADA user) has priority over the Local user. This means that the Local operation is only possible when this functionality is allowed by the SCADA user.

Finally, as the developed SCADA platform is web enabled, all the displayed data is on-line accessible through the internet, by means of "remote desktop" connection between the provider station and a remote PC.

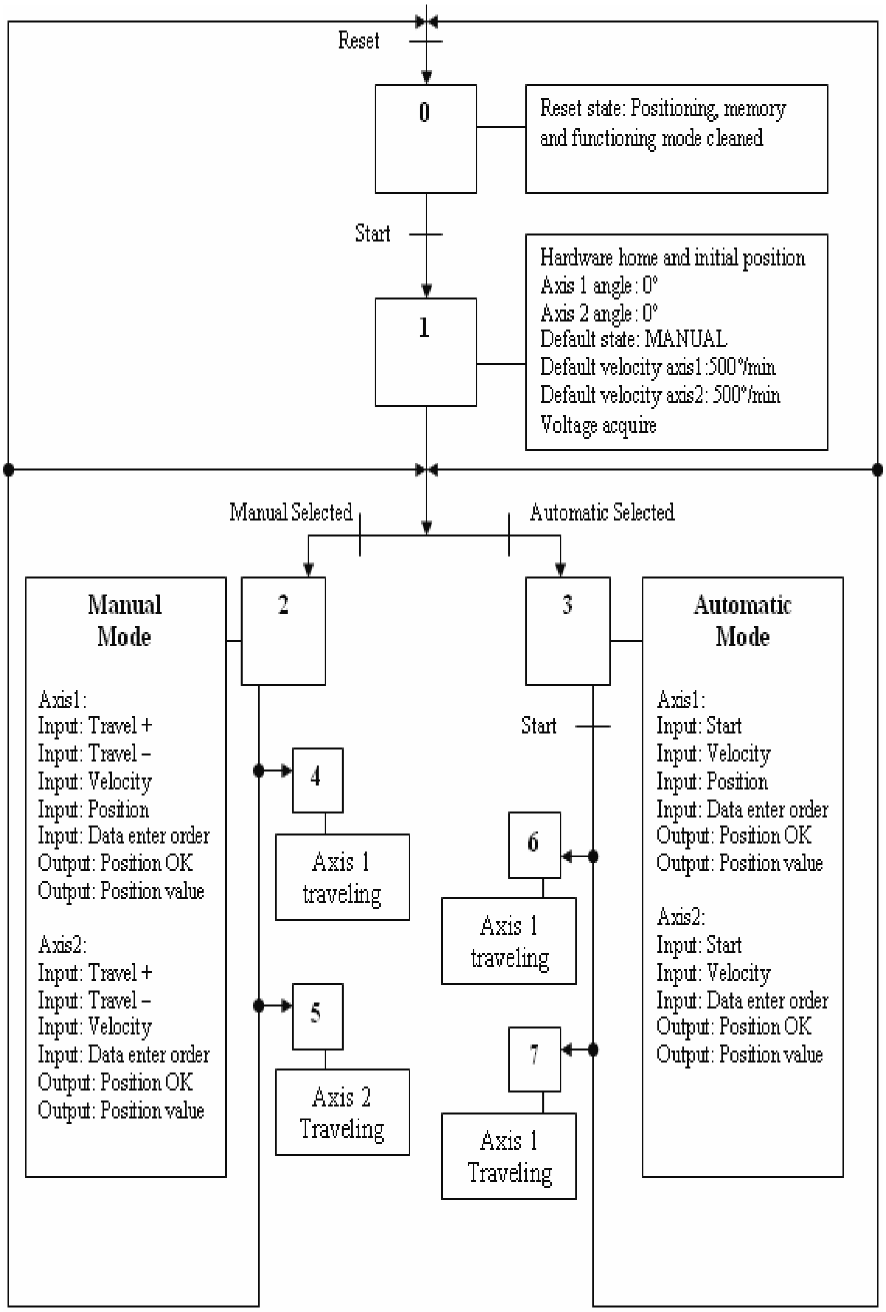


Fig. 4. PLC-application: Flux diagram

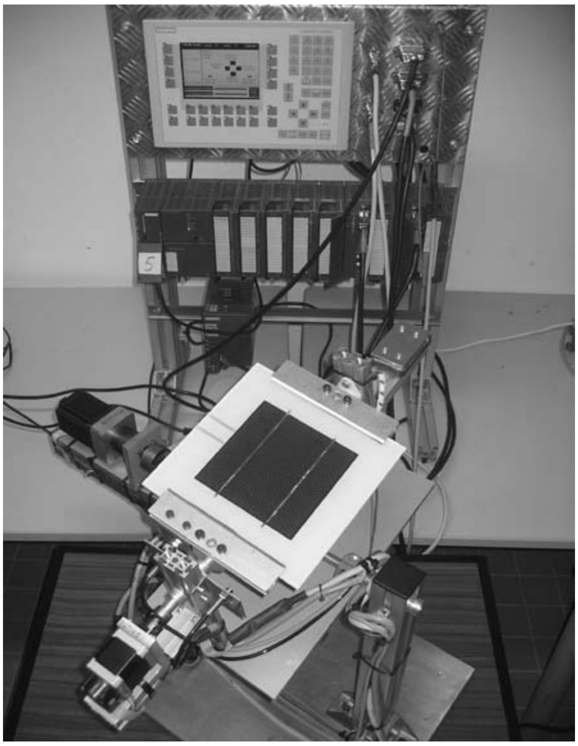


Fig. 5. Controlled Solar-Tracker Prototype

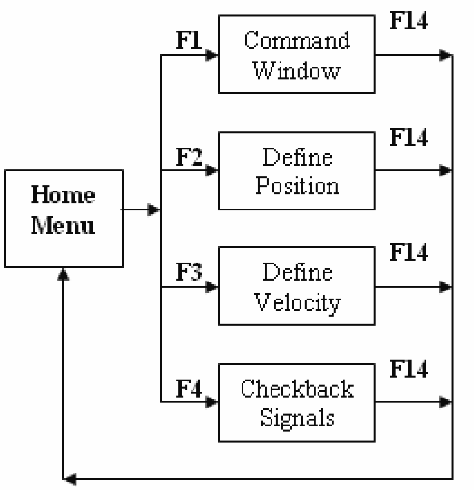


Fig. 6. Local User Interface – main structure

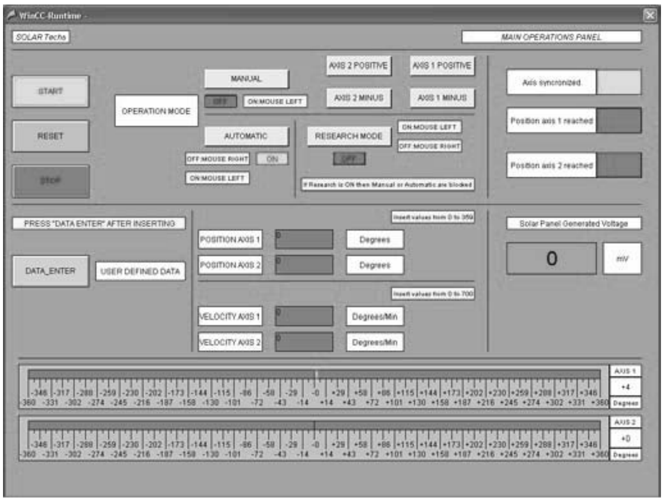


Fig. 7. Remote Control: SCADA Main Menu

C. Experimental Results

In this section two experimental results are shown concerning each one of the developed User Control Interfaces: *Local Control* and *Remote Control*.

The positioning capacities of the prototype were completely evaluated in (Robalo, 2010). These tests concern the calculation of the accuracy of the PV-panel reaching the target orientations in both axis 1 and 2. The following tests were performed:

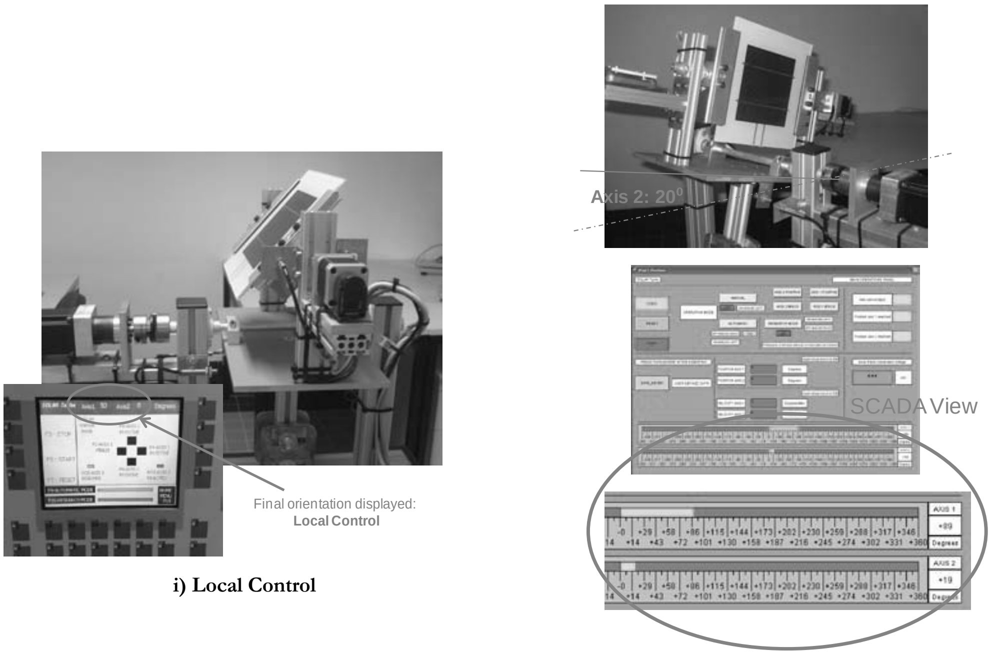
- Accuracy evaluation in hard-home positioning;
- Accuracy evaluation in user-defined positioning;
- Characterization of the error between the two available angle measuring devices (encoders and step-motors).

The obtained results showed an accuracy of ca. 3º in axis 1 and ca. 7º in axis 2.

Figure 8 presents an example of the performed tests with both Local and Remote Controllers. The target orientation introduced in the Local HMI Operator panel was: Axis 1 set to 50º / Axis 2 set to 0º.

The target orientation sent by the SCADA system to the PLC Control Unit was: Axis 1 set to 90º / Axis 2 set to 20º.

As it can be seen in Fig.8, there is more information available in the SCADA platform than in the Local User Interface, because additionally to the axis-orientation data (also available in the Local Control) the SCADA system provides complementary information concerning the electricity generated by the PV-Cell for the actual orientation.



i) Local Control

ii) **Supervisory Control**

Fig. 8. Experimental results with Local Control and Supervisory Control

4. Conclusions

This study focuses on the optimization of the electric energy production by photovoltaic cells through the development of an intelligent sun-tracker system. The developed tracker is innovative in relation to the usual sun tracker solutions available in the market. In fact, the developed solution has many advantages in relation to similar existing devices, as this system is autonomous regarding the information needed to process the optimal orientation and is intelligent in a way that it performs the on-line monitoring of the photovoltaic energy production.

The increase in power generation, in relation to other PV-systems, without tracking devices, is of similar magnitude (ca. 25%) as for other usual tracking solutions. However, this system has a relative advantage, as it measures exactly the controlled variable: the actual PV-power generation.

The developed platform has two main control modes: Local control and Remote supervisory control. The local interface was developed over an industrial Operator Panel (HMI). The remote interface was developed over a SCADA system.

Two industrial connection buses were used: i) ProfiBus DP for the local control communication between the Operator Panel and the Control Unit and ii) Ethernet communication for the Remote Control.

The experimental prototype worked very well. Several positions and control modes were tested achieving reasonable performance in system positioning as well as providing the user a complete and actual information data.

Future works will focus on the improvement of the optimal orientation algorithms in order to optimize the following characteristics: device accuracy, MPP searching time and the power consumption.

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The Mw=8.8 Maule earthquake in Chile: a preliminary view

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Abstract
The Maule, Chile earthquake of 27 February 2010 ruptured a zone of about 450 km in length along the coast and some 120 km in width across the plate interface. This is the first major earthquake in the Chilean subduction zone that is well recorded by a variety of observational techniques ranging from strong motion, seismic waves, tsunami waves and long period waves measured in continuous GPS recorders. At the other extreme we have static observations provided by a large number of GPS sites deployed in the area since the end of the 1990s. The earthquake was expected because the central segment of the event had last ruptured in 1835. Recent GPS studies concluded that the area was fully locked for at least the last 10 years. The 2010 event, like previous mega-earthquakes in Chile had a large moment release, but it was not very destructive event.

1. Introduction

Central Chile suffered a large Mw 8.8 earthquake on 27 February 2010. This event had been announced for quite some time, since several Chilean researchers (Barrientos, 1989, Campos and Kausel, 1989) discovered that the large Mw 8 earthquake that destroyed the city of Chillan on 28 January 1939 was actually an intraplate event that occurred inside the subducted Nazca plate at a depth of about 90 km. The depth of this event was confirmed by Beck et al (1998) who used old seismic data to determine its fault plane and a source depth of 90 km. Reexamination of the catalogs of Chilean earthquakes collected by Montessus de Ballore (1910-1924) and Lomnitz (1970, 2004) showed that the central Chile area from 35°S to 37°S had not had a large earthquake since 1835. The 1835 event is one of the most studied events of the 19th century in Chile because it coincided with visit to Chile by the HMS Beagle on board of which was Charles Darwin. His book (Darwin, 1845) contains a wealth of information about the 1835 earthquake that can be used to better understand and compare it against the Maule earthquake of 2010.

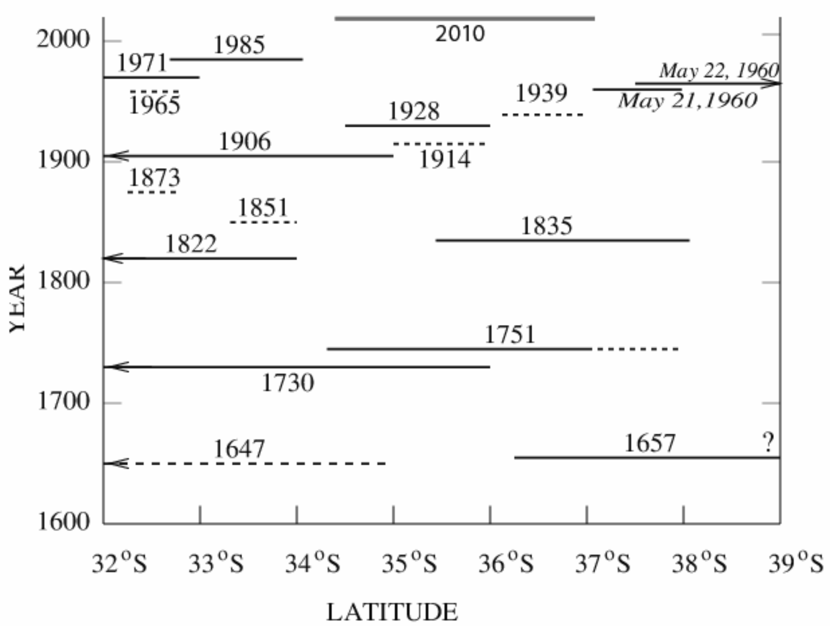

Fig. 1. Seismic history of central Chile from the 32°S to the 39°S parallel. The rupture zone of the different earthquakes is inferred from reports of damage and are, therefore, not all very well determined. The 2010 earthquake filled the gap left by the 1835 earthquake but extended well beyond it, especially to the North where it ruptured again the region of the 1928 earthquake.

In 1996 we carried out the first seismological study of the area and a campaign mode network of GPS sites was measured for the first time. Seismic data reported by Madariaga et al (1998) and Campos et al (2002) showed that although the region of the gap was very active at depth, it showed practically no activity on the plate interface, suggesting that it was completely locked.

2. Seismic gaps in Central Chile

The seismicity of central Chile is very well known, at least for the major events, since the arrival of Spaniards in Chile. Thanks to the work of many historians and his own research, Montessus de Ballore (1912-1916) wrote a monumental treatise on Andean earthquakes. This work was completed by many authors including Greve (1964), Lomnitz (1970, 2004), etc. Further data was available from tsunami histories of the Pacific. From these works we derived the earthquake history shown in Figure 1.

Although the 2010 earthquake broke the expected area (the region of the 1835 event) it broke a much larger area that is, as far as we know at the time of writing, very similar to that of the 25 May 1751 earthquake. That event produced a similar tsunami that lead to the relocation of the city of Concepción to a new more protected site at the Bio-Bio River. The new city founded on 8 December 1754 became present day Concepción.

The geodetic network deployed in the area from 35°S to 38°S was measured several times at irregular intervals. A first study by Ruegg et al (2002) showed that the area was locked. More detailed studies by Moreno et al (2008) and Ruegg et al (2009) confirmed that the area was fully locked and that the depth of locking was greater in the gap than elsewhere along the Chilean coast.

In Fig. 2 we show the state of the plate interface just before the Maule earthquake computed using all available data by Madariaga et al (2010). From geodetic observation we computed the slip rate at different points on the plate interface and converted it into coupling. Coupling is 1 if slip rate is zero, meaning that the fault is locked. At the other end a coupling of 0 means that the two plates are freely slipping. The main conclusion drawn from Fig 2 is that the area of the 27 February 2010 earthquake was ready to break at any moment when this Figure was computed in the late 2009.

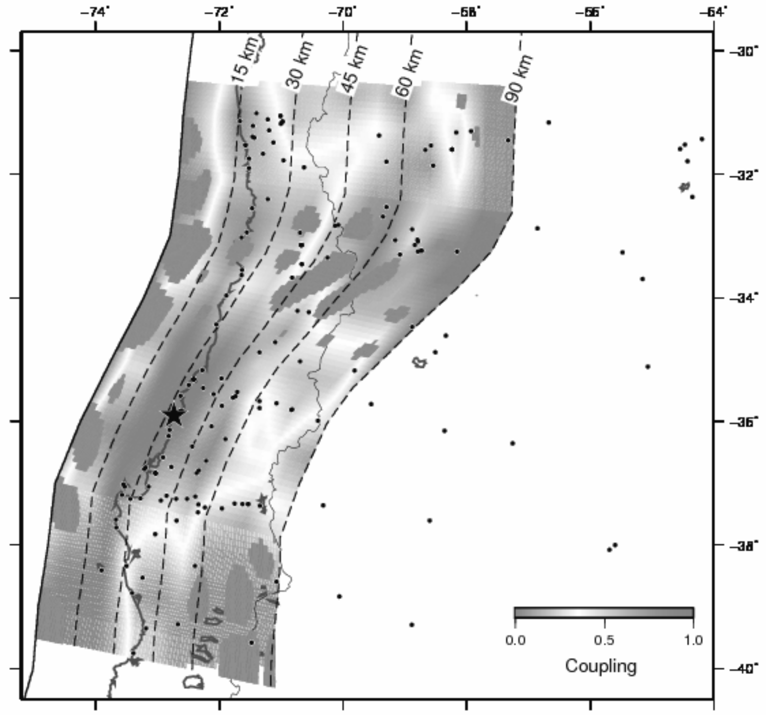

Fig. 2. Stress accumulation in Central Chile before the Mw 8.8 Maule earthquake of 27 February 2010. The figure shows the degree of coupling (or locking) of the plate interface between the Nazca and South American plates. The dark red areas coincide very well with the rupture zone sketched by the yellow ellipse. Dots are the GPS sites used to generate the image. The large black star is the epicentre of the earthquake

3. Far field inversion of the 2010 Maule earthquake

The 2010 was recorded by more than 1000 stations of the broad band world wised networks. We used a selected group of them that provides good azimuthal coverage to model the earthquake. Far field records contain overall information about the rupture process, but they often lack resolution and inversions are non unique. A first inversion of the 2010 Maule earthquake was published very rapidly by Richard Hayes on the NEIC web site based on the far field inversion method proposed by Ji et al (2002). Several other solutions are available on web sites.

For our inversion we adopted the fault plane solution obtained by the Global CMT project. The fault plane had a strike of 12°N, a dip of only 18°W and a rake (angle of slip) of 112 °. The rake means that slip on the fault was mainly reverse faulting with a small right lateral slip component. Adopting a very simple local velocity model, a crustal layer over a half space we inverted far field records. For lack of sufficient information we assumed a very simple rupture model where rupture nucleates on the hypocenter (point of coordinates (0,0) in Fig 3 and then propagates bilaterally as a growing circle with a speed of 3 km/s. The slip distribution is plotted in Figure 3, where slip is plotted on the main fault plane oriented 12 °N. On this plot the North is to the right and the vertical coordinate points downward across the fault. Slip shown in color was computed by the method of Kikuchi and Kanamori (1991). The arrows indicate the direction of slip on the fault. The level lines of slip are plotted every 2 m The slip is on average close to 5 m, but it contains two patches with a maximum slip of close to 9 m on the Northern end of the rupture (right on the plot)

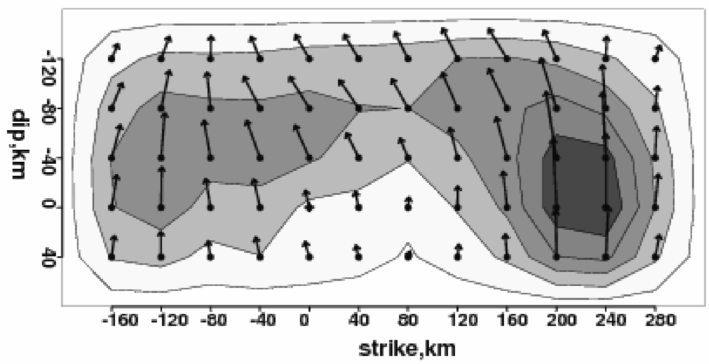

Fig. 3. Slip distribution of the Mw 8.8, Maule earthquake in Central Chile. The levellines are every 2 m of slip. The largest slip is at the Northern (right) end of the distribution. A common feature found by all inversions is that the area north of the hypocenter has very little slip.

An important parameter that can be estimated from the inversion of the slip distribution is the moment rate, the rate at which seismic moment was released by the fault. This is shown in Fig. 4. We observe that moment release started relatively slowly reached a plateau for about 30 s and then decreased abruptly from about 100 s to 120 s. The main features found here were also found by other researchers that have published preliminary source models. The total moment, the blue area in Fig. 4 was 1.4 10^{22} Nm, equivalent to a moment magnitude Mw = 8.7. We notice that this is lower than the moment determined by free oscillations at very low frequencies, or that determined by static GPS, see below. This is typical of large Chilean earthquakes, the same was observed for the 1960 mega earthquake whose Mw from free oscillations was 9.75, but less than 9.5 from surface waves or long period body waves.

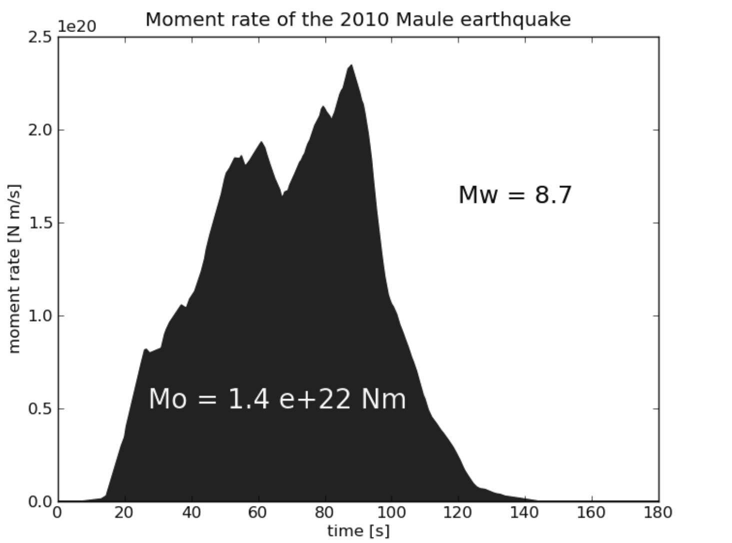

Fig. 4. Moment rate distribution of the Mw 8.8 Maule earthquake of Central Chile. The earthquake grew slowly but it stopped abruptly at about 100 s with a decay of about 20 s.

Our solution differs in some important details from that of other researchers (A. Sladen, C. Ji, personal communication, 2010) but it matches observed records equally well. We can verify the fit of the model to the observations by comparing the observed records (thick lines) with the synthetics (thin lines) as shown in Fig. 5. The comparison is very good as is the case for most large earthquakes of recent times. The 4 stations on the right of Fig. 5 are situated to the East of the source in a region where the P waves have large amplitudes. The 4 stations on the left of the figure are situated in the Pacific to the West of central Chile. Those stations have smaller amplitudes because the P waves leave the source in the direction of the auxiliary fault plane. We observe on the eastern stations a clear effect of directivity. Let us consider the last impulse in the seismograms. It arrives at the Northern most station, ANWB, at about 85 s. The same pulse arrives at the southernmost station, TRIS, on the Island of Tristan da Cunha at about a 100 s. This is a clear effect of directivity and it means that in the Atlantic the later part of the far-field seismic records are dominated by waves coming from the Northern end of the rupture. This is the large asperity (large slip concentration) seen about 200 km North of the hypocenter in Fig. 3.

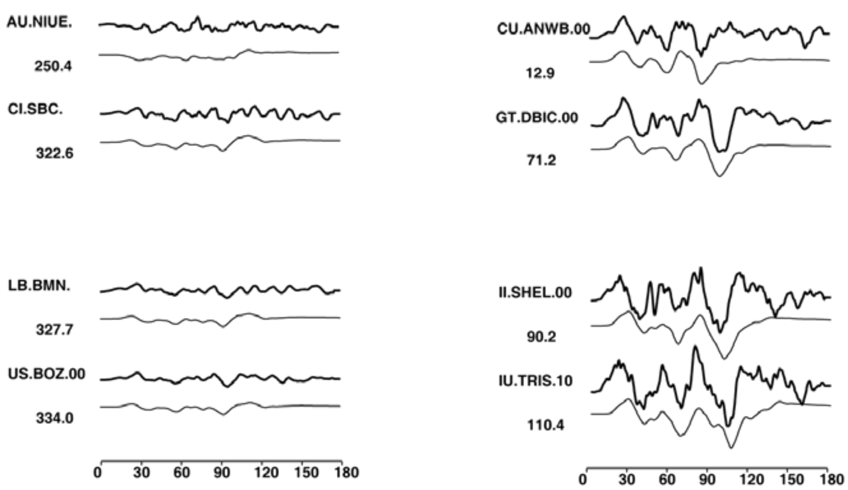

Fig. 5. Comparison between observed (thick lines) and synthetic (thin lines) records at 4 seismic stations used to invert for the slip distribution of the 2010 Maule earthquake in Central Chile.

4. GPS observations

In 1997 a network of campaign mode GPS sites was deployed in the area of the 1835 Concepcion-Constitucion gap with the goal of observing any changes in the area in order to detect any particular signal related to the earthquake preparation process (see Ruegg et al, 2002). The network was measured for the last time before the Maule earthquake in 2003 and a report on the observations was published by Ruegg et al (2009). These authors concluded that the area was completely locked accumulating strain for a future event in the region. A few days after the 27 February 2010 event the network was measured again and the displacement of all the campaign sites was computed.

Figure 6 shows the displacement vectors computed at each of the campaign GPS sites by Vigny et al (in preparation, 2010). The displacements near the coast all oriented in a WSW direction with an angle of roughly 15 ° with respect to the W. Although there are obvious variations in displacement, the all the stations moved by a distance of about 3.5 m towards the ocean. The largest horizontal displacements are observed in the Arauco Peninsula just south of 37°S. The tip of the peninsula, at the Lavapiés station, moved almost 4.9 m. This is normal because that point is much closer than any other to the rupture zone of the earthquake. Although these data have not been inverted yet, they are compatible with slip of 9 m on a fault of 450x140 km.

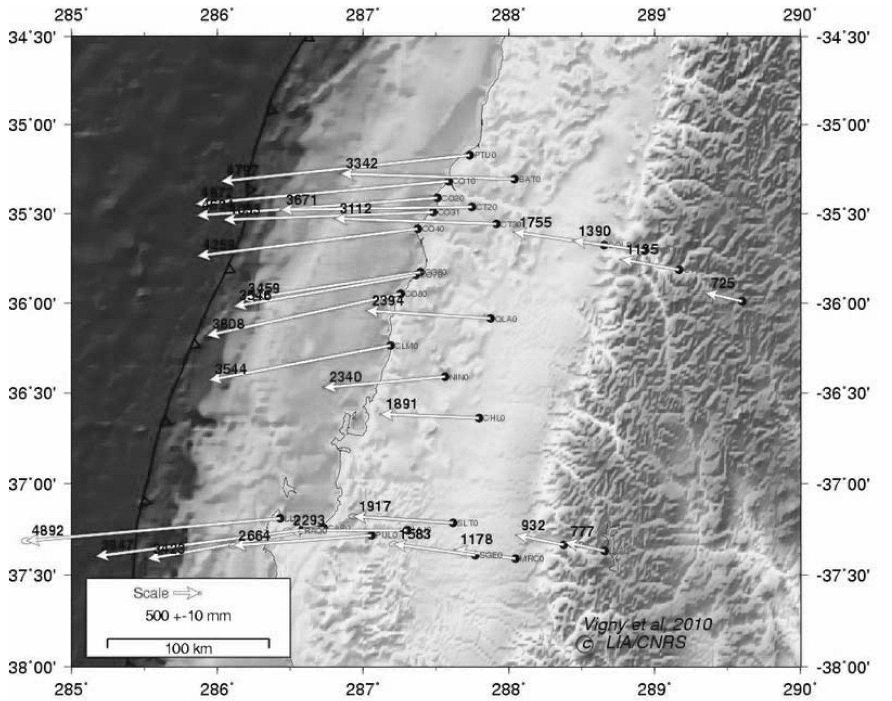

Fig. 6. Displacement vectors determined by campaign mode GPS observations in the area of the 2010 Maule earthquake by Vigny and colleagues (submitted to Science, 2010)

5. Seismic near-field data

As we mentioned the area of South central Chile was under surveillance because we expected an earthquake in the 1835 gap. The central Chile region was equipped with a number of accelerometers and continuously recording

GPS sites. The former record ground acceleration at rates close to 100 samples per second, while the GPS recorders sample the displacement of the ground at rates of 1 sample per second. cGPS stations can resolve all frequencies lower than 0.2 Hz. Thus we have two complementary set of data that we have combined to show the general properties of the seismic source in the near field.

The Maule earthquake is so large that usual concepts like near an intermediate field are blurred because at distances of a few hundred km we are still in the near field. This is the case of the cGPS and accelerograms shown in Fig. 7.

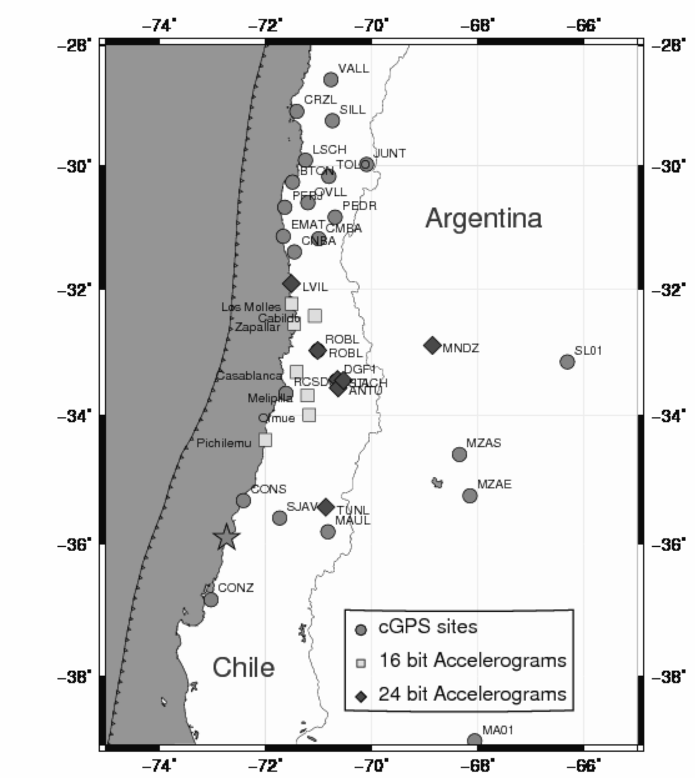

Fig. 7. Distribution of cGPS and seismic stations available for the study of the Maule earthquake. Accelerograms may be integrated to velocities and displacements at most sites, but the frequency band of 16 bit accelerogram (green sites) is rather narrow.

Observation of near field data

Unfortunately, as can be seen from Fig. 7, the Maule earthquake was well recorded mainly in its Northern end because the Department of Geophysics of the University of Chile had most of its instruments in that region. There is no equivalent in the Southern city of Concepcion, although it is still possible that additional seismograms and accelerograms will eventually become available from private sources.

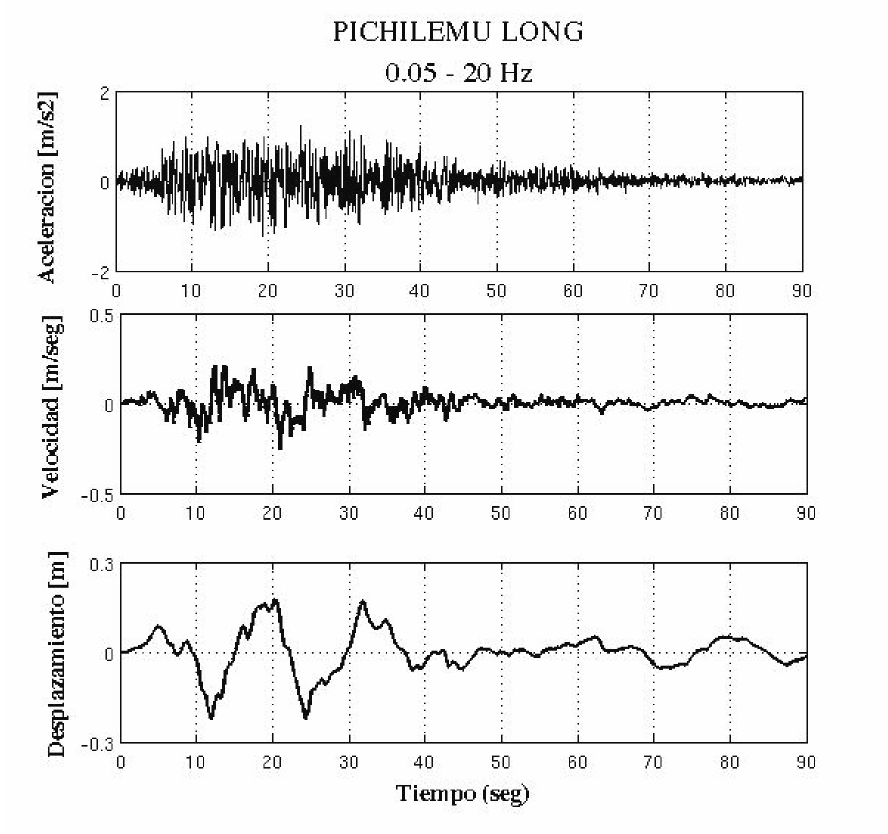

Fig. 8. Acceleration, velocity and displacement computed for a horizontal component at station Pichilemu situated on top of the Northern end of the rupture zone of the Maule earthquake. Pichilemu is a rock site. Peak ground acceleration is very

low, about 12% of g. Displacement seismogram shows the two sources observed everywhere in the North of the earthquake

Figure 8 shows the acceleration at a site situated in the town of Pichilemu, very close the Northern end of the rupture zone of the Maule earthquake (see Figure 7). The most striking feature of this record is the low amplitude of the accelerogram: peak ground acceleration is 12% of ground acceleration. Duration of strong motion is 60 s, but the record was triggered somewhat late, so that the P wave may not have been properly recorded. We integrated the accelerogram using standard procedures to ground velocity and displacement in the 0.05 – 20 Hz band. The records lack long period energy. Both velocity (peak 20 cm/s) and displacement (peak 25 cm) are normal for such a large earthquake and similar in value to those observed during the Tocopilla earthquake in Northern Chile (see Peyrat et al, 2010). The displacement field in the frequency band higher than 0.05 Hz is about an order of magnitude smaller than the static displacement. Although we do not have a GPS station near Pichilemu, the displacements observed at sites about 80 km south shown in Fig. 6 were of the order of 3 m. This difference between static and dynamic displacements is observed in all other stations in the Northern end of the fault zone. Even if these 16 bit data do not have resolution at low frequencies there is a clear hint that the earthquake was smaller at high frequencies than suggested by the static GPS data and by the far field data shown earlier in the paper.

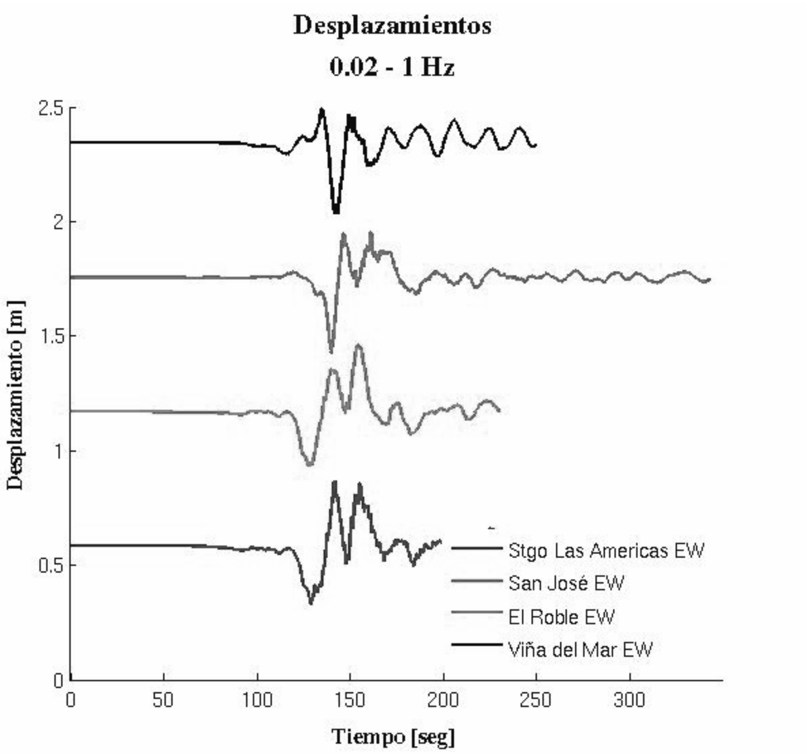

Fig. 9. Displacement integrated from 24 bit accelerograms at 4 statons in the Santiago-Valparaiso area of central Chile. These records are situated about 200 km from the Northern end of the rupture zone of the Maule earthquake.

Observations in the intermediate field in the Valparaiso-Santiago area.

The Metropolitan area was better equipped with accelerograms of high dynamic range. Those can be integrated to displacements over a much broader range that the 16 bit records like that of Fig. 8. In Fig 9 we show a set of three records that extend from Viña del Mar near the coast to San Jose in the Andes. We observe that the records are all very similar with a clear directivity towards the North. The records of Viña del Mar and El Roble situated in the Northern direction from the source are shorter and present one clear spike. Stations to the West in Santiago and San Jose are longer and present two broader peaks. The records were not corrected for fault plane solution. They clearly indicate a directivity of the seismic waves in the Northern direction, just as those in the far field discussed earlier. Further discussion of the stations in central Chile will be carried out using array techniques in future work. The displacement waveforms record in Central Chile can be compared very well to those recorded by continuous GPS stations as discussed next.

6. Continuous GPS data

The Maule earthquake is the first large event recorded by an extensive network of continuously recording cGPS stations. These stations recorded ground motion with a sampling rate of 1 Hz. Although nominally the cGPS stations record displacements without aliasing, the spectral resolution of cGPS recordings is close to 0.2 Hz. Only a couple of cGPS sites were situated close to an accelerogram site and only one, the record at Cerro El Roble (ROBL in Fig. 7) had a cGPS and an accelerogram working at the same site.

Figure 10 shows the comparison between the cGPS and displacement record obtained by integration of the accelerogram at El Roble a station situated on a mountain top mid-way between Santiago and Valparaiso. In order to verify that cGPS and accelerometers record the same ground motion and that processing of both type of data are correct, we integrated the accelerogram twice to obtain ground displacement in the band from 0.01 to 0.2 Hz. The 24 bit accelerograms have good resolution in this band and the cGPS station resolve frequencies higher than 0.2 Hz. Two components of ground displacement at El Roble are shown in Fig. 10 where the integrated accelerogram is shown with continuous line and the filtered displacement measured with cGPS is shown with the discontinuous line. The match is excellent for the EW component; both accelerograms and cGPS record exactly the same thing. The match is certainly less good in the vertical component due, perhaps, to errors in the processing of the vertical GPS. The accelerograms were integrated using Buttersworth filters and integrators from the SAC package. cGPS was processed using the TRACK software.

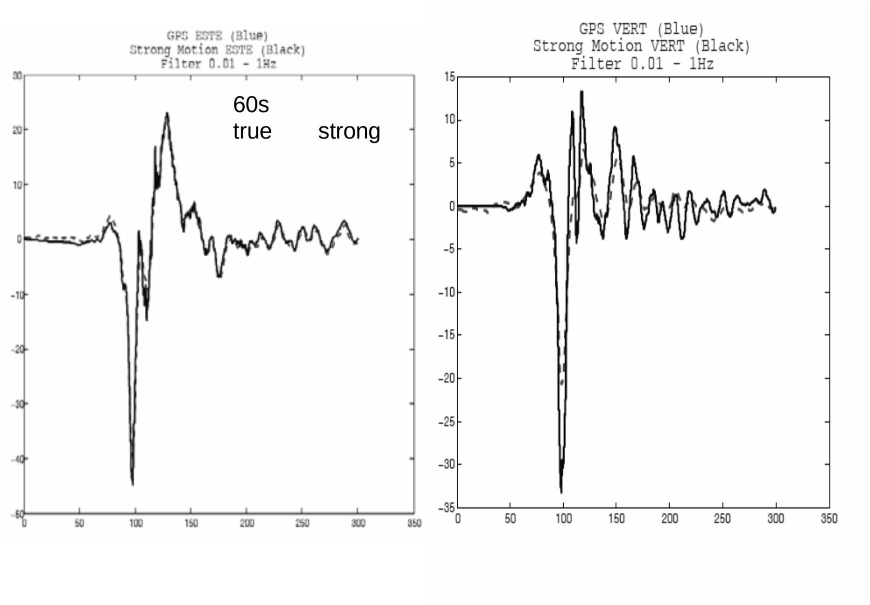

Fig. 10. Displacement integrated from 24 bit accelerograms at 4 statons in the Santiago-Valparaiso area of central Chile. These records are situated about 200 km from the Northern end of the rupture zone of the Maule earthquake. The data was filtered in the 0.01-0.2 Hz band.

Finally we present in Figure 11 a "seismic" section computed using cGPS records. Since 2003 a network of continuously recording GPS sites were deployed in Central Chile from Constitucion in the Maule region to the North of the Coquimbo region. To this data we add recordings made by a similar network in Argentina. More than 20 sites are available for modeling the intermediate field of the Maule earthquake. Fig. 11 shows 8 recordings along a NS line that stretches for a little more than 8 degrees (about 900 km) along the coast of Chile. As in classical seismic section we did two things (1) we reduced the time in the records with a velocity of Vs = 4 km/s that is very close to that of shear waves in Chile. Time in Fig. 11 is then $t = t - D/Vs$, where D is the distance from the hypocenter to the station. The signals are very well aligned by this apparent velocity. We also introduced a dynamic correction in Fig. 11: we multiplied the records by the distance to the station in order to "correct" for geometrical divergence. The records are almost same amplitude now indicating that the signals are propagating mainly as shear waves or very long period Love waves. At the northern most stations we observe some amplification indicating that geometrical spreading is perhaps of square-root type as expected for surface waves. More detailed modeling will remove the ambiguity. Let us remark that the dominant wavelength in these records is of the order of 120 km, so that the difference between body and surface waves is not clear. We will apply full waveform modeling to these records.

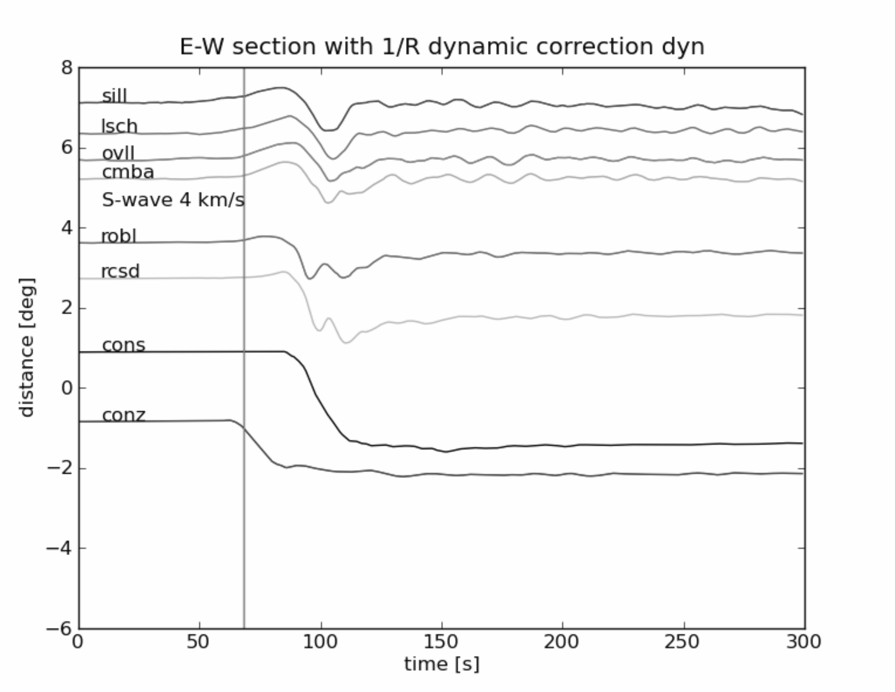

Fig. 11. Displacement observed at 8 cGPS sites located along the Chilean coast. Recordings are aligned vertically as a function of distance from the epicenter of the earthquake. Time is reduced by an apparent velocity of 4 km/s and a $1/R$ dynamic correction was applied to the amplitude of the records. The location of the sites is shown in Fig. 7.

7. Conclusions

This is a very preliminary report on the main features of the recent Maule earthquake of Mw 8.8 in South central Chile. We are near the final stages of data accumulation and correction. There are still a few accelerograms we have not recovered. The Seismic and campaign GPS data provide a very complete overall view of the earthquake of 27 February 2010. It broke a region of about 450 km by 140 km with a seismic moment of $1.5\ 10^{22}$ Nm (Mw = 8.8). The earthquake was recorded in the Northern end of the fault by a set of accelerometers, many of them unfortunately of only 16 bit dynamic range. With these records it is not possible to obtain ground displacements in the 0.01-0.1

Hz range that includes the corner frequency of this earthquake. For this reason records like that of Pichilemu (Fig. 9) are not very representative of the full rupture process of the Maule event. Near Santiago there were several 24 bit accelerograms that could be integrated to displacement and compared in at least one station with a cGPS record. Continuous GPS records from Chile and Argentina provide a very complete view of the rupture process in the Northern end of the rupture zone. We hope that additional accelerograms and GPS stations will become available in the Southern termination of the earthquake in order to get a better view of the entire rupture process.

Acknowledgements

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Seismicity and Ground Motion Simulations of the SW Iberia Margin

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Abstract
In this study, we focus on the region between Gorringe Bank and the Horseshoe Fault located in the SW Iberia margin, which is believed to be the site of the great 1755 earthquake. We model ground motions using an extended source located near the Horseshoe scarp to generate synthetic waveforms using a wave propagation code, based on the finite-difference method. We compare the simulated waveforms using a 3-D velocity model down to the Moho discontinuity with a simple 1-D layered model. The radiated wave field is very sensitive to the velocity model and a small number of source parameters; in particular, the rupture directivity. The rupture directivity (controlled by the rupture initiation location), the strike direction and the fault dimensions are critical to the azimuthal distribution of the maximum amplitude oscillations. We show that the use of a stratified 1-D model is inappropriate in SW Iberia, where sources are located in the oceanic domain and receivers in the continental domain. The crustal structure varies dramatically along the ray paths, with large-scale heterogeneities of low or high velocities. Moreover, combined with the geometric limitations inherent to the region, a strong trade-off between several parameters is often observed; this is particularly critical when studying moderate magnitude earthquakes (M< 6), which constitute the bulk of the seismic catalogue in SW Iberia.

1. Introduction

The interaction between Iberia and Nubia results in a complex region located in the western part of the Eurasia–Nubia plate boundary (Fig. 1). This region corresponds to the transition from an oceanic boundary (between the Azores and the Gorringe Bank) to a continental boundary, where Iberia and Nubia meet (Borges et al., 2001; Buforn et al., 2004, Grandin et al., 2007a). The current tectonic regime at the boundary of the Nubian and Eurasian plates varies with longitude (Fig. 1) as a result of the rotation of Nubia, with respect to Eurasia, around a Euler pole located offshore Morocco, close to 20ºN, 20ºW (Argus et al., 1989; DeMets et al., 1994). This boundary can be divided into five sections (Bezzeghoud et al., 2008). To the west, between the

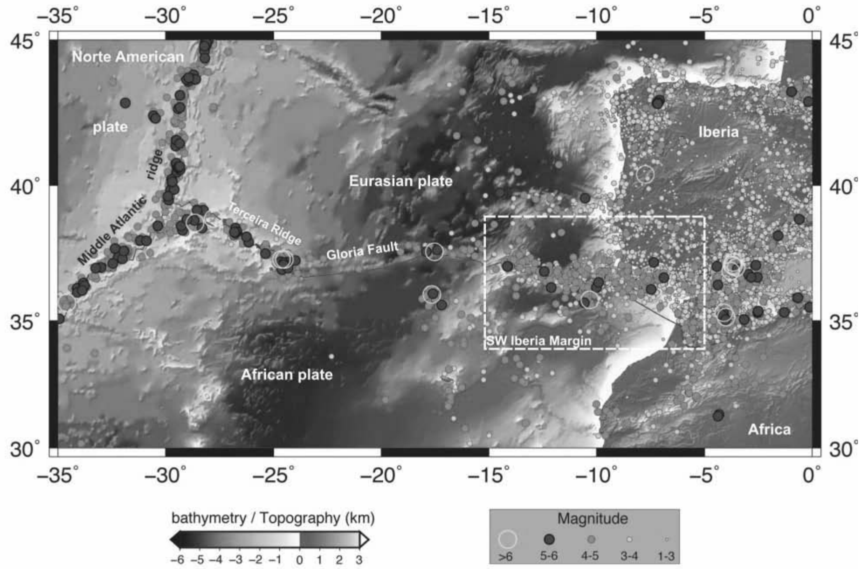


Fig. 1. Seismicity in the western part of the Eurasia–Nubia plate boundary for the period 1973–2010 (NEIC Data File).

Nubia–Eurasia–North America triple junction (35ºW) on the eastern end of the Terceira Ridge (24ºN), the regime is transtensional, with an extension rate of 4.2 mm yr–1 (Borges et al., 2007, Borges et al., 2008; Bezzeghoud et al., 2008), and is responsible for the active volcanism found in the Azores archipelago. In the central section, the relative motion of the two plates seems to be accommodated by a single right-lateral fault, the Gloria Fault, although significant seismic activity is observed in a broad region off the fault (Lynnes & Ruff, 1985). East of 16ºW, the bathymetric continuation of the Gloria Fault cannot be followed, and the definition of the boundary is less clear. A transpressive tectonic regime dominates, with a very low convergence rate of 4 mm yr–1 (Argus et al., 1989; McClusky et al., 2003) trending NW-NNW, consistent with the observed maximum horizontal stress direction (Ribeiro et al., 1996; Borges et al,. 2001; Stich et al., 2003; Carrilho et al., 2004). Deformation is distributed over an increasingly large area that reaches a N-S width of 300 km near the continental margin of Iberia (Chen & Grimison, 1989). In this section, the seismicity is scattered, with most events concentrated along a 100-km-wide band that trends ESE-WNW from 16ºW to 7ºW (Fig. 2). A progressive shift of focal mechanisms, from strike-slip mechanisms in the west to predominant reverse faulting in the east, has also been reported (Buforn et al., 1988; Borges et al., 2001; Buforn et al., 2004) and can be interpreted as an increasing plunge of the minimum compression axis. In the Gulf

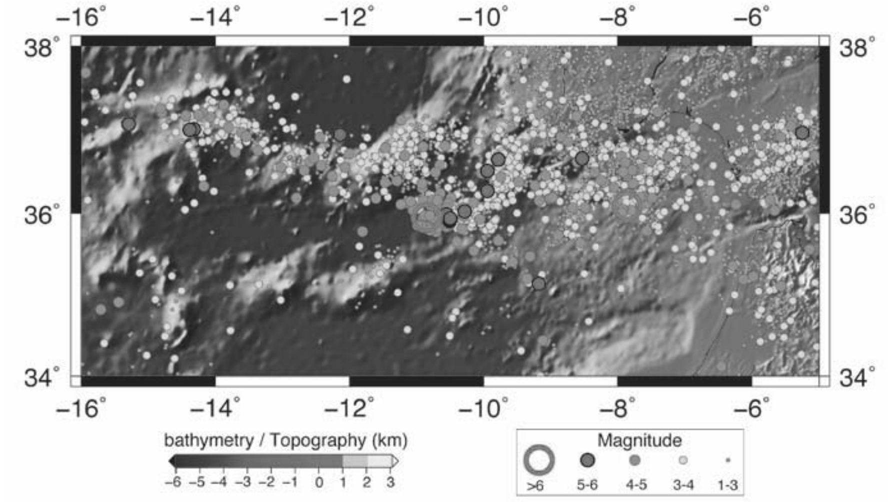


Fig. 2. - Seismicity provided by the Institute of Meteorology (IM, Portugal) in the southwestern Iberian margin for the period 1961–2010.

of Cadiz, the seismicity is denser to the north, around the Guadalquivir Bank (Fig. 2). East of the Strait of Gibraltar, in the Alboran domain and the Betic-Rif Arc, seismicity (Calvert et al., 2000) and GPS data (Fadil et al., 2006) both suggest that active deformation is spread over several hundred kilometres. In this study, we focus on the central section, which is believed to be the site of the great 1755 earthquake. We concentrate our analysis on ground motion modelling using an extended source located near the Horseshoe structure to generate synthetic waveforms using a wave propagation code based on the finite-difference method. We compare simulated waveforms using a 3-D velocity model down to the Moho discontinuity with a simple 1-D layered model. We confirm that the radiated wave field is very sensitive to the velocity model and the rupture directivity. The rupture directivity, strike direction and fault dimensions are critical factors for correctly modelling the azimuthal distribution of maximum amplitude oscillations.

2. Seismo-tectonic setting

The region east of 16°W is dominated by a transpressive tectonic regime, with a very low convergence rate between 4.0 and 5.5 mm/year (Argus et al., 1989; Buforn et al., 2004; Bezzeghoud et al., 2008) trending NW to NNW, consistent with the observed maximum horizontal stress direction (Ribeiro et al., 1996; Borges et al., 2001; Jimenez-Munt et al., 2001). Deformation may be distributed over a large area (Chen and Grimison, 1988) as a result of the complex boundary conditions imposed on the Iberian plate (Andeweg et al., 1999; Jimenez-Munt et al., 2001). As a result of the complex tectonic history of the area, the western Iberian margin and its onshore extension are made up of a succession of uplifted blocks and areas of relative subsidence (Alves et al., 2003). East of 16ºW, the absence of a continuous bathymetric trace along the Africa–Iberia boundary does not allow plate boundaries to be defined with certainty. An ongoing transition between passive and active margin stages of the Wilson cycle can explain the seismo-tectonic setting observed offshore (Ribeiro, 2002). In this region, we do not see a clear delineation between plates, and deformation is distributed over an increasingly large area that can reach a N-S width of 300 km near the continental margin of Iberia. The seismicity is scattered, but most events are concentrated along a 100-km-wide band, trending ESE-WNW from 16°W to 9°W. In this area, a series of topographic structures trend WSW-ENE (Zittelini et al., 2009). The Horseshoe scarp and the Marquês de Pombal scarp (Fig. 3), parallel to the St. Vicente Canyon, have experienced deformation since at least the Miocene. This scenario is supported by the occurrence of unusually large oceanic earthquakes within the area of scattered seismicity, such as the 1969 earthquake (Ms=8.0) and the 1755 Lisbon earthquake (Fig. 3, Table 1).

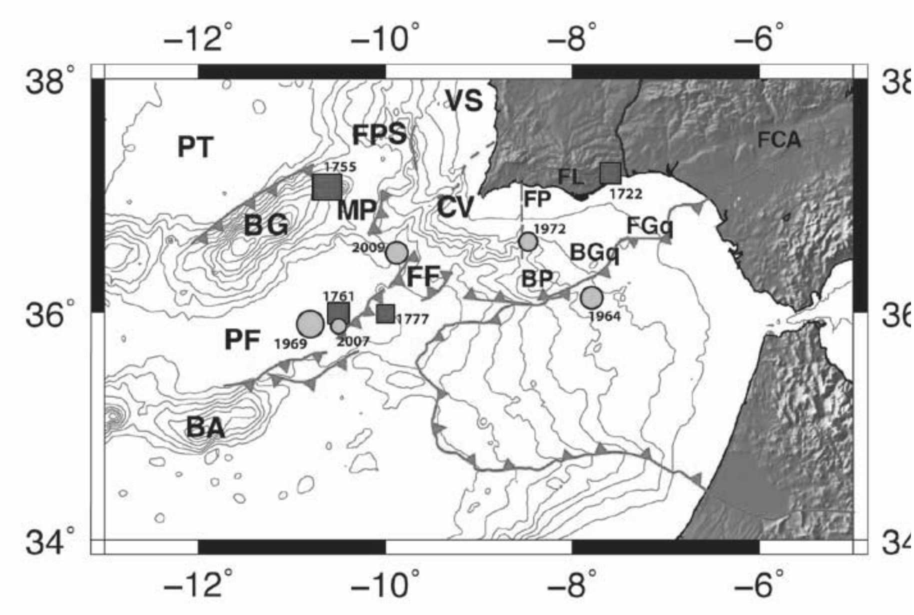


Fig. 3. - Significant earthquakes (see Table 1) and major active faults (adapted from Zitellini et al., 2009) in the southwestern Iberian margin. PT = Tejo plain; FPS: Pereira de Sousa Fault; PF = Horseshoe plain; FF= Horseshoe Fault; BA = Ampere bank; BGq = Guadalquivir bank; VS = Vale do Sado; MP = Marquês de Pombal Fault; BG = Gorringe bank; FGq = Guadalquivir Fault; FM = Messejana Fault; FL = Loulé Fault; FP = Portimão Fault; CV = St. Vicente Cape; FCA = Cadiz-Alicante Fault.

Table 1. Significant earthquakes in the southwestern part of the Iberian margin. Earthquakes from historical times to 1960 are taken from Sousa et al. (1992).

Date *dd/mm/year*	***Lat.***	***Long.***	***Mw***	***Location***
27/12/1722	37.2N	7.6W	7.5	Tavira (Algarve)
01/11/1755	37.0N	10.5W	8.5	SW S. Vicente Cape
31/03/1761	36.0N	10.5W	7.5	SW S. Vicente Cape
12/04/1777	36.0N	10.0W	7.0	SW S. Vicente Cape
15/03/1964	36.1N	7.8W	6.2	SE S. Vicente Cape
28/02/1969	35.9N	10.8W	7.5	SW S. Vicente Cape
12/02/2007	35.9N	10.5W	5.9	SW S. Vicente Cape
14/06/1972	36.6N	8.5W	5.2	SE S. Vicente Cape
17/12/2009	36.5N	9.9W	6.0	SW S. Vicente Cape

2.1. Instrumental seismicity

Onland, the seismicity exhibits significant scattering, with a maximum focal depth of 15–20 km (Buforn et al., 2004). In the Lusitanian basin, microseismicity reveals a complex pattern of focal mechanisms, and the depths of earthquakes, between 14 and 23 km, suggest that the sediment deformation is controlled by tectonic activity deep within the basement (Fonseca and Long, 1989). Seismic activity in the region of Évora is associated structures at un known depths (Borges et al., 2000). It is clearly possible to define microtremor alignments around Monchique that suggest a correlation with two probable faults that were recently identified in this area (Rocha et al., 2008; Rocha, 2010). In the NW region of Almodôvar, a trend in the distribution of epicentres may indicate the existence of an uncharted fault in this zone (Rocha, 2010).

In the last five years, there has been an increase in seismic activity in the area between Gorringe Bank and the Horseshoe Fault (Fig. 2). The largest recorded earthquake occurred offshore in 1969 (Mw=7.3), but since then, only two earthquakes have reached a magnitude of 6 (Table 1). These earthquakes all struck the region located between the Horseshoe Abyssal Plain and Cape St. Vicente where seismic activity decreases towards the coast. In this area, a series of topographic structures trending WSW-ENE exhibits clear seismic activity (Fig. 3). The Horseshoe scarp and the Marques de Pombal scarp, parallel to the St. Vicente Canyon (Fig. 3), show active deformation since at least the Miocene (Gràcia et al., 2003a) and are located above the transitional domain of the ocean–continent transition (OCT). The most prominent seamount is Gorringe Bank (Fig. 3), an uplifted thrust block of crustal and upper mantle rocks that culminates 25 m below sea level and was emplaced during the Miocene (12 Ma) by plate breakup, differential loading and NW-SE shortening of the Jurassic oceanic lithosphere (150 Ma) (Hayward et al., 1999). North of the Coral Patch Seamount and Coral Patch Ridge, scarps with the same trend affect the seafloor, and large amplitude folds involve the sedimentary cover down to the basement (Hayward et al., 1999). Most earthquakes occurring in this zone (Figs. 2 and 3) are located at depths between 5 and 25 km and can reach 90 km (Buforn et al., 1988), even in the oceanic domain, where the Moho lies at a depth of 15 km. Despite large errors in hypocentral depth calculations (up to 10 km) due to poor azimuthal coverage, this suggests that brittle deformation also involves the upper mantle. The passive western Iberian margin may be undergoing activation, with an incipient east-dipping subduction developing between the continental and transitional domains of the OCT, which might account for these observations (Ribeiro, 2002). Eastwards, widespread seismicity, with compressional and strike-slip fault plane solutions and a large, elongated positive free-air gravity anomaly, suggests that the Guadalquivir Bank is bounded by active faults (Grácia et al., 2003b). In the Guadalquivir foreland basin, seismicity is low (Figs. 2 and 3) and seems to be limited to the buried Subbetics frontal thrust.

2.2. Historical seismicity along the margin

Most major submarine canyons are aligned with NE-SW-trending faults on land, suggesting tectonic control over a broad area (Fig. 3). These faults were reactivated as reverse faults during Miocene compression, and historical records of large earthquakes show that they are still active today (Fig. 3). The Nazaré Canyon corresponds to the Nazaré Fault, which has been active since the middle Cretaceous. It may be responsible for earthquake activity in the Batalha-Alcobaça region, with the latest event dating to 1890 (M=4.5). The Lower Tagus Fault Zone, whose seismo-tectonic interpretation is still under debate, might be extended by the Lisbon Canyon. This fault zone was active in 1344 (M=6.0), 1531 (M=7.1) and 1909 (M=6.0) (Moreira, 1982; Teves-Costa et al., 1999). The system may also have been activated during the 1755 Lisbon earthquake (Vilanova et al., 2003), suggesting a recurrence interval of 200 years. The source of the 1858 Setùbal earthquake (M=7.1) may be a blind thrust fault, trending NNE-SSW, located below the Setùbal Canyon, in the Sado Valley (Ribeiro, 2002). The St. Vicente Canyon is aligned with the Messejana Fault, a deep fault of lithospheric dimensions, showing 1 to 2 km of vertical throw in the upper crust on seismic profiles (Matias, 1996), but no clear seismic activity. The Portimão Fault, dating to the Permian, shows seismic activity and can be followed along the Portimão Canyon. The Loulé Fault may accommodate a significant part of the shortening across the Algarve basin, due to the presence of halokinetic structures in its footwall, and may have exhibited recent seismic activity in 1587 (M=5.5) and 1856 (M=5.5) (Moreira, 1984; Terrinha, 1998). The source of the tsunamigenic 1722 Tavira earthquake (M=7.8) may be located offshore the southern Portuguese coast, possibly near the Guadalquivir bank area. The 1761 earthquake (M=8.0) also occurred offshore, generating a large tsunami, but its location is extremely uncertain (Baptista et al., 2006). This is also the case for the largest earthquake ever reported in Europe, which occurred in this region in 1755 (M=8.5), accompanied by a massive tsunami. For this event, different seismogenic origins are currently supported by various authors (e.g., Zitellini et al., 2001; Gutscher et al., 2002; Grandin et al., 2007b).

3. Ground motion modelling and directivity effects

3.1 – A 3-D velocity model and the 1755 earthquake source

A realistic velocity model, embedded in a wave propagation code, is an appropriate way to study the source parameters of the 1755 earthquake, provided that there are sufficient data. The finite-difference method is well adapted to this strategy, because it has sufficient computational efficiency to enable a large number of tests and is accurate in the low-frequency range (f < 0.5 Hz), which is most significant for studying the destructive effects of large earthquakes at the regional scale. The velocity model used here was proposed and validated by Grandin et al. (2007a).

The velocity model of the crust used in this study incorporates the major seismogenic centres observed offshore SW Iberia, between Gorringe Bank and the Betic Cordillera in the region lying between latitudes 35.2ºN and 39.7ºN and between longitudes 11.8ºW and 6.1ºW. The crust is stratified and is made of a superposition of a finite number of layers, with varying depths and thicknesses. Only the depth of each interface between layers must be specified at given points; then, a Delaunay triangulation can be applied to fill the spaces between these points (Watson, 1982). A layer can thus taper off and reach zero thickness, if necessary, which is convenient for modelling sedimentary basins or the OCT: To account for their complex geometries and high variations of thickness/depth, these regions only require a denser network of data points. We also assumed that both continental and oceanic crust could be described with the same layers, by coupling layers that have similar

wave propagation velocities and densities in the two domains. The links between coupled layers are assessed based on seismic profiles. However, their resolutions are often insufficient to locate small lateral velocity discontinuities, and we thus focus on large wavelength variations of major intra-crustal layer thicknesses. In this model, the purely oceanic crust is separated from the continental crust by a transitional domain, probably made up of thinned, highly faulted or intruded continental crust. The classification for continental crust layers uses nine different layers with distinct physical identified properties. These overlie the upper mantle, which is modelled as a half-space, with a uniform velocity of 8.1 km/s and a Vp/Vs ratio of 1.74 to deduce S-wave velocities from P-wave velocities (Grandin et al., 2007a). Densities were set based on experimental measures of density for a set of crustal rocks. The complete SWIB2006 velocity model is discussed in Grandin et al. (2007a) and posted on the webpage:
http://evunix.uevora.pt/~jborges/3DSEISM/get_SWIBmod.html; it is freely available to the public.

The 1755 November 1 earthquake was the strongest earthquake ever reported in Europe and was extremely destructive (Portugal: Pereira de Sousa 1919; Spain: Martínez-Solares et al., 1979; Morocco: Levret, 1991) – the shock was felt even in Northern Germany, the Azores and the Cape Verde Islands (Reid, 1914). The large size of the earthquake is further evidenced by observations of seiches in southern England and Holland and as far as Finland (Reid, 1914). The large tsunami waves generated by the earthquake also caused extensive damage along the coasts of Portugal, southern Spain and Morocco and were even detected in the Lesser Antilles and southwestern England. Extensive geological evidence of tsunami deposits associated with the 1755 earthquake has been reported in Europe (e.g., Andrade, 1992; Dawson et al., 1995; Abrantes et al., 2005; Scheffers & Kelletat, 2005). The problem of epicentral location has been addressed by various early studies (Reid, 1914; Pereira de Sousa, 1919), and since the beginning of the instrumental period, a consensus has attributed the origin of the earthquake to a structure located between the Gorringe Bank and the Coral Patch Ridge (Machado, 1966; Moreira, 1985; Johnston, 1996; Grandin et al., 2007b). In the most recent hypothesis, Grandin et al. (2007b) tested, by forward modelling, three published sources for the 1755 earthquake that can be considered as end-members of the set of proposed offshore seismic sources (Johnston, 1996; Zitellini et al., 2001; Terrinha et al., 2003; Gutscher et al., 2002; Gutscher et al., 2006; Thiebot & Gutscher, 2006). Following the results of these tests, Grandin et al. (2007b) concluded that a fault located below Gorringe Bank, with a rupture directed towards the SW, reproduces the overall pattern of macroseismic observations better than a fault aligned along the Marquês de Pombal–Pereira de Sousa Fault zone or a subduction-related thrust fault in the Gulf of Cádiz. Except for Grandin et al. (2007b), all seismic modelling of the 1755 Lisbon earthquake performed by various authors (Mendes-Victor et al., 1999; Baptista et al., 2003; Gutscher et al., 2006) suffer limitations, because they do not take into account physical considerations related to the complexity and directivity of the seismic source on one hand, or the propagation medium on the other hand (Grandin et al., 2007a,b).

3.2 - Propagation medium and directivity of the seismic source

To model the propagation of seismic waves in a 3-D medium, we used the code E3D, an explicit 2-D/3-D elastic finite-difference wave propagation code (Larsen & Schultz, 1995) based on the work of Madariaga (1976). The method, computational issues related to the finite-difference scheme and source implementation are given in detail in Grandin et al. (2007a,b). The method has been successfully applied by a large number of authors to generate synthetic seismograms (e.g., Olsen & Archuleta, 1996; Larsen et al., 1997; Dreger et al., 2001; Pitarka et al., 2004; Hartzell et al., 2006; Kagawa et al., 2004; Grandin et al., 2007a,b).

For a source like that of the 1755 Lisbon earthquake (Mw~8.5), the finiteness of the fault dimensions and of the duration of rupture cannot be ignored. Following the source implementation scheme of E3D, we model this extended source by superimposing a large number of point sources over a rectangular fault plane that has the same strike and dip as the individual subevents. The kinematics of the rupture, namely, the rupture propagation direction, are simulated by triggering a rupture on each subfault at the right time: a rupture can nucleate at a certain location on the fault and then propagate radially until the fault edge is reached – the rupture velocity is assumed to be constant over the fault plane. To prevent high-frequency noise from entering the radiated spectrum and to thus generate a smooth source time function, it is important that the rupture on each subfault is initiated before the rupture on the previous adjacent subfault has stopped. We chose to use a Brune signal as the elementary source time function for rupture on each subfault (Brune, 1970). In the case of a finite source, the rupture velocity is fixed at 2.5 km s–1 and the grid spacing is 1 km (maximum frequency of 0.3 Hz). We also assume a uniform seismic moment distribution over the fault plane. Thus, the slip is not uniform, due to variations in the rigidity modulus with depth in the velocity model. However, in the epicentral distance range considered here (d > 100 km), we have verified that this condition does not induce significant differences from a uniform geometric moment distribution. Furthermore, we set the depth to the top of the fault so that co-seismic rupture does not extend beyond the seismic basement. This prevents the occurrence of super-shear rupture velocities in the shallow sedimentary cover, but assumes that sediments are not involved in significant seismic wave generation. This hypothesis is valid from a seismological point of view (Grandin et al., 2007b).

The stability of this method has already been verified by Grandin et al. (2007a,b) through a large number of simulations to evaluate the importance of the arbitrarily fixed parameters, such as the characteristic time of subevent rupture, which sets both the rise time and the duration of the rupture, the rupture velocity, and the complex geometry. On the other hand, variations in the focal parameters, fault plane geometry and rupture directivity have strong effects on the resulting radiated wave field. The computational domain has a grid spacing of 1 km and extends to a depth of 70 km.

Table 2. - Source parameters used to compute synthetic waveforms.

Scenario	*Nucleation point X; Y (km)*	*Fault area L x W*	*H km*	*M_o x 10^{22} (Nm)*	*M_w*	*Strike*	*Dip*	*Rake*	*Vr (km/s)*
Directive	53.33; 50	200 x 80	8	1.16	8.7	60	40	90	2.7
Bi-directive	53.33; 0								
Anti directive	53.33; - 50								

For this study, we compare simulated waveforms based on the source parameters given in Table 2 for a 3-D velocity model down to the Moho discontinuity versus a simple 1-D layered model (Figs. 4 and 5). We confirm that the radiated wave field is very sensitive to the velocity model (Fig. 5) and a small number of source parameters; in particular, the rupture directivity (Fig. 6). In contrast, the computation is not very sensitive to other source parameters, such as the dip, the rake, the rupture velocity, the depth to the top of the fault or the duration and shape of the source time function. Figures 4 and 5 show that the use of a stratified 1-D model is definitively inappropriate in SW Iberia, where sources are located in the oceanic domain and receivers in the continental domain; the crustal structure varies dramatically along the ray

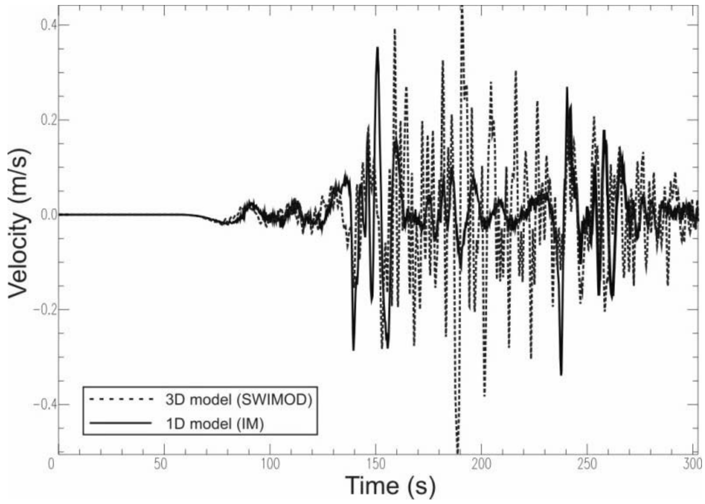


Fig. 4. - Comparison between simulated waveforms obtained using a 3-D velocity model and a simple 1-D layered model for the first point close to Faro city (see profile located on the top of the 3-D structure model of Fig. 5).

paths, with large-scale heterogeneities of low or high velocities. Figure 5 shows that in the Mesozoic basin, the 3-D velocity model gives maximum velocity values that are about a factor of two higher than those given by the 1-D velocity model. Moreover, combined with the geometric limitations inherent to the region, a strong trade-off between several parameters is often observed: this is particularly critical when studying moderate magnitude earthquakes (M< 6), which constitute the bulk of the seismic catalogue in SW Iberia. Figure 6 shows the significance of the directivity effect, which is controlled by the rupture initiation location, for three rupture scenarios: directive, anti-directive and bi-lateral. The directive rupture gives the maximum velocity values; in the Mesozoic basin, they are greater than those of the anti-directive rupture by a factor of about 6 and are greater than those of the bilateral rupture by a factor of 3.5. The rupture directivity, velocity model, strike direction and fault dimensions are critical factors controlling the azimuthal distribution of the maximum amplitude oscillations. The radiation that issues from an extended seismic source when a rupture spreads in preferential directions can be distinguished from that emitted by a point source. This distinctive characteristic, which is known as directivity (Ben-Menahem, 1961), is manifested by an increase in the frequency and amplitude of seismic waves when the ruptu-

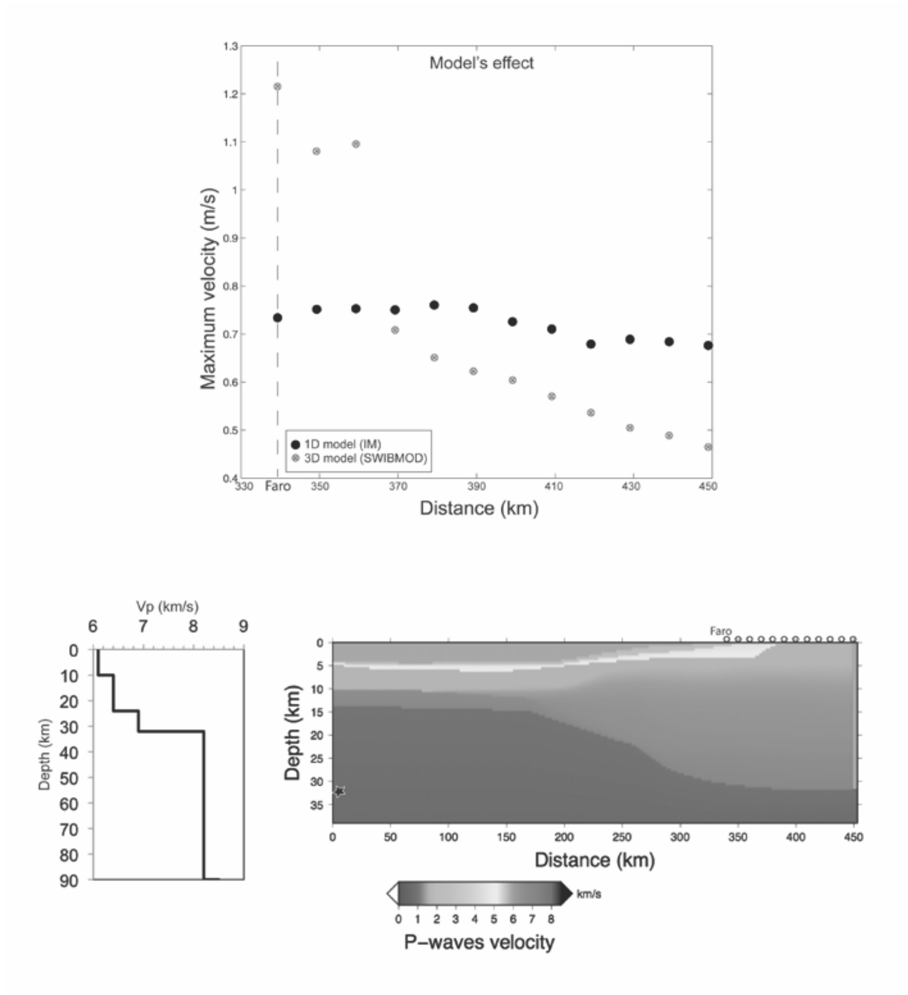
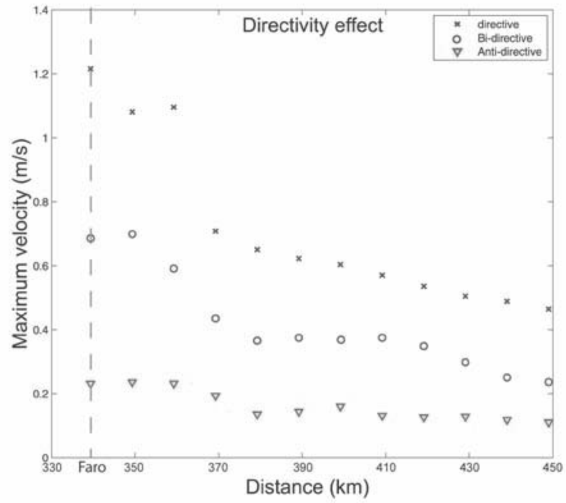


Fig. 5. - Top: 3-D velocity model effects. Comparison between simulated maximum velocities obtained using a 3-D velocity model with a simple 1-D layered model along the line, represented by open circles, shown on top of the 3-D P-wave velocity model represented below. Below: 1-D P-wave velocity model (left) and 3-D P-wave velocity model (right) extracted from the SWIBMOD (Grandin et al., 2007a), model along the profile located at the bottom of Fig. 6.

re occurs in the direction of the seismic station and a decrease if it occurs in the opposite direction (e.g., Caldeira et al., 2009). Moreover, these effects are not present when the rupture direction is perpendicular to the propagation direction.



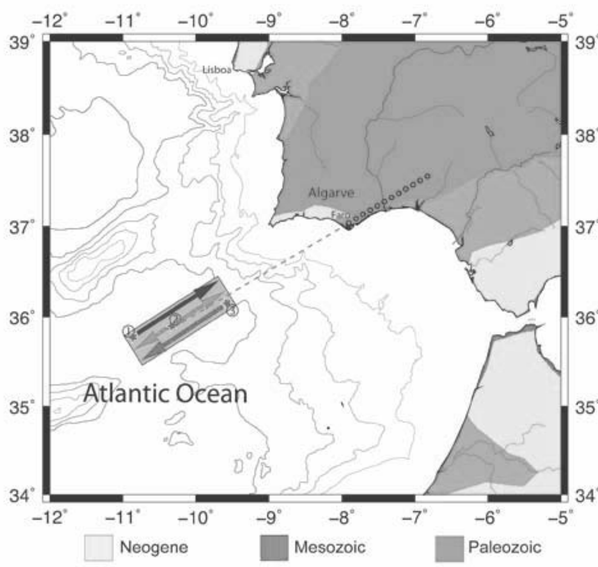


Fig. 6. - Top: Directivity effect. Comparison of simulated maximum velocities obtained using a 3-D velocity model for the 3 proposed rupture process scenarios: directive, bi-lateral and anti-directive. Bottom: Source location and rupture process used for the simulated waveforms determined in this study. Red star=the epicentre, arrows=average direction and the extent of the rupture front during the related period for the directive, bi-lateral and anti-directive scenarios. Open circles=the profile where simulated waveforms are determined. The corresponding values are indicated at the tops of Figs. 5, 6.

4. Discussion

Most great tsunamigenic earthquakes are related to well-defined interplate convergence zones: the circum-Pacific seismic belt, the Sunda arc, the Hellenic arc or the Antilles arc. One exception is the massive earthquake that struck Iberia and Morocco on November 1, 1755, which was felt throughout a large part of Europe and produced a powerful tsunami that crossed the Atlantic Ocean. This earthquake occurred along a passive margin, in a region where plate boundaries are not unequivocally defined by bathymetry and where the existence of an active subduction zone is not clearly supported by seismological evidence. Thus, despite the large size of the fault that was responsible for this extreme event (several hundred kilometres), many hypotheses have been proposed by various authors regarding its location (Grandin et al., 2007b). However, a fault located below Gorringe Bank, with a rupture directed towards the SW, better reproduces the overall pattern of macroseismic observations than a fault aligned along the Marquês de Pombal–Pereira de Sousa Fault zone or a subduction-related thrust fault in the Gulf of Cádiz (Grandin et al., 2007b).

Observations from the mega (Mw 9.3) earthquake of December 2004 in Sumatra and the Mw 8.8 Maule (Chile) earthquake offer new insights concerning rupture and tsunami generation in great subduction earthquakes, which may be applicable to the study of the 1755 earthquake and tsunami. The earthquake of 1755 generated a tsunami with waves about 6 m high at Lisbon, 15 m high along the coast of the Algarve and 20 m high at Cadiz, Spain. The waves travelled on to Martinique, a distance of 6100 km, in 10 hours and there rose to a height of 4 m. For the Sumatra mega earthquake, the waves may have been 15 to 30 m high along the entire 100-km stretch of coast from Kreung Sabe to the northwestern part of the island (USGS).

The great Lisbon earthquake of 1 November 1755 (Mw~9.0) probably released as much or more energy as any seismic event in recorded history prior to December 2004. The Azores–Gilbratar fracture zone (AGFZ) marks the boundary of active tectonic interaction between the African and Eurasian plates. This is an active seismic region where large earthquakes occur frequently, and some of them, near the eastern segment of the AGFZ, are capable of generating tsunamis. The tectonic interactions of the eastern segment of the AGFZ involve a thrusting component in the NW direction along a NE-trending strike plane (Buforn et al., 2004; Grandin et al., 2007b; Bezzeghoud et al., 2008).

An earthquake rupture can spread across a fault in a variety of ways. However, the fundamental characteristics of the rupture propagation are based mainly on the rupture directivity (unilateral or bilateral). Based on a study of large and moderate shallow earthquakes (Mw≥7.0), McGuire et al. (2002)

showed that the majority of large earthquakes have a predominantly unilateral rupture. This observation quantifies what appears to be a general property of large earthquake dynamics. The unilateral character determined for the Mw 9.3 and 8.7 Sumatra earthquakes (Bezzeghoud et al., 2005), for the Mw 8.5 1755 Lisbon earthquake (Grandin et al., 2007b) and for the recent Mw 8.8 Maule (Chile) earthquake of 27 February 2008 (Raul Madariaga, personal communication) supports the observation made by McGuire et al. (2002) that ruptures are predominantly unilateral. Furthermore, numerous studies of extended-source earthquake models examining the spatial and temporal evolution of earthquake slip on fault planes have shown that slips are spatially variable, and 48% of events nucleate in regions of low slip (Mai et al., 2005). This behaviour was also observed for the 2004 and 2005 Sumatra earthquakes (Bezzeghoud et al., 2005).

The results of this study clearly show that earthquake directivity is the focusing of wave energy along the fault in the direction of rupture. This means that, exclusive of local site conditions such as soft soils, the stronger ground motions and damage (if the earthquake is large enough) will be distributed in an elongated pattern centred along the axis of the fault. The distance to the fault is not the only consideration for ground motion amplitude: the structure and the rupture directivity are also important. When a fault ruptures unilaterally (with the epicentre at or near one end of the fault break), the radiated waves are stronger in one direction along the fault. The characteristics of ground shaking close to a fault rupture generally depend on whether the rupture moves towards the building site or away from it. These two cases are often referred to as forward and backward directivity conditions, respectively. In the forward directivity case, the ground motion tends to have a pulse that is often very apparent in the velocity time histories. The average period of such pulses, which appears to depend on magnitude, may vary from about 1.5 s for a Mw 6.5 event to more than 3 s for a Mw 7.5 earthquake (Somerville, 2003). These moderate-to-long period pulses have been recognised to generate, on average, systematically larger responses in moderate-to-long period structures, as compared to the responses induced by more typical "rumbling" ground motions of similar severity. The latter ground motions are more common both at sites that are located close to the causative fault but in the backward directivity region and at sites that are far away from the rupture.

We conclude that it is very important, particularly in seismic risk studies, to take into account the rupture directivity and 3-D velocity model. This provides encouraging results for the computation of low-frequency seismograms in the region and can be used to study larger earthquakes, for which the radiated wave field has a predominant low-frequency spectrum

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Effect of urban landscapes on the atmosphere

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Abstract
The interaction of urban areas with the weather has been studied for many years. However it is often not appreciated that changes to weather brought about by this interaction may approach the magnitude of those changes likely to be induced locally by climate change and, therefore, significantly influence human wellbeing in cities. Urban areas have been documented to affect air quality, temperature distributions, wind patterns and the development of clouds and precipitation in and around cities. The human activities and the modification of the nature and morphology of the land surface perturb the land surface- atmosphere balances of energy, mass and momentum, leading to the modification of the atmospheric boundary layer and affecting the weather processes.

It is important that we understand the details of how the fabric of our cities influences the local climate in a way which can lead to practical guidelines. This will enable city planners to optimise the built environment to provide the best local atmospheric environment possible. In this paper we discuss a model which provides a means of studying how changes in buildings and their distribution will influence the urban environment.

1. Introduction

It has been known for many years that urban areas impact local weather through modification of the distribution of temperature (the urban heat island) , wind (local circulations) and precipitation (see for example the review of Collier, 2006). In recent years high resolution Numerical Weather Prediction (NWP) models have been developed on scales appropriate to local circulations in cities. Likewise, dispersion models have enabled the distribution and movement of pollutants generated in and around urban areas to be studied in detail.

It is recognised that urban planning must take account of these features of atmospheric-land interactions. Gal and Unger (2009) stressed the importance to urban planning of the identification of ventilation pathways for ensuring the wellbeing of the city population. Such pathways were investigated in Szeged, Hungary using a three dimensional data set of the urban morphology. Roughness parameters were derived using previously published equations relating building height, frontal and plan area and drag coefficient of isolated obstacles.

In this paper a similar, but somewhat different, approach to derive roughness parameters is adopted using combined data sets for a part of Greater Manchester, UK, derived from aerial photographs, downward pointing airborne laser measurements, maps and field surveys. The database for the roughness parameters developed here was used to investigate the surface sensible heat flux distribution over Greater Manchester urban area (Carraça and Collier, 2007).

The modelling of the urban atmospheric boundary layer in both process studies and operational meteorological models requires specific representations of the urban morphology. The database for the roughness parameters developed here can be used for many urban studies in the future.

1. The model

A simple model of the surface sensible heat flux was used to explore the impact of urban canopy heterogeneity. The numerical scheme, based upon several published systems, principally Voogt and Grimmond (2000) and Grimmond and Oke (1999), was developed to derive fields of surface sensible heat flux for a range of wind and temperature over an urban area. The model estimates the sensible heat flux at a level z_S, above the surface within the atmospheric inertial sub layer, where the Monin-Obukhov similarity theory (MOST) is valid. The surface sensible heat flux, Q_H, was calculated from the bulk equation

$$Q_H = \varrho \; c_p \frac{(T_R - T_a)}{r_H} \tag{1}$$

where ϱ is the air density, c_p the specific heat capacity for the air; r_H is the resistance to heat transfer between the surface (at $T=T_R$) and a atmospheric level z_S (at $T=T_a$).

The resistance in equation (1) is defined in terms of the von Karman's constant (k), the wind speed (u) at a level z_S in the surface layer, the roughness parameters zero-plan displacement length (z_D) and roughness lengths for momentum and heat (z_{0M} and z_{0H}, respectively), and the stability correction functions for momentum and heat, $\Psi_M(\zeta)$ and $\Psi_H(\zeta)$ (see M. G. D. Carraça and C. G. Collier, 2007).

In this formulation the resistance to heat transfer is given by

$$r_H = \frac{1}{k\,u_*}\left[\ln\left(\frac{z_s - z_D}{z_{0M}}\right) - \Psi_H\right] + \frac{1}{k\,u_*}\ln\left(\frac{z_{0M}}{z_{0H}}\right) \qquad (2)$$

Therefore, some meteorological variables are needed to model the surface sensible heat flux: the satellite radiometric surface temperature, T_R, the air temperature, T_a, and the wind velocity, u. T_a and u are typically measured several meters above the surface, at the measurement height, z_S, in the inertial sub-layer.

In addition to the meteorological variables the model requires some input roughness parameters: z_D, z_{0M}, and z_{0H}. The zero-plane displacement length, z_D, and roughness length for momentum, z_{0M}, were estimated as a function of building height, z_H, and frontal area index, λ_F , using Raupach's (1994, 1995) method, which is one of the morphometric approaches recommended by Grimmond and Oke (1999) for urban areas. The roughness length for heat, z_{0H}, is determined as a function of z_{0M} and roughness Reynold's number using the formulation proposed by Brutsaert (1982) for bluff-rough surfaces.

Therefore, estimates of morphologic parameters, mean surface elements height ($\overline{z_H}$, or simply z_H) and frontal area index (λ_F) must be considered in order to derive the surface roughness parameters.

Fig. 1 illustrates surface dimensions used in morphometric analyses. Based in these dimensions, some nondimensional ratios are defined to characterise the morphometry: plan area index, λ_P, frontal area index, λ_F, for example.

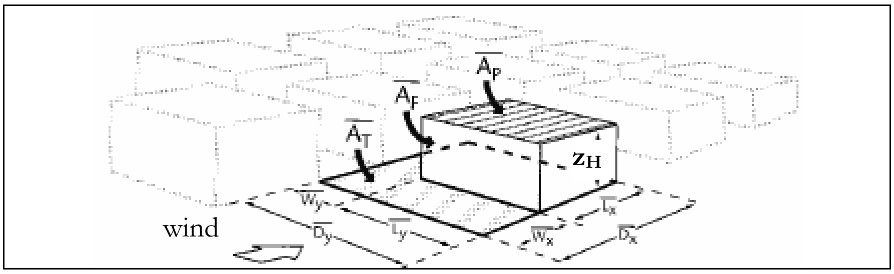

Fig. 1. Definition of surface dimensions used in morphometric analysis. The element portrayed has the characteristic mean dimensions, spacing, and total lot area (A_T) of the urban array (after Grimmond and Oke, 1999).

The surface elements height (z_H) and the frontal area index (λ_F) were derived by the author from a surface morphologic database for Greater Manchester that has being developed from analysis of digitised georeferenced lidar data of the surface elements provided by the Environment Agency (EA) and the Cities Revealed User Group (CR), aerial photographs, maps and field surveys.

In our study the mean buildings height, $\overline{z_H}$, and the plan area index, λ_F, for an urban homogeneous array, are direct results from the CR data statistics performed using GIS software. The fraction of built up area, i. e., the quotient between the total horizontal plan built area over an urban array and the total lot area of the urban array, is taken as an estimate of the roughness parameter λ_P - plan area index.

The frontal area index, λ_F, is calculated from the CR digitised data in the following way. Consider the equivalences,

$$\lambda_P = \frac{\overline{A_P}}{\overline{A_T}} = \frac{A_P}{A_T} \tag{3}$$

and

$$\lambda_F = \frac{\overline{A_F}}{\overline{A_T}} = \frac{A_F}{A_T}, \tag{4}$$

where $\overline{z_H}$ is the mean buildings height, A_T the total lot area of the urban array, $\overline{A_T}$ the mean lot area, A_P the total plan built area over the urban array, $\overline{A_P}$ the mean plan area of the buildings, λ_P the plan area index, A_F the total frontal area of the buildings over the urban array, $\overline{A_F}$ the mean frontal area of the buildings and λ_F is the frontal area index.

Therefore, taking equations (3) and (4), the frontal area index can be estimated from the expression

$$\lambda_F = \frac{\overline{A_F}}{\overline{A_P}} \frac{A_P}{A_T} \tag{5}$$

In this equation $\overline{A_P}$, A_P, and A_T are direct results from the CR data statistics performed using GIS software. The mean frontal area $\overline{A_F}$ is calculated using the approximation that buildings are rectangular parallelepipeds with a squared base, thus

$$\overline{A_F} = \overline{z_H}\sqrt{\overline{A_P}} \tag{11}$$

Note that this calculation involves two important approximations. The buildings are approximated to rectangular parallelepiped and the frontal area index (λ_F) of the elements, as "seen" by the oncoming wind, is considered independent of the wind direction.

3. The surface morphologic database, and model estimates of the roughness parameters z_D, and z_{0M}

A classification of 15 land-use categories has been established for Greater Manchester and reference morphologic parameters, such as surface elements height (z_H), plan area index (λ_P) and frontal area index (λ_F), were attributed to each category.

For built areas (nine categories: *City Centre, City Centre Periphery, New Centre, Residential High, Residential, Commercial/ Residential, Commercial/ Industrial, Railway Station, University*) the attributes z_H, λ_P and λ_F were derived from analysis of surface form according to the Grimmond and Oke (1999) methodology discussed in section 2. However, for natural surfaces these morphologic parameters are estimated using reference tables shown in the literature (for example, Grimmond and Oke, 1999, Wieringa, 1993, Brutsaert, 1982, Grimmond et al., 1998). Although the definitions illustrated in fig.1 are also general and apply to permeable-rough surfaces covered with vegetation, in this case it is not easy from geometric analyse to assign values to z_H and λ_F.

Comparisons with earlier published work (e.g., Ellefsen, 1990/91, for U.S.A. cities) revealed similarities to previous representations, but also some differences. These differences are probably due to the nature of the urban areas in the United Kingdom, for example the distribution and type of buildings and green spaces.

The morphologic parameters, (z_H) and frontal area index (λ_F), were estimated and mapped over a rectangular grid of 1 x 1 km^2 resolution, for the Greater Manchester study domain (Fig. 2a and 2b, respectively). The estimates of the height of the buildings, z_H, and of the frontal area index, λ_F, for each cell were weighted averages of the values attributed for each urban category, considering the percentage of each category present in the grid cell. The resulting spatial distributions of surface element heights (z_H) and frontal area index (λ_F) reveal the difference between the rural areas to the east and south compared to the urban areas. The area of high rise buildings is clearly evident.

The model estimates of the zero-plane displacement length, z_D, and roughness length for momentum, z_{0M}, derived from the values of z_H and λ_F, were also estimated for the study domain (Fig. 3a and 3b, respectively). These estimates of the roughness parameters z_D ,and z_{0M} are comparable to previously published values. In addition, taking the roughness values obtained for the entire study domain it was found that $z_D=5z_{0M}$, $z_D=0.4z_H$, $z_{0M}= 0.08z_H$. These results are in agreement with published literature (see, for example, Grimmond and Oke, 1999).

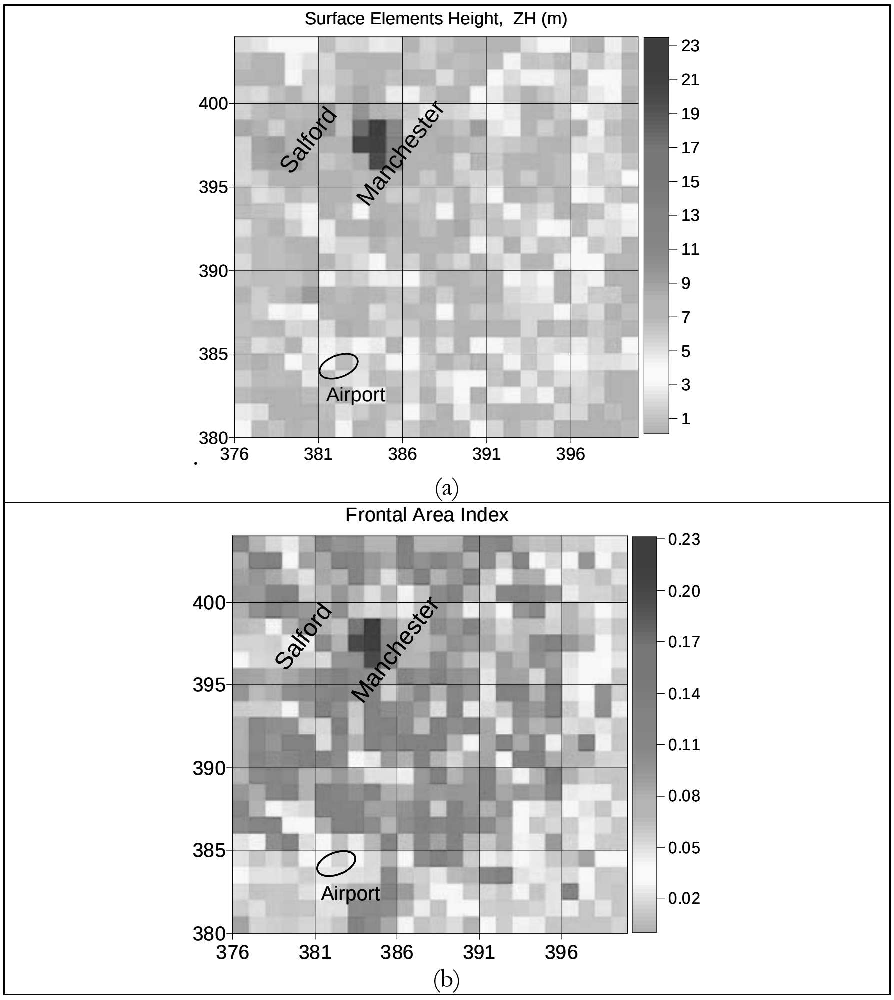

Fig. 2. Morphologic data for the Greater Manchester study domain. The total study area is 24 x 24 km^2 and the area of each grid square 1x1 km^2. The coordinates X and Y are the U.K. National Coordinates. (a) Mean building height, z_H, for each cell in the study domain. The legend on the right-hand side refers to the values of z_H expressed in m. (b) Mean frontal area index, λ_F, for the same study area. The legend on the right-hand side refers to the values of λ_F.

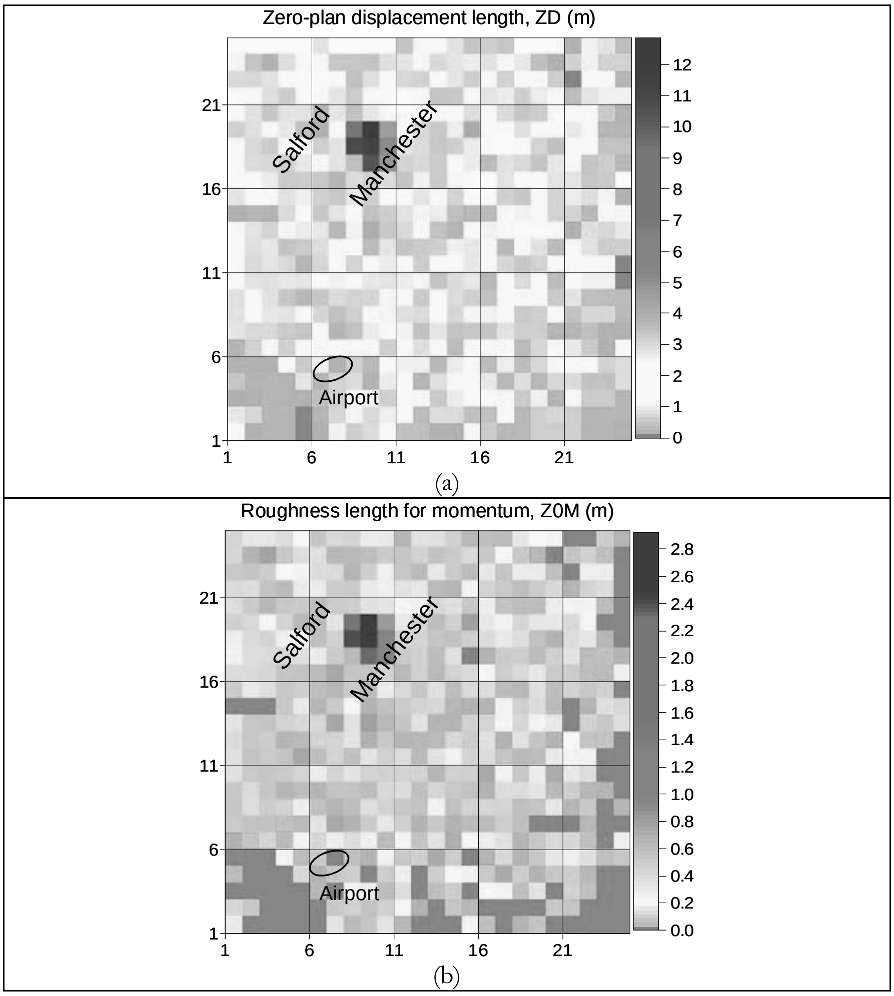

Fig. 3. Model estimates of roughness parameters for the Greater Manchester study domain. The total study area is 24 x 24 km^2 and the area of each grid square 1 km^2. (a) Zero-plan displacement height, z_D , for each domain cell. The legend on the right-hand side refers to the values of z_D expressed in m. (b) Roughness height for momentum, z_{0M}, for each domain cell. The legend on the right-hand side refers to the values of z_{0M} expressed in m.

Notice that, the surface roughness parameters characteristic of the Greater Manchester study area were considered to be the same for all study situations. In fact, for the construction of the present surface morphology database, it has been assumed that the roughness surface elements such as buildings are rigid parallelepipeds and that the roughness effects do not vary with the wind direction. A more realistic approach must take into consideration the orientation and shape of the buildings. Further improvements on the data base should involve a dynamic approach, where roughness parameters such as the frontal area index may assume different values depending on the wind direction.

4. Application of the model

The model of surface sensible heat flux was formulated for Greater Manchester, over a study area of 24x24 km^2 and on a grid of 1x1 km^2 resolution. The bulk equations were used and the model parameters were specified as averages over each grid square. The model was applied to the study area, at different seasons of the year.

The surface temperature, T_R, data used to model of surface sensible heat flux were derived from MODIS Terra/Aqua (1 km, 5 min) satellite imagery over Greater Manchester at around midday. The model input values of air temperature, T_a, and wind speed, u, were the hourly values observed at the Manchester airport at the same time as the MODIS satellite imagery. These data refer to a particular hour of the day (around midday) depending on the time of the satellite overpass available for each specific day.

The spatial distribution of surface temperatures, T_R, at 1x1 km^2 resolution over Greater Manchester study area (see the example of Fig. 4) showed that, as expected, higher values of surface temperature are found over urbanised zones than over rural zones. The surface temperature is significantly lower at the Airport, situated in a rural area, than at the urban zones of Salford and Manchester. The values of the surface temperature in these urban observational sites are nearly the maximum observed over the entire study domain.

Notice that, although derived from different data sources, the patterns of the surface temperature T_R and roughness expressed by the parameters z_H, λ_F, z_D, and z_{0M} are similar (see Fig. 2, 3 and 4); they reveal the presence of the city and the variations of the building density and urban morphology.

The model estimates of sensible heat flux, Q_H, around midday, have been mapped for the 24 x 24km^2 Greater Manchester study area at 1 x 1km^2 resolution for the different study days (see example of Fig.5). As expected higher values of sensible heat flux were found over urbanised zones than over rural zones. The pattern of the modelled spatial distribution of Q_H seems to be similar for the different study days.

The spatial distribution of the model estimates of sensible heat flux Q_H follows the same pattern as the urban fraction, T_R, z_H, and λ_F, but for λ_F (λ_F <0.29) the Q_H decreases as this parameter increases to the threshold of λ_F , thereafter Q_H is expected to increase (see Fig. 2, 3, 4 and 5).

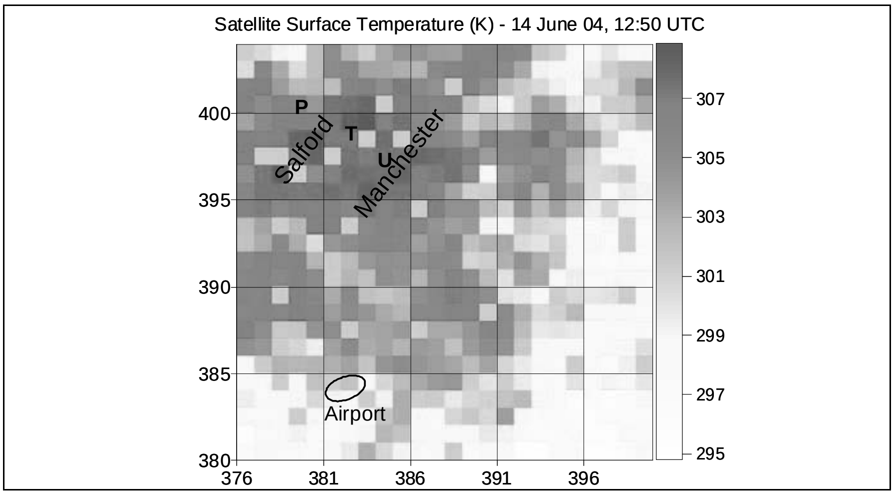

Fig. 4. Surface temperature, T_R, derived from satellite imagery over Greater Manchester on the clear sky day of 14th June 2004, around 13 UTC. The total study area is 24 x 24 km^2 and the area of each grid square is 1 km^2. The coordinates X and Y are the U.K. National Coordinates. The legend on the right-hand side of each figure refers to the values of the temperature expressed in K. The grey areas are either missing data due to the mapping technique or areas of clouds.

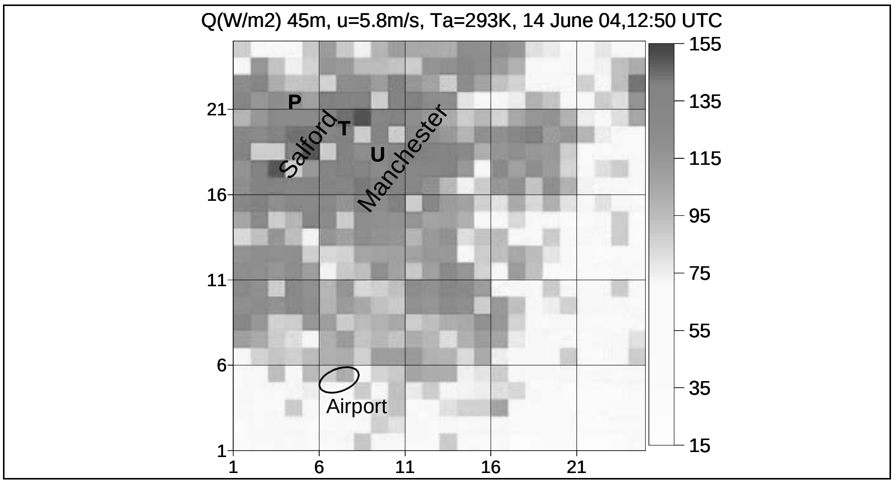

Fig. 5. Model estimates of surface sensible heat flux, Q_H, around 13 UTC, on the clear sky day of 14th, for the Greater Manchester study area (24x24 km^2) shown in Fig. 2, 3 and 4. The legend on the right-hand side of each figure refers to the values of Q_H expressed in W/m^2. The grey areas are either missing data due to the mapping technique or areas of clouds.

Tests to evaluate the impact of the roughness differences on the spatial distribution of sensible heat flux, Q_H, for Greater Manchester reveal that higher values of the surface sensible heat flux, Q_H, occur in the urban sectors with relatively lower surface roughness, expressed by λ_F, and vice-versa. This result is in agreement with the basic model equations (Raupach (1994, 1995)). This is due to the fact that the λ_F values over all the study area are less than the threshold value of 0.29. While $\lambda_F < 0.29$, z_{0H} and Q_H decrease as λ_F increases. However, there is a different behaviour of the roughness parameter z_{0M} for values of $\lambda_F > 0.29$. The physical meaning of this threshold relates to "over sheltering" (Raupach, 1994).

6. Final remarks

Urbanisation and regeneration in cities will influence the distribution of surface heating leading to changes in the urban heat island, and if conditions are appropriate increases in rainfall in the suburbs and rural areas downstream of the urban area. Such changes will require modifications to building design and city planning in order to mitigate the occasional detrimental impacts on human health through adverse weather conditions and poor air quality.

Further developments in urban centres with the eventual construction of high-rise buildings, either on open spaces or by replacement of old buildings, are expected to modify significantly the city microclimate, and increase the impact of the city on regional weather, through the enhancement of convective developments.

These changes will arise through significant alteration of the surface balances of energy, momentum and humidity. For example, the surface sensible heat flux, Q_H, may increase due to the enhancement of the vertical temperature gradient and turbulence.

The increase in the total area of the buildings surface means an increase in the area of the materials used (absorbing more radiation) and the consequent enhancement of the surface and air temperatures, with an increase on the vertical temperature gradient and on the atmospheric turbulence. Also the change of the building materials used in the urban area can contribute to this effects.

On the other hand, the enhancement of the volume of buildings leads not only to increased buildings height z_H, but also to increases in the frontal area index λ_F and plan area index λ_P. This will affect the airflow, through increased uplift and turbulence, and also intensifies the surface heat fluxes. The frontal area index may increase and eventually reach values in excess of the threshold of 0.29, leading to increases in Q_H.

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Analysis of the atmospheric electric field of Lisbon in the period 1955-91

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Abstract
Besides long period influences (e.g. cosmic radiation variation) the Earth's fair-weather electric field at ground level is known to be also influenced by the local meteorology, namely cloudiness, relative humidity, intensity and direction of the wind beyond other minor contributions. In this work we analyze, daily and annual variations of the vertical component of the atmospheric electric field in fair-weather conditions at the ground level. Data of the electric field strength recorded at the Portela meteorological station (Lisbon) (38º47'N, 9º08'W) in the period 1955-1991. We found that for north-eastern winds a weak correlation exists between relative humidity and fair weather atmospheric electric field for lag times of 2 e 3 hours. The correlation of the anomaly of the fair weather electric field with wind intensity is strong for wind directions north and north-east and for the 3-22 UTC and 4-15 UTC, respectively. We also found that correlation of cloud cover with fair weather electric field anomalies is strong for *Cumulus*. It is also presented a curve of the mean hourly values the fair-weather atmospheric electric field in Évora in the period 2005-2009.

1. Introduction

Many studies indicate mutual influences between meteorology and the atmospheric electric field. In general, data of atmospheric electric field are not easily related to a specific factor, due to the diversity of influences that have to be considered (Harrison, 2002). However, fair-weather measurements of the electric field may be related to some boundary layer phenomenology, and in some cases be used as predictors.

Influences from local meteorology on the atmospheric electric field have also been studied by many authors (e.g. Kamra *et al.*, 1997; Nagaraja *et al.*, 2003, Harrison *et al.*, 2010). Recent work by Serrano *et al.* (2006) indicates that cosmic radiation has affected the atmospheric electric field of the region of Lisbon in the period 1955-91. These influences are of long period, and add to influences from the local meteorology like humidity, wind intensity and wind direction and others (e.g. clouds).

In fair-weather conditions, the atmospheric electric field *E*, drives an ohmic current density,

$$J = \sigma E \qquad (1)$$

where σ is the electric conductivity of the air (see for example McGorman and Rust, 1998). As the fair-weather current density is nearly constant, the field strength varies inversely with the electric conductivity of the air, which depends on the concentration and mobility of the atmospheric ions. Actually, the electric conductivity is related to ion concentration *n,* electric charge *q*, and mobility μ, through:

$$\sigma = \eta_+ q_+ \mu_+ + \eta_- q_- \mu_- \qquad (2)$$

where the subscripts + and – refer to positive and negative charges, respectively.

From Eqs. (1) and (2) we observe that the product of ion density to ion mobility practically determines the fair-weather electric field strength.

Ion density depends upon a variety of factors. Solar radiation, artificial radioactivity and cosmic radiation definitely are major ion sources in the atmosphere. Solar radiation generates ions during daytime especially in the electrosphere, i.e. the outermost layer of the atmosphere. Artificial radioactivity, which comes out mainly from nuclear blasts in the atmosphere during the late fifties, generates ions in the boundary layer, namely up to 1 km height. Cosmic radiation acts directly upon the electric field over all the atmosphere levels (see for example Harrison and Carslaw, 2003), while mediating water vapour nucleation on aerosols in the boundary layer. On the other hand, wind intensity affects convection currents, J_C. Therefore, the correction of equation (1) for the case when convection currents are significant reads:

$$J = \sigma E + J_C \qquad (3)$$

Ion mobility is lowered through water vapor nucleation on ions, followed by hygroscopic growth and through ion attachment to coarse aerosol particles, namely those that result from volcanic emissions, combustion and dust re-suspension.

Ion mobility may also be lowered through attachment to solid particles, namely those that result from volcanic eruptions that are released at large amounts into the atmosphere. These eruptions also enhance the SO_2 aerosol concentration in the atmosphere, therefore contributing to CN (nuclei condensation) formation. The aerosol optical thickness of the atmosphere is an indirect measure of the concentration of these aerosols. Stothers (1996) noticed that, in the period 1881-92, about 80% of SO_2 stratospheric aerosols were originated by volcanic eruptions.

Due to the fact that the air electric conductivity is proportional to the product of ion density and ion mobility (see Eq. (2)) one should expect that cosmic radiation intensity, artificial radioactivity and aerosol optical thickness of the atmosphere are somehow related to fair-weather electric field intensity (see Eq. (1)). In this work we investigated the extent in which fair-weather electric field anomaly is correlated to these parameters and investigate if wind intensity and relative humidity associated to wind direction (for quadrants N, NE, E, SE, S, SW, W and NW) is associated with atmospheric electric field strength in Lisbon in fair weather situations, so as to evaluate the respective significance in the period of 1970-91. We also have also studied if cloudiness correlated with the atmospheric electric field in the same period.

The component of the atmospheric electric field due to global (planetary) influences was separated from that of local influences by calculating the differences between the actual hourly values and the corresponding values averaged over a twenty years period.

2. Fair-weather electric field in Lisbon in the period 1955-91

Hourly values of the atmospheric electric field intensity at ground level recorded at the meteorological station of Lisbon-Portela (38º47' N, 9º08' W) were used to draw the curve of the annual averaged values of the fair-weather electric field in Lisbon in the period 1955-91, which is shown in Fig.1. All the values were recorded with a Benndorff electrograph with a probe at 1 meter height. The data series was interrupted in 1975-1977 at what time the electrometer was switched off for maintenance reasons. The records restarted in March 1977. The same calibration procedure was used throughout all the operation periods. According to the international standards (Voeikov, 1965) fair weather days were selected as those with cloudiness less than 0.2, wind speed less than 20 km h^{-1} and with the absence either of fog or precipitation.

As the main feature of the curve represented in Fig. 1 we see that the electric field strength shows a marked decline from 1955 through 1967. This tendency was observed in almost all European stations as was pointed out by several authors (e.g. Hamilton, 1967; Pierce, 1972; Stewart, 1986; Harrison, 2002, Harrison and Carslaw, 2003). Pierce (1972) pointed out that proportionality existed between electric field anomalies and frequency and magnitude of nuclear blasts in the atmosphere during this period. These tests ended by the end of 1962 and the electric field has gradually recovered to normal values in the next five years. Air ionization increased in this period due to the radioactive elements released to the atmosphere; therefore air conductivity also increased leading to the low values of the electric field strength recorded in this period. Increase in artificial radioactivity levels was also observed in Portugal (Fig. 2). Lopes *et al.* (1975) measured the concentration of the ^{14}C radioactive isotope in the period 1950-1974, in Portuguese wines from the Douro region, and observed that the increase in concentration in the period 1954-1963 followed closely the frequency and magnitude of nuclear tests. From 1963 on, artificial radioactivity levels dropped down to normal values and therefore other factors should be considered to explain the fluctuations in the annual values of the electric field strength. Among these factors, cosmic radiation and volcanic aerosols certainly played a major role. We observe from Fig. 1 and Fig. 3 that, in general, the electric field varied inversely with cosmic radiation flux as should be expected from the relation between cosmic radiation and atmospheric ionization level. In addition to short period fluctuations we see that cosmic radiation also displays long period fluctuations that might be responsible for a planetary reduction of 15% in the electric field strength during the twentieth century (Kirkby and Harrison, 2003).

The global contribution of volcanic aerosols to the columnar resistance in the upper atmosphere, whose concentration may be inferred from measurements of aerosol optical thickness, may have been significant in the years 1963-1965 the period in which the Agung eruption occurred, and may also explain the abrupt rise observed in the electric field in 1983 which corresponds to the big eruption of the volcano El Chichón (see Figs. 1 and 3 for both cases).

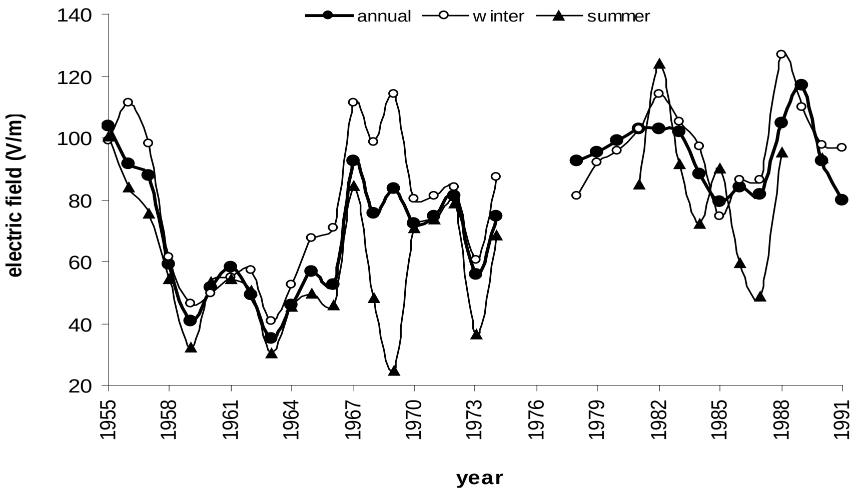


Fig. 1. Annual averages of fair weather electric field strength in Lisbon in the period 1955-91.

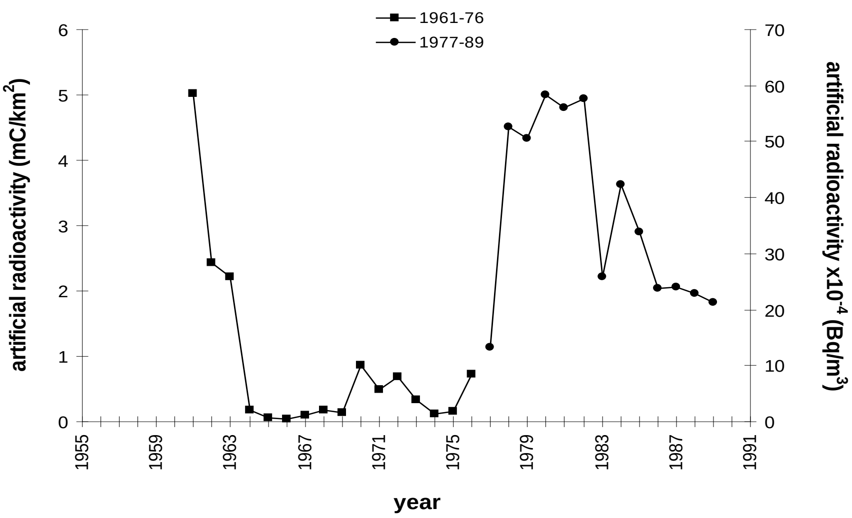


Fig. 2. Annual averages of artificial radioactivity intensity in Lisbon, in the periods 1967-76 and 1977-91.

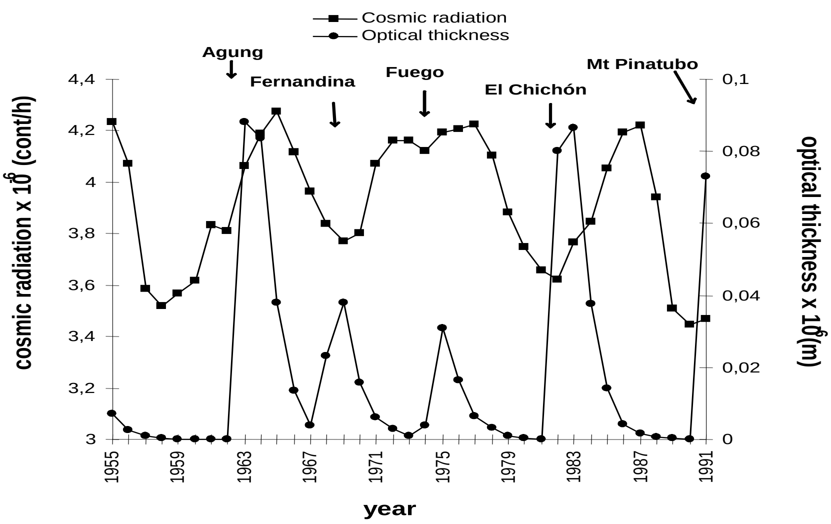


Fig. 3. Cosmic radiation intensity and aerosol optical thickness between 1955 and 1991.

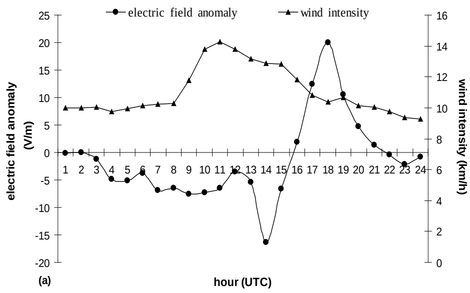
2. Local influences upon the atmospheric electric field

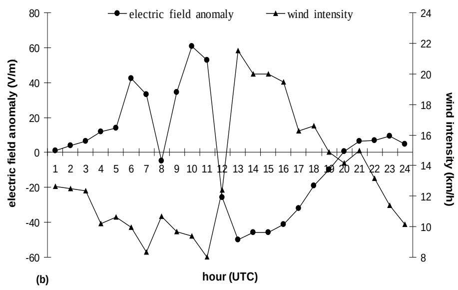
2.1. Intensity and direction of the wind

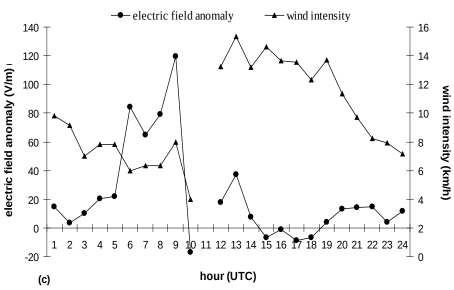
With the purpose of searching for correlations of the intensity and direction of the wind in the atmospheric electric field anomaly, in the fair-weather conditions and zero cloudiness, the series representing the period 1970-91 (Figs. 4 (a)-(d)) have been analyzed. The electric field anomaly is defined as $\left((E-\bar{E})/\bar{E}\right)$ where E stands for the annual mean of the fair-weather electric field and $\bar{E}$ is the average value of the annual means in the period under consideration. From Figs 4 (a)-(d) is verified that the atmospheric electric field varies with direction of the wind. The atmospheric electric field decreases with the intensity of the wind ("mirror effect"). This increase of wind intensity leads to increase in the vertical current J_c and therefore to decrease of the atmospheric electric field.

In figure 4 we can observe that from the 19 UTC on, the anomaly of the atmospheric electric field reduces significantly therefore suggesting that the wind intensity is a permanent influence on the electric field. It is also observed that in nighttimes the convection currents are less intense.

While western winds carry marine ions that increase the electric conductivity and the ohmic current, therefore reducing the atmospheric electric field, northern, north-western and north-eastern winds carry continental aerosols (heavy particles) and this might be the cause of the increase in the electric field.







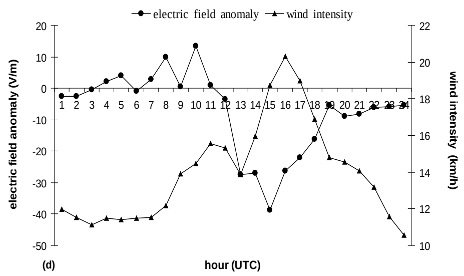


Fig. 4. Hourly averages of fair weather electric field and wind intensity, for four wind direction: a)north-east (NE); b) north-west (NW); c) west (W); d) north (N), in Lisbon in the period 1970 - 91.

The analysis of the correlation of the anomalies of the electric field atmospheric with the direction of the wind showed that the correlation is not always strong. As a general criterion, statistical significance was considered whenever the p-value stayed below 0.05. The correlation of the anomaly of the fair weather electric field with wind intensity is strong for the wind directions north, northeast and east for hourly values between 3-22 UTC, 4-15 UTC and 7-17 UTC, respectively. For south-east and south-west winds the correlation is practically inexistent, while for the north-west, west and south winds the correlation is very weak. Even so, the calculations indicate that the direction and the intensity of the wind do influence the value of the electric field. Nevertheless one has to assume that influences from other meteorological factors might exist. In general, it was found that wind intensity has the general effect of reducing the intensity of the electric field (inverse correlation).

3.2. Relative humidity

So as to search for a possible correlation with relative humidity (RH) in the diurnal cycle of the atmospheric electric field in fair-weather situations, the anomalies of the synoptic values of electric field and humidity were determined for the cases when values of the relative humidity were in between 75% and 98%, with relation to the average values of the field in situations of relative humidity inferior to 75%:

$$\Delta E = E_{0.75 \le RH \le 0.98} - \overline{E}_{RH<0.75} \qquad (3)$$

The correlation of the synoptic values of ΔE with the relative humidity for $0.75 \le RH \le 0.98$ and the atmospheric electric field anomaly in the intervals 1 –

9 UTC and 17-24 UTC was analyzed, for the period 1970-91, for the different quadrants of the direction of the wind, for lag time of 0, 1, 2 and 3 hours. These intervals have been chosen in view that relative humidity would possible be one of the factors explaining the behaviour of the electric field in this period. The value of 75% of relative humidity was fixed by considering that the hygroscopic growth of aerosols normally occurs at values of relative humidity higher than 75% (Pruppacher and Klett, 1997).

We found that the relative humidity falls within the considered interval during a short period in the morning and when wind is from N and W. It was found that for north eastern winds the correlation is significant for lag times of 2 and 3 hours. However, the correlation of the relative humidity on the anomaly of the atmospheric electric field of fair weather is not significant for the other wind directions, in which the effect of the relative humidity might be outshined by the convection currents.

In fact, one would expect to observe increase in the atmospheric electric field with relative humidity (namely for high values of the relative humidity) which provoke reduction of ion mobility (Wilding and Harrison, 2005), resulting from water vapour condensation and consequent hygroscopic growth. However, the influence of the relative humidity on the strength of the atmospheric electric field in the station of Lisbon/Portela was found not to be significant and can be ignored. A similar conclusion is that of Retalis *et al.* (1991) in a study carried out for the region of Atenas, where a weak negative correlation was observed, for 3 hours lag time.

3.3. Cloudiness

For the study of the influence cloudiness (*Cumulus (Cu)* and *Stratocumulus (Sc)*) with the atmospheric electric field in fair-weather situations, the anomalies of the synoptic value of the atmospheric electric field relative to the average values of the field in situation of zero cloudiness were determined for the period 1970-91:

$$\Delta E = E_{Cu,Sc} - \overline{E}_{N=0} \tag{4}$$

The influence of clouds on atmospheric electric field may vary depending on the type, thickness and shape. However, the atmospheric electric field is sensitive to the presence of low clouds, especially cumuliform clouds where it occurs charge separation at greater extent.

We observed that correlation between anomaly of the atmospheric electric field and cloudiness exists and is strong for *Cumulus* while it is weak for *Stratocumulus*. In the case of the *Cumulus*, the correlation of the fair weather electric field anomalies with cloudiness, is strong between 3-8 UTC, but poor from 9 UTC on. This correlation may be due to the fact that electrons in the atmosphere increase in concentration as the sun rises and are absorbed at the cloud bottom, making them more negative, thus contributing to fair weather electric field reduction at the ground level.

4. Atmospheric electric field in Évora

The vertical component of atmospheric electric field in Évora was measured in the period 2005 to 2009 with a probe at 1 m height. This unit is installed in the Geophysics Centre of Évora (38°34'N, 7°54'W) and continuously records the vertical component of atmospheric electric field.

Mean hourly values of the vertical component of atmospheric electric field in this 5-year period are plotted in the curves of Fig.5. The fair weather data were selected according to the new criterion $0 < E < 300$ V/m that is adopted by some authors (Märcz and Harrison, 2003; Israelsson and Tammett, 2001) for the cases when not enough values of total cloud cover, cases of fog and mist, are available to meet the standards set by the International Commission on Atmospheric Electricity, which is the case of the Évora station.

The curves of the Figure 5 show a pattern of variation with a maximum close to 20 UTC. This maximum may be due the conjugated contributions of the planetary electric activity, because it is at this time that all the planetary influences of the electrical activity of storms in América, África, Ásia e Europa (MacGorman and Rust, 1998) are at its maximum, and of the local convection currents that are significantly reduction by the late afternoon. Fig. 5 also shows a minimum of atmospheric electric field around 5 UTC, which meets the minimum of planetary electric contributions.

Though a detailed climatic analysis is not yet possible due to the short data series it appears that the atmospheric electric field in Évora follows the global pattern with variations that might be due to local influences (aerosols, convection currents, and wind).

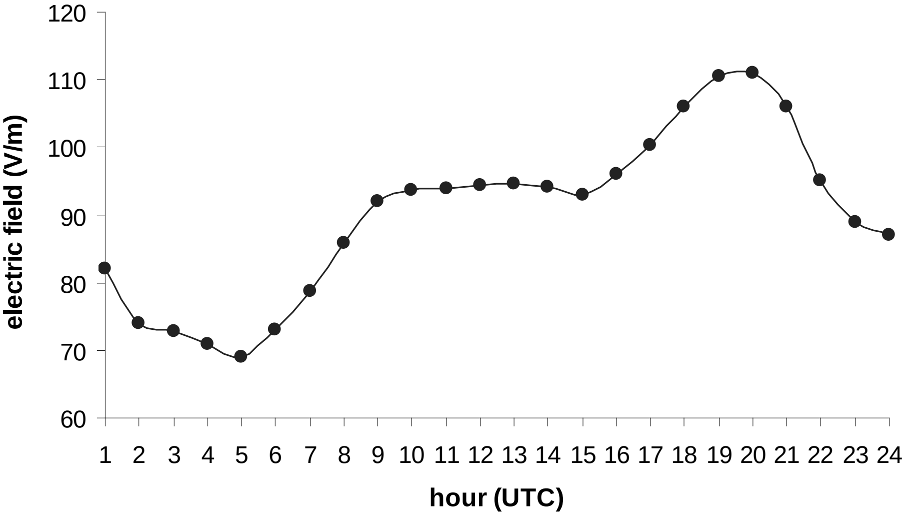


Fig. 5 – Hourly averaged values of fair weather electric field strength in Évora in the period 2005-2009.

4. Conclusions

The curve of the annual mean of the fair-weather atmospheric electric field strenght in Lisbon shows that a strong reduction occurred in the period 1957-67. This same tendency was observed by other authors that studied the behaviour of the fair-weather electric field recorded in the same period in some stations of the northern hemisphere, namely in the stations of Nagycenk (Hungary), Kew (England) and Eskdalemuir (Scotland). The reduction in the fair-weather electric field strength was endorsed to the increase in the artificial radioactivity concentration in the atmosphere due to nuclear tests realized in that period.

From the analysis of the correlations of hourly anomalies of the vertical component of the fair weather atmospheric electric field at ground level with local meteorological variables, we identified some correlations. The most significant are wind direction and intensity, cloudiness and cloud type. The influence of wind direction and intensity upon the atmospheric electric field is shown to be significant for some wind directions. In general, in fair-weather conditions increase in wind intensity leads to decrease in the atmospheric electric field. The fact that correlation with relative humidity is found to have no statistical significance suggests that the effect of humidity level might be masked by the stronger effect of boundary layer convection currents.

On the other hand, the correlation between the fair weather electric field anomalies with cloudiness is statistically significant only for *Cumulus*.

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Construction of a high quality database of solar irradiance data for Évora, Portugal.

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Abstract
The Geophysics Center of Évora performed measurements of solar irradiance at five stations in and around Évora, Portugal. However, as it is normal in such measurements, there are data problems that need to be looked up: data gaps, incorrect time, missing re-calibrations, outliers among others. This article deals with the detection of errors in the time series of the individual stations and subsequently how the data of the five stations can be combined to remove errors and to fill data gaps in order to construct a high quality data suitable for renewable energy and especially photovoltaic system applications in the region of Évora. The final irradiance data covers the time period between 2000 and 2009. Hence inter-annual variations can be investigated and taken into account for PV applications, namely in the sizing of the systems.

1. Introduction

The increase of energy efficiency and of the use of renewable energy sources are important measures to reduce greenhouse gas emissions and comply with the Kyoto Protocol (United Nations, 1998) to the United Nations Framework Convention on Climate Change (United Nation, 1992) and with other commitments of the European Union beyond 2012 (European Union, 2009b). Europe is particularly active as far as the promotion of renewable energy sources is concerned, and in April 2009 a new Directive on the promotion of the different renewable energy sources was published (European Union, 2009a). This Directive establishes new targets: a 20% share of energy from renewable sources by 2020 and a 10% share of renewable energy in the transport sector. Mandatory national targets for each Member State are set consistent with the global target of the global Community 20% target. For example for Portugal and Germany, the share of the renewable energy sources by 2020 should be 31% and 18%, respectively.

Solar photovoltaic systems contribute to attain Europe's 20% target and is a clear bet of the Member States – 80% of the world's installed photovoltaic power capacity is located in Europe (EurObserv'ER, 2009). On 2007, the installed capacity was 1833.1 MWp (EurObserv'ER, 2009) and this figure more than doubled on 2008, reaching 5074.1 MWp (EurObserv'ER, 2010).

The design of a photovoltaic system needs climatic data, namely temperature and irradiation, for the location of the renewable energy project that is being considered.

The analysis of the large volumes of climatic data from instruments has many different applications and the specifications of each application determine the characteristics of the databases used. This is the reason why the climatic databases should be tailored for the design of photovoltaic systems, or, more generally, for the design of any clean energy project. Adding to this, it was already reported that, among the several possible sources available, the choice of the solar radiation data might have a significant influence on the sizing of photovoltaic systems (e.g., Lorenzo and Narvarte, 2000; Mougueira, 2007). Having this in mind, this manuscript focuses the construction of high quality databases of irradiance for photovoltaic applications.

When sizing photovoltaic systems, the solar irradiance data should be accurate and ideally long-term time series at the hourly level are needed (Page, 2003). However, such data are relatively rare (Page, 2003). This paper has the objective of presenting the methodology for constructing a high quality long-term database of daily solar irradiation for the region Évora, Portugal. Since 2000, the Évora's Geophysics Centre has been measuring solar irradiance at several stations in the region. With these data, a ten year solar irradiation database was constructed which can be used in clean energy projects.

2. Data

Solar irradiance was measured at five different locations in the Évora region. The data were obtained with pyranometers that are a part of meteorological stations run by the Évora's Geophysics Centre. Fig. 1 shows the locations of these stations: Évora, E, (38.56783ºN, 7.91150ºW, 293 m asl), Mitra, M, (38.52542ºN, 8.01657ºW, 265 m asl), Pa, Pardiela (38.64994ºN, 7.70741ºW, 222 m asl), Portel, P, (38.30653ºN, 7.68944ºW, 274 m asl) and Reguengos, R, (38,47307ºN, 7,4687ºW, 263 m asl). As one can see the five stations are located within 50 km distance and the difference in altitude is smaller than 30 m. Not all stations reported measurements at all times. The measurements were taken between 2002-2010 at Évora, between 2000 and 2010 at Mitra, between 2000 and 2010 at Portel, between 2008 and 2010 at Pardiela, and between 2000 and 2008 at Reguengos.

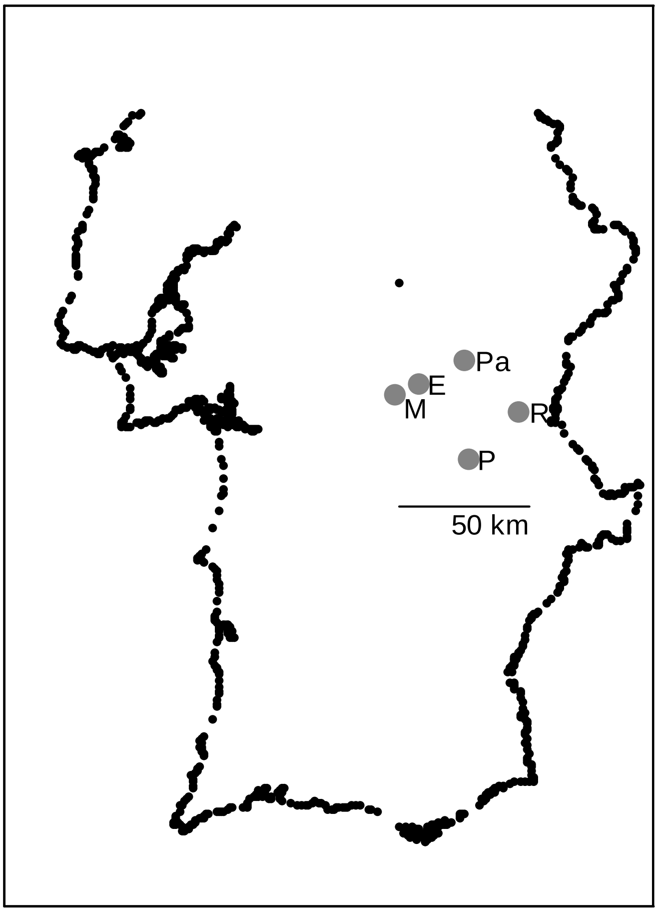

Fig. 1. Location of the five meteorological stations: E denotes Évora, M – Mitra, P – Portel, Pa – Pardiela, and R stands for Reguengos.

The pyranometers were mounted on meteorological stations. Fig. 2 shows an example for the site Mitra. It can be seen that the instruments were placed according to meteorological standards, i.e. no obstacles were shading the radiation devices.

The data used for this manuscript are the raw data, that is, the values represent data as they are stored by the data logger (10 min, hourly and daily values) and no data checking or supervision with subsequent data correction was applied prior to the analysis presented in this paper. Due to the data averaging by the data logger the given value at a certain time corresponds to measurements in the interval before the respective time. For example, the average value over 1 hour provided at 11:00 h corresponds to the measurements in the time interval between 10:00h and 11:00h. This information is important when the data are interpreted or compared with solar or astronomical data or times, e.g. sunrise and sunset.

Fig. 2. View of the meteorological station in Mitra.

3. Methodology

Before the database for the Évora region could be constructed, errors in the individual time series for each station have to be detected. After this, when possible, these errors should be corrected and, finally, the data of the five stations can be combined to obtain a high quality time series of irradiance data.

Daily solar irradiance values at one station can be compared with the irradiance values of the neighboring stations as the weather should be equal in a small region within ~50 km. This can be justified from the meteorological point of view as follows:

- for clear skies the similarity of meteorological parameters is obvious,
- for completely overcast skies again the similarity is obvious
- for partly cloudy skies it can be assumed that the same cloud at different times or different clouds having similar properties influence the actual weather at a certain station but the influence is similar for all stations on a daily basis. Furthermore, as all stations are located in a similar landscape, local effects will have almost no impact on cloudiness and consequently on the solar irradiance measured near the ground. From the astronomical point of view, i.e. taken into account the distance of the sun, uncertainties due to the different locations can be neglected.

The following sections describe the type of errors encountered, how to detect them and how subsequently these erroneous data were treated. Some examples will be given to illustrate the description.

3.1 Error detection

3.1.1 Special values used to mark bad data

As already said, the database of CGE contains raw data. However, some of these raw data are specially marked with either 9999 or -99999 or +99999. It is obvious in the context of meteorological data that such values do not correspond to valid measurements; instead these values denote errors. As the objective of this work is solely to construct a high quality database, the origin of these errors is not investigated.

3.1.2 Outliers

An outlier is defined in statistics as an observation that appears to deviate markedly from other members of the sample in which it occurs (Grubbs, 1969). An example is provided in Fig. 3 showing *obvious* outliers.

Outliers in this work are detected in three different ways:

1) Incorrect data can easily be detected if one has a second identical instrument measuring at the same time and at the same place. Over several years, two instruments were operated at the observational platform of CGE at Évora. To illustrate this, Fig. 4 shows the solar irradiance measured by these two instruments in 2006. From this figure, one can conclude that the

agreement is very good between January and October, but in November and December one device shows too high values.

2) Outlier can also be determined through a threshold. The solar irradiance at the top of the atmosphere was used to check daily averaged values measured by the pyranometer. In principal, this method could also be applied for higher time-resolved data but in case an outlier is detected a manual supervision is needed, since it is possible to have higher irradiance values at the ground than at the top-of-the-atmosphere when a cloud is located close to the sun but not obscuring the sun (for example see Suehrke and McCormick, 1989 or Tovar et al., 1998).

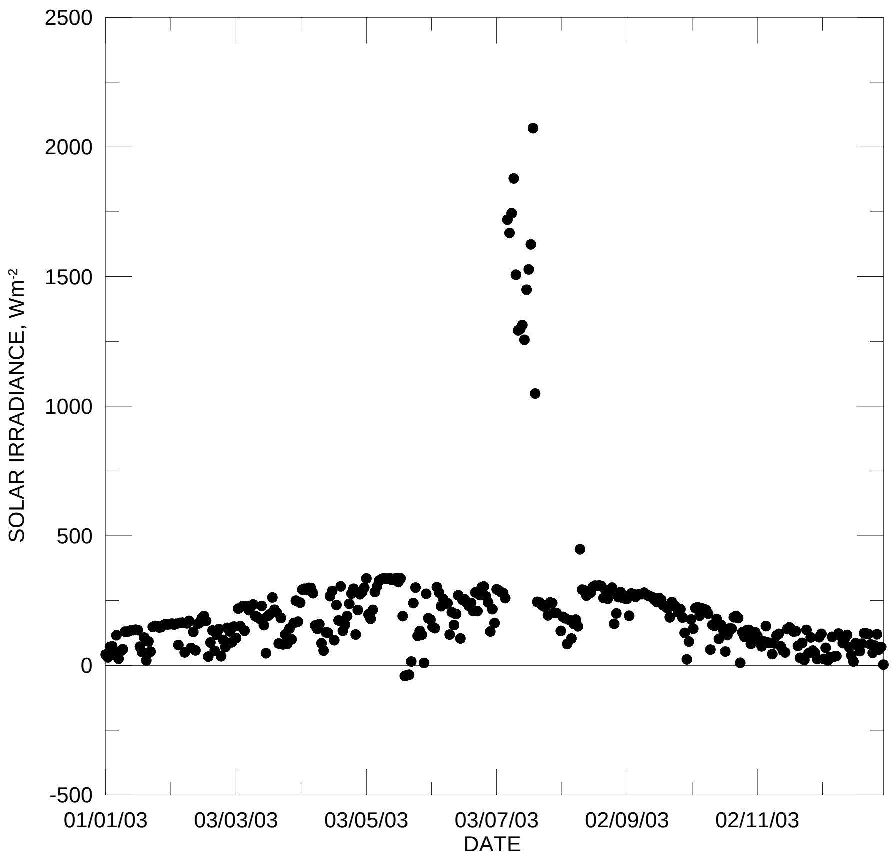

Fig. 3. Example for obvious outliers. Data are shown for the station Reguengos in 2003.

3) Outliers that could not be detected with methods (1) or (2) could still be detected if one compares the irradiance values at neighboring stations. As

pointed out above, for daily values, the irradiance of neighbouring should be similar. In this paper the following two criteria were applied:

a) The data point for an individual station should lie in the interval of the mean +/- 2 standard deviation of the other stations.

b) And the ratio standard deviation/mean should be below a certain threshold. The method (b) is needed to refine (a) as it possible that under clear sky condition the measurements are very similar and hence the standard deviation is very small. Then due to measurement uncertainties and the neglected minor effects (albedo, station height, etc.) it is possible that good data would be misclassified as outliers according to criteria (a).

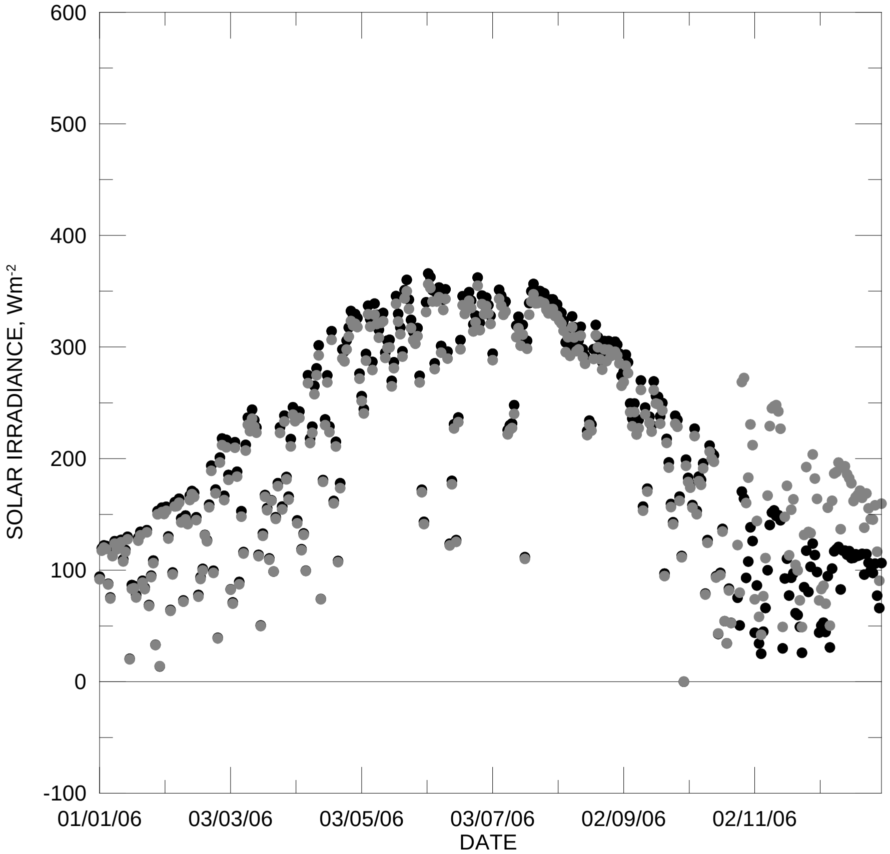

Fig. 4. Solar irradiance measured by two instruments at Évora in 2006. The agreement is very good between January and October, but in November and December one device shows too high values.

3.1.3 Data gaps

Data gaps exist for various reasons such as maintenance of the instrument, calibration of the device, lack of electrical power among others. There appearance in time series is obvious. They can be automatically detected through simply calculating the time difference between 2 subsequent data points. This difference has to be constant for all points. Fig. 5 shows a daily solar irradiance for a year with many gaps in order to illustrate the problem. The number of missing days differs from station to station. Table 1 shows the number of missing days between January 2000 and December 2009 for each station and each year. Note, as mentioned in section 2, that some stations were not providing measurements for all years.

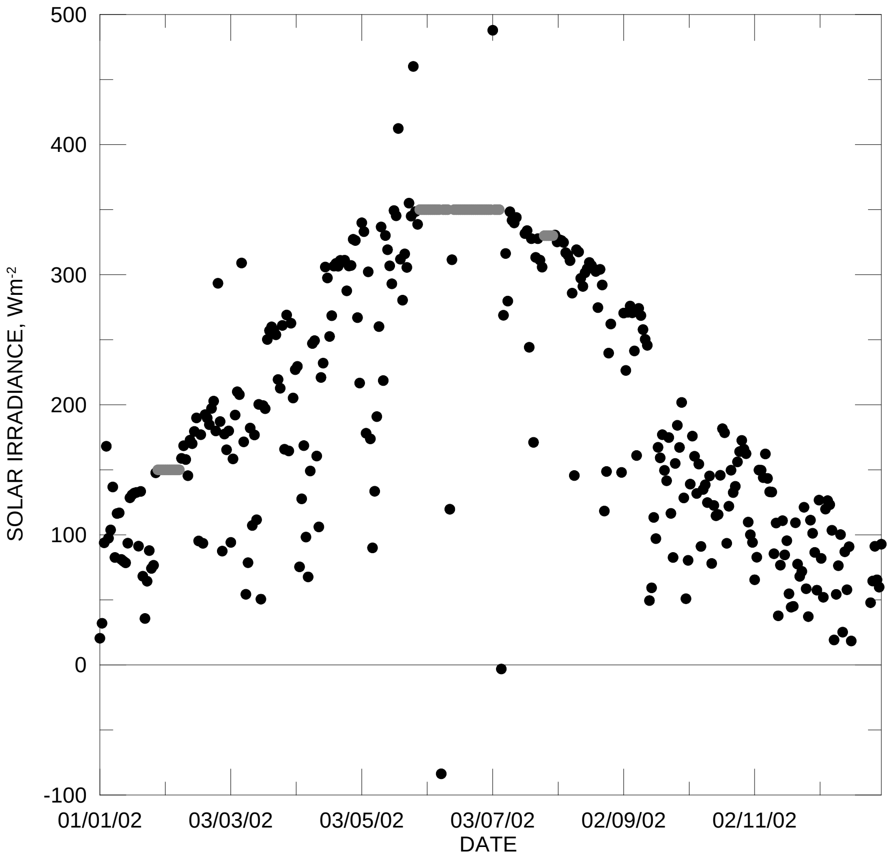

Fig. 5. Example of missing days. Data are shown for the station Portel in 2002. Black dots denote actual measured data and red dots indicate days without solar irradiance values.

3.1.4 Time errors

Time errors can be caused by either the clock of the data logger is not correct or the data are stored at incorrect times. Sun shine during night-time was detected in a few cases. This is obviously related to a time error. However as it is almost impossible to know the magnitude of the time shift, it is consequently impossible to correct this error. Therefore these days were treated as days without measurements.

Additionally meteorological data are usually stored at UTC (Universal Time Coordinated). The local time in Portugal is UTC in winter and UTC +1 hour in summer. Comparing hourly values of one station with another for a clear sky day easily shows if there is a time shift of 1 hour (Fig. 6). However, this does not provide information if the hour is UTC or not. The UTC time can be checked if one compares the time of sunrise, sunset and noon with the times of 10 min data of solar irradiance values for the respective event. Although this problem has no effect on daily data, it detecting was included in the current analysis of the quality of the raw data.

Table 1. Number of missing days in the five stations for each of the years between 2000 and 2009.

Station	Évora	Mitra	Pardiela	Portel	Reguengos
2000	366	57	366	77	91
2001	365	14	365	23	0
2002	35	0	365	58	0
2003	0	21	365	0	0
2004	17	7	366	5	20
2005	0	5	365	0	0
2006	0	13	365	0	0
2007	0	1	365	0	1
2008	0	1	46	1	46
2009	0	0	0	0	365

3.1.5 Calibration errors

Radiometer, e.g. pyranometer, should be regularly re-calibrated in order to account for a possible drift of the instrument. Usually calibrations every year are considered as a good compromise between too many and too few re-calibrations. However, the instruments of CGE were re-calibrated less frequently. The error introduced by improper calibration cannot be quantified.

As the age of each instrument is different, the potential drift will be different too. Large drifts can be detected with the methods described above and subsequently corrected according to the error treatment for each individual error source. Small errors can almost be ignored as the aim of the work is to provide a database which is suitable for use in photovoltaic applications and their sizing.

3.2 Error treatment

The aim of the work is to construct a high quality database of solar irrandiance values for the region Évora, Portugal. Therefore it was decided that the measured values at the Évora station serve as a basis. All days for which errors could be detected (outliers, time errors) were removed from the database. That means, errors resulted in data gaps.

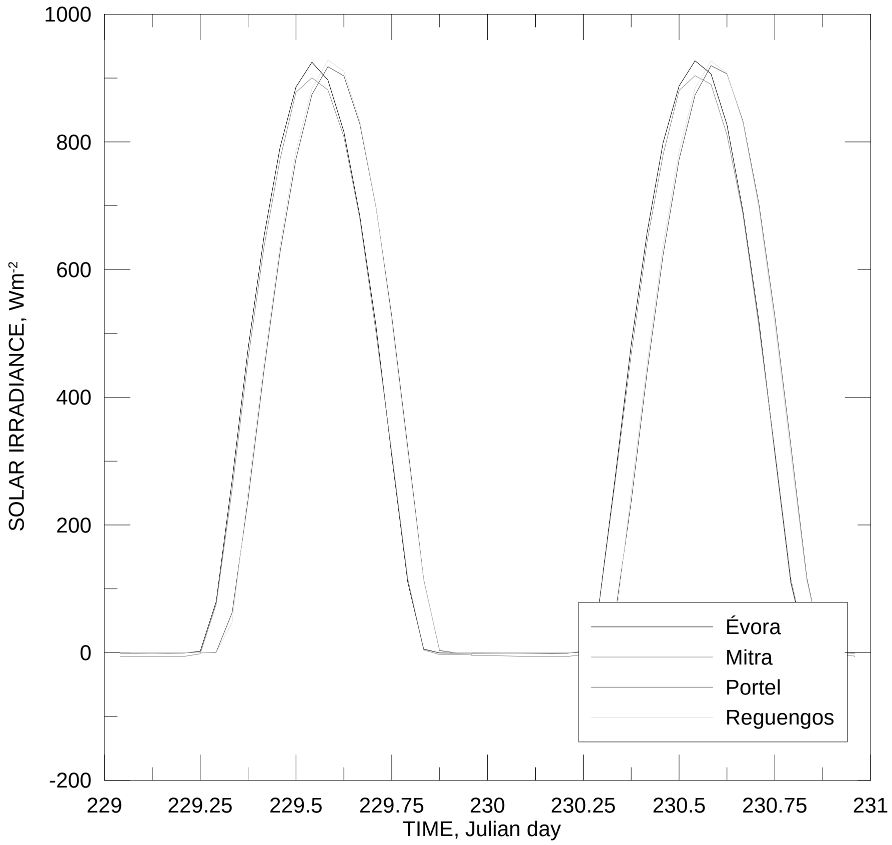

Fig. 6. Solar irradiance at 4 stations during clear skies in summer, showing a time difference of 1 hour which can be traced back to the difference between UTC and Portuguese summer time.

As Mitra is the closest station to Évora, Mitra was chosen as the station to fill data gaps in Évora time series. In order to correct for a small (but possible) systematic bias between both stations, all days with measurements for both stations were used and a linear regression analysis was performed. This regression was then applied to the data of Mitra in order to transfer solar irradiance values measured at Mitra to the Évora time series. There were a few days in 2000 and 2001 without data for Mitra. For these days the average of the values of Portel and Reguengos was used. Fig. 7 shows the final time series for Évora region for the year 2008.

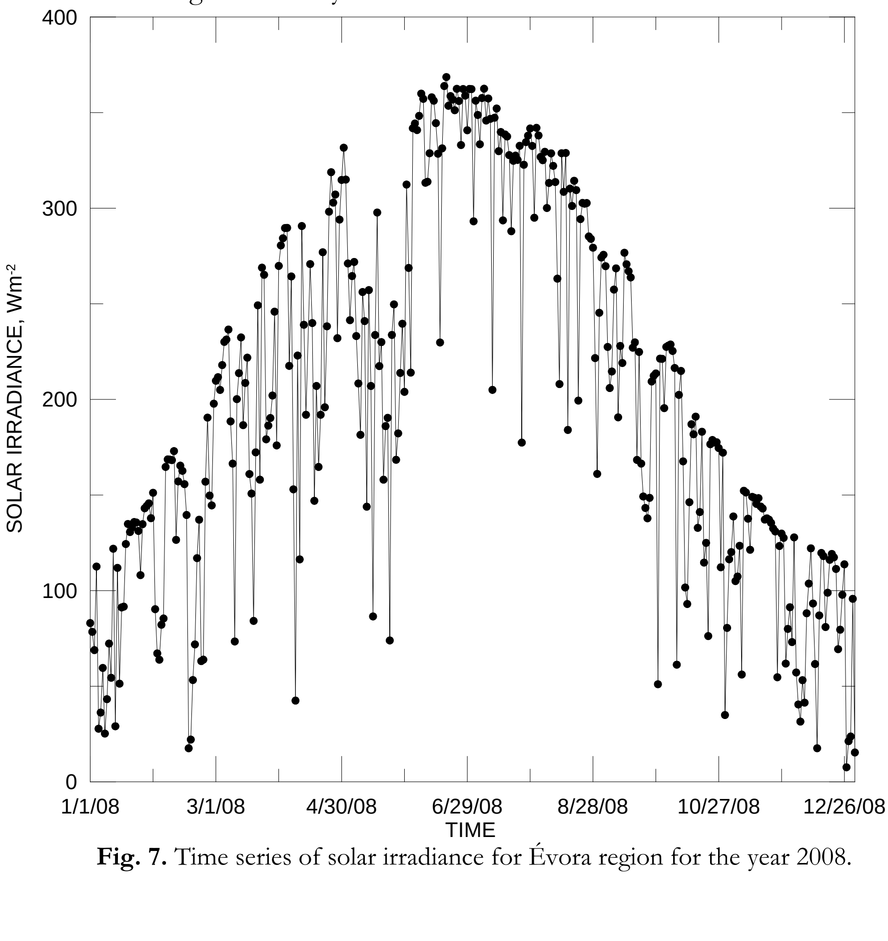

Fig. 7. Time series of solar irradiance for Évora region for the year 2008.

4. Summary and Conclusions

Solar irradiance (raw) data at five stations in the region Évora were checked for possible errors. These errors were outliers, time errors, calibration errors, and data gaps. Subsequently the measurements were combined and a new database of daily values of solar irradiance was constructed. This new database has a considerable higher quality as the direct available raw data and is hence suitable to be used for renewable energy and especially photovoltaic system applications. The final irradiance data covers the time period between 2000 and 2009. Inter-annual variations can be further investigated and taken into account for PV applications, namely in the sizing of the systems.

5. Acknowledgments

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About the heat flow from the Earth's interior

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Abstract
The main objective of this work is to show how values of heat loss from the Earth' interior can be obtained. There are two kinds of data necessary for this calculation: heat flow at the surface and geological data. We present these data as they appear in recent works. Because the distribution of heat flow data-points is inhomogeneous, it is necessary to make estimations in some regions and to use average values in other. We then discuss methods used to compute heat flow in continents, including the method used by Jaupart et al (2007) which questions the relationship between heat flow and the age of continents presented by Polyak and Smirnov (1968). We than present models used to obtain heat flow in oceans. The estimated values of heat loss range between (29 -34) TW and (47±2) TW.

1.Introduction

The phenomena of Volcanic eruptions, earthquakes, and plate tectonics, are evidence that energy from inside the Earth's manifests itself at the surface. Volcanic and geothermal activity allow us to assert that the temperature inside the Earth is higher than the temperature observed on its surface. It is natural then, that there is a transfer of energy, by conduction, from the interior to the surface of the Earth. What we will discuss in this work is that energy continuously comes to the surface of the Earth, without us noticing .

Studies of heat flow from the interior, on a global scale, have been performed by several authors. These studies have aimed to obtain information about phenomena occurring inside the Earth. The first data we use in this work were presented by Lee and Uyeda (1965) and the latest data were presented by Davies and Davies (2010).These studies usually work with values obtained at the surface, which include heat flux from the core, heat from radioactive elements in the mantle and crust, and the secular cooling of the Earth. These data are used in models of the Earth's evolution and in dynamic models of the mantle and core.

Determining and describing variations in the global heat flow field is very important in global geophysics, especially when studying phenomena that strongly depend on the temperature distribution in the outer few hundred kilometres of the Earth (e.g. continents and ocean basin tectonics, seismicity, seismic wave velocities in the Earth's crust and upper mantle, and the maturation of hydrocarbons). The magnitude of heat loss is significant compared to other solid Earth geophysical processes.

The best way to determine the heat loss in a region is to obtain a mean heat flow value and to make an integration over the entire region. This method fails in the oceans where there are large regions without data and where the v high scatter of the data obtained in young regions necessitates the use of theoretical models instead of measured values.

2. Heat flow data

Heat flow data are obtained using the thermal conductivity values, of a measured formation, and from vertical thermal gradient values. In continents, thermal gradient values are obtained from boreholes or mine galleries. In oceans or lakes, thermal gradients are obtained from sediments. More information regarding heat flow determinations and the main corrections used,can be found in Haenel, Rybach and Stegena (1988) or Beardsmore and Cull (2001).

The first continental heat flow measurements were made in Great Britain, by Benfield (1939) and in South Africa, by Bullard (1939). The first oceanic measurements were made by Revelle and Maxwell (1952) in the eastern North Pacific Ocean. The first heat flow data compilation on a global scale was presented by Birch (1954), with 43 values obtained in continental regions and 20 values obtained in oceanic regions. Davies and Davies (2010) have recently presented a heat flow data compilation with a total of 38374 data-points. Fig 1 shows the global distribution of heat flow measurements. We can see that the distribution of data-points is inhomogeneous. We can also see that there is a strong concentration of data in regions like Europe and North America , while other regions like Antarctica, Greenland, and large areas of Africa are unsampled. In South America and some parts of Asia, the data are scarce.

Fig. 2 shows histograms of the heat flow measurements, presented by Davies and Davies (2010).

We can see in Fig. 2. that the peak obtained with data from continents and the peak obtained with oceanic data occur at the same heat flux values. We can also see that more high heat flux values were obtained from oceans.

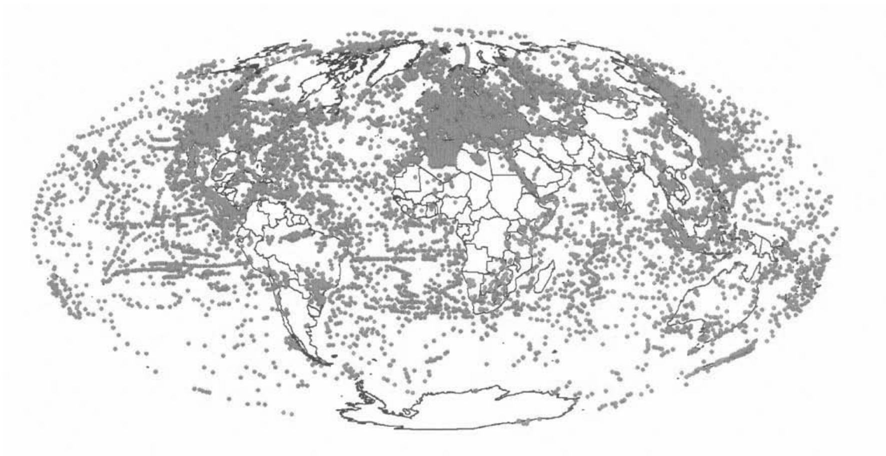

Fig. 1. Global distribution of heat flow measurements showing the inhomogeneous distribution of the data- points (From Davies and Davies, 2010)

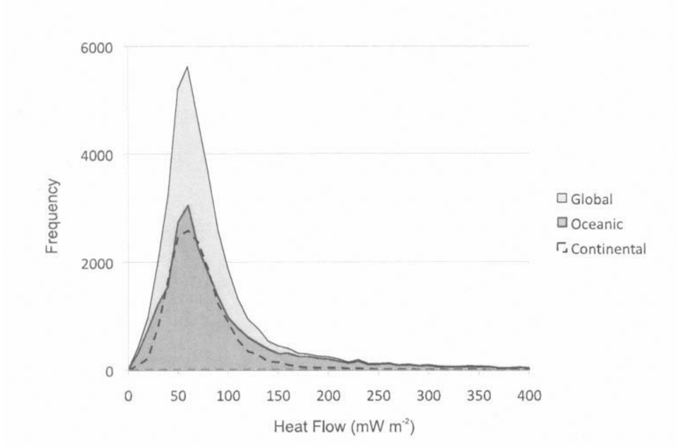

Fig. 2. Histogram of heat flow measurements (global, oceanic and continental). (From Davies and Davies, 2010)

3. Geological data

Geological data are fundamental for estimating heat flow in regions that are unsampled or have a few data.

The first heat flow measurements were made before the development of plate tectonics. The work presented by Lee and Uyeda (1965),for example, used 1044 data sites. As they were unaware of the importance of water circulation in the oceanic crust, they underestimated the heat lost through the oceans, and they obtained a global heat loss of $26x10^{12}$ W. Williams and Von Herzen (1974) made an estimate of the effects of hydrothermal circulation in young oceanic crust and they obtained a global heat loss of $43x10^{12}$W.

Before the work of Davies and Davies (2010) the authors used World Geological Maps to relate heat flow to geological units. Davies and Davies (2010) used two geological data-sets.: the Geological Map of the World (Commission for the Geological Map of the World (2000)) which assigns a geological unit to every point on the Earth's surface, and a data-set of continental geology that includes virtually all land above sea level, excluding Antarctica and Greenland.

4. How to obtain a grid of heat flow values to compute heat loss

Pollack et al. (1993) covered the Earth's surface with a 5º grid, and they verified that grid elements with at least one measurement comprised about 62 % of the Earth's surface. Half of the elements on this sampling grid contained observations represented by seven or fewer measurements. In regions where there were detailed surveys, some grid elements had several tens of measurements. To resolve this disparity, it is necessary to estimate heat flow in areas without measurements and to make averages in areas with an excess of measurements.

Pollack et al (1993) derived empirical estimators from the data used by referencing the heat flow measurements to the geological units where they were obtained. They assumed that similar geologic units should have similar heat flow, and they estimated surface heat flow values for regions of the globe that had no observations. To obtain a better estimate, they divided the surface of the Earth into 1ºx1º grid-cells. An estimate of heat flow was made for each cell, according to the geological unit indicated on the map. The heat flow data in each cell were then averaged, and the resulting cell values were used to estimate an average heat flow for each geological unit. The total heat flux was evaluated by summing the contribution of each geological unit.

Davies and Davies (2010) used a high-resolution geologic data-set using GIS, which allows geological units to be defined by high-resolution irregular polygons in digital maps. They used over 93,000 polygons. GIS enables them to evaluate the areas of the geological units exactly, and they matched the heat flow measurements to the specific local geology. They included a Glacier category, which covers 3% of the Earth's surface area. This category includes

Greenland and Antarctica. They obtained for this category a mean heat flow value of between 105 and 120 mWm^{-2}. Because these values are high, they used the value of 65 mWm^{-2} presented by Maule et al. (2005), with the error estimate based on the difference between 105 and 65 mWm^{-2}.

5. Heat flux in continents

Heat flux in continents is generally obtained using a relation between heat and geological unit, including geological age. Jaupart et al (2007) questioned the relation between heat flux and the age of the continents. The main component of surface heat flux in continents is crustal heat production, and there is a decrease in heat production with age, but this does not explain the differences between heat flow values. Jaupart et al. (2007) showed that the differences of average heat flux values between geological provinces cannot be accounted for by changes in mantle heat flux but must be attributed to changes in crustal heat production. Mareschal (2010) suggests that with the present sampling of continental heat flux, it is preferable to estimate its mean value by a weighted average of area. The value obtained, by Marechal and Jaupart (2009), for continental heat loss is $(14\pm1)x10^{12}$ W.

6 . Heat flux in oceans

Heat flux obtained in oceans is the highest at midocean ridges, and it decreases with the age of the lithosphere. Fig 3 presents a plot of the heat flux data in oceans against age (Ma). We can see that the highest values corre-

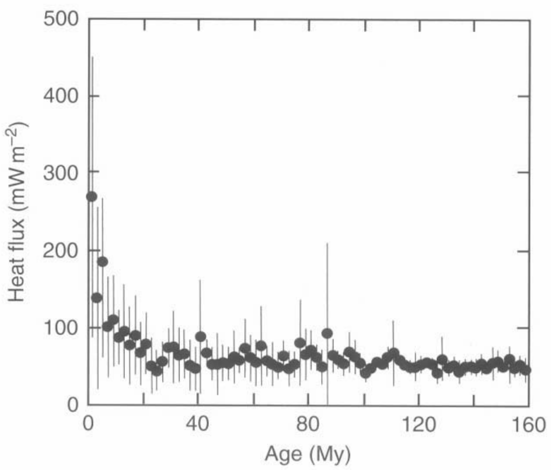

Fig. 3. Heat flow values obtained in oceans versus age (from Stein and Stein, 1992)

spond to the youngest ages. The average heat flow is greater than about 100 mW m^{-2} for the youngest (< 10 Ma) parts of the lithosphere. We can also see an extremely large data scatter at young ages, but the scatter decreases with increasing lithospheric age. The ocean depths in these regions increase with age.

Two classes of models have been made for heat flux in oceans. One is the half-space cooling model, in which heat flow varies as the reciprocal of the squared root of age. The second is the plate model, in which the lithosphere behaves as a cooling boundary layer until it reaches ages at which the effects of the lower boundary cause the heat flux to vary more slowly with age. For young ages the heat flux values obtained with these models , are higher than the measured values. We can divide authors into two groups, based on how they explain this fact. Those like Pollack et al. (1993), Wei and Sandwell (2006) and Davies and Davies (2010), suggest that the heat flow in young crust is affected by water circulation and that this explains the scatter shown in Fig 3 and the relatively low values obtained in young crust. The other group includes Hofmeister and Criss (2005) and Hamza et al. (2008), who suggest that the discrepancies between calculated and measured heat fluxes are not due to hydrothermal circulation.

6.1. Models that consider hydrothermal circulation in the lithosphere

Pollack et al (1993) considered the circulation of seawater through oceanic crust a significant mode of heat transfer in young oceanic crust. In older oceanic regions, conductive heat transfer dominates. They used a relation, found by Stein and Stein (1992), between heat flow and the age of formation of the young oceanic crust:

$$Q(t) = C\, t^{-1/2} \tag{1}$$

where the value of C may be determined empirically from the data. They used 510 mW m^{-2} $Myr^{0.5}$ as the C value. This relation is valid up to 65±10 Ma. Wei and Sandwell (2006) used a C value of 480 mW m^{-2} $Myr^{0.5}$, but they added to the data a basal heat flow of 38 mW m^{-2}. Jaupart et al (2007) used C=490±20 mW m^{-2} $Myr^{0.5}$, which corresponds to an uncertainty of ±4%. Davies and Davies (2010) used the same value of Jaupart et al (2007) but they considered errors 50% greater.

6.2. Other models

Hofmeister and Criss (2005) states that a magmatic source provides too little energy for hydrothermal circulation. They also say that the half-space cooling model fails in assuming constant thermal conductivity, and that it provides infinite flux along the ridge centres. They obtained a mean continental heat flux of 60 mW m^{-2}. This value was obtained by simple averages computed by excluding the highest value of heat flux (above 200 mW m^{-2}). They also say that eq (1) does not well describe the data below 50 Ma, but this is the only part of the half space cooling model that is used by Pollack et al. (1993), to obtain mean oceanic flux. They obtained a median heat flux for the oceans in the range 59-65 mWm^{-2}.

Hamza et al (2008) asserted that previous works failed to make corrections accounting for the hypothetical effects of regional-scale convection heat transfer in some areas of the oceanic crust. They calculated coefficients for a 12° spherical harmonic expansion and they derived maps on the basis of these coefficients. The magnitudes of the heat flow anomalies of the ocean ridge segments were found to have values of 150 mW m^{-2}. The mean global heat flow values for the raw and binned data fell within 56-67 mW m^{-2}. These estimates are lower than the global mean value of 87 mW m^{-2} calculated by Pollack et al (1993), but they are in agreement with the mean value of 63 mW m^{-2}, obtained by Hofmeister and Criss (2005).

Hamza et al. (2010) presented a magma accretion model of the oceanic lithosphere, called" Variable Basal accretion-VBA". The new model assumes the existence of lateral variation in magma accretion rates and in temperatures at

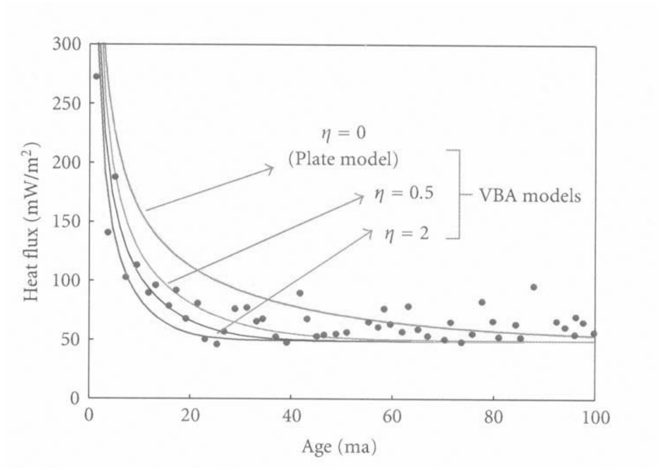

Fig. 4. Comparison of VBA models with oceanic heat flow values. We can see that the curves obtained with η values of 0.5 or 2 fit the experimental data well

the boundary zone between the lithosphere and the asthenosphere. The ratio of advection to conduction heat transfer (η) is considered a space dependent variable. Fig. 4 shows the relation between heat flux and age of the lithosphere. The mean heat flow values used in this figure were reported by Stein and Stein (1992) for ocean crust younger than 100 Ma.

The model curves for η (the factor that determines the basal accretion rate) between 0.5 and 2 fit the data between 0 and 55 Ma well. For ages greater than 55 Ma, the model curves tend towards an asymptotic limit.

7. Heat loss by the Earth

The highest obtained value of heat loss by the Earth to date, was found by Davies and Davies (2010), a value of 47± 2 TW. This value partially overlaps that found by Jaupart et al (2007), 46±3 TW. These values are about 5% higher than the value obtained by Pollack et al. (1993). According to Stein (2010), these high values appear to come from three main factors: a - slightly higher heat flux from the continents, a higher estimated heat flow from currently glaciated continents, and a high value of flux from oceanic hotspots. The estimate obtained by Wei and Sandwell (2006),42 to 44 TW, agrees with the value obtained by Pollack et al. (1993) which was 44± 1 TW.

Table 1 shows the heat sources that enabled this thermal energy transfer at the surface, presented by Jaupart et al. (2007)

Table 1. Total heat loss and sources of heat data

	Heat loss (TW)
Total heat loss	46
Continental heat production	7
Mantle heat production	13
Mantle differentiation	0.3
Tidal dissipation	0.1
Core heat loss	8
Mantle cooling	18

Hofmeister and Criss (2005) noted that estimates of continental flux have changed little since 1965 and they agree with a median value of 60 mW m^{-2}. They also agree with estimates of total heat loss across continents. The CI model, or mixed models, have been considered as providing the bulk chemistry of the Earth. The heat generated by radioactive methods does not agree with the radioactive power generated by a GI model. The differences between these values are assigned to heat from delayed secular cooling and other sources. Recent geodynamic studies (Van den Berg et al., 2002) have provided an upper limit to the delays of approximately 1 billion years, which is too short for secular cooling to provide a source of heat today.

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