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Research on Climate Change and Impacts, Ozone Depletion, Observations and Natural Hazards : Past achievements, latest results and research needs for the 7th Framework Programme

Climate Change Research Challenges

SCIENTIFIC REPORT

Dedicated to the memory of Anver Ghazi

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Climate Change Research Challenges

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FOREWORD

PREFACE

Climate change, its impacts and links with natural hazards will become one of the burning international problems of the 21st century. There is rising evidence that human induced climate change has already started with potential negative impacts on society with a variety of consequences for air quality, human health, ecosystem health and productivity, and stratospheric ozone. Based on scientific warnings policies have been formulated and measures implemented at international level to counteract and mitigate the projected changes and impacts. But at the same time we have to confess that the functioning of the climate and the earth system and their future evolution is still not fully understood.

The scientific uncertainties, the global dimension of the problem and the political commitment and leadership of the European Union in environment legislation are calling for strong complementary European research programmes to further advance our understanding and to ensure that interventions will be effective and economically sound. During recent decades research has been instrumental in clarifying and quantifying the climate mechanisms and to underpin the political and regulatory measures taken. In particular international research assessments have provided the basis for global policy action, implemented under the Kyoto and Montreal Protocols to safeguard our climate and to protect the stratospheric ozone layer.

The Climate Change Research Symposium has been used as a platform to present past achievements and latest research results in the area of climate change, natural hazards, ozone depletion and earth observations. The Symposium was a very fruitful and dynamic forum for stimulating discussions and identifying research needs and challenges for the up-coming 7th Framework Programme. It became evident that the complexity of climate change processes necessitates a high level of interdisciplinary European research collaboration. Building on our achievements the report points to the need to consolidate and strengthen these efforts by developing a pan-European strategy for climate research and natural hazards in close collaboration with related disciplines.

The Symposium was dedicated to the memory of Dr. Anver Ghazi, who sadly passed away on 25 July 2005. He was Head of the Climate Change and Natural Hazards Unit for more than 9 years and was deeply committed to the advancement of environmental research. He was highly respected by his colleagues and he will be fondly remembered.

Finally, on behalf of the European Commission I would like to express my sincere thanks to the speakers of the Symposium and authors of this report for their committed work and would also use the opportunity to thank the Royal Academy of Science and Art of Belgium, hosting this event for their kind support.

Janez Potočnik,
European Commissioner for Science and Research

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

The Climate Change Research Challenges Symposium was organised by DG Research-Environment and Climate System Unit and it attracted more than 200 participants from 30 countries.

I would like to express my gratitude to the members of the Unit for their work and commitment to the success of the Symposium. Special thanks are due to Claus Brüning and Sandrine Geeraert. I would like also to acknowledge the organisational support we received from the other units of the Environment Directorate.

We take this opportunity to warmly thank the family of Anver Ghazi for being with us during the entire Symposium.

This publication provides the scientific output of the Symposium presented by world recognised experts.

During and also after the Symposium we received numerous valuable contributions on key research priorities for Climate Change and Natural Hazard research which we used for the development of the workprogramme for the 7th Framework Programme. I would like to thank all Symposium participants.

We believe that this publication will contribute to the ongoing debate on the key research challenges associated with the greatest environmental challenge today, Climate Change.

Elisabeth Lipiatou, Head of Environment and Climate System Unit

OPENING REMARKS

Opening remarks by J. Potočnik
European Commissioner for Science and Research

Ladies and Gentlemen,

It is a great pleasure for me to open this Symposium on climate change.

The timing for this Symposium is excellent: awareness of our changing climate is probably the highest it has ever been; the United Nations Conference in Montreal was concluded successfully two months ago. Equally, we are negotiating the 7th Research Framework Programme with Parliament and Member States. Climate change is at the centre of these discussions. Everybody can observe changes in temperature and ice-cover; we are seeing more frequent natural disasters, causing ever greater human, physical and economic damage of natural hazards. Discussions have also started on Post-Kyoto measures and associated costs and benefits.

I am also pleased to be here, because this Symposium is dedicated to the memory of a highly respected colleague, Mr Anver Ghazi. I appreciate how much people like me owe to people like him and his team. Without their expertise and commitment, my work today would simply be impossible! Mr Ghazi was engaged in a prominent position in the European Commission. The fact that we have a strong European Research Community on Climate Change Research and Natural hazards is very much thanks to his 8 years of commitment and enthusiasm. We owe him a very special "thank you".

Let me now enter into the questions and **public concerns** about climate change. There is no doubt that human-induced climate change is a reality, and that society is facing enormous challenges. But are we prepared for these challenges? What do we know about the future impacts on atmospheric composition, on land ecosystems, on ocean life, on water resources? What are the implications for society?

Latest figures show that the year 2005 was the warmest on record; and there also seems to be increased frequency of extreme events in Europe and elsewhere.
The public is alarmed and requesting answers: is there a link between a record hurricane season last year and climate change? What are the causes of the severe flooding in Central and Southern Europe these past few years and which have caused so much displacement and economic loss? How can we prevent and mitigate these disasters and what is the link with climate change?
In the year 2003 Europe underwent a heat wave never experienced before and which caused thousands of casualties. Was this just a single incident or was it a sign of what the average European summer will be? Even if we only look from an economic point of view, which we should not, recent research suggests that a temperature increase of 3°C might cause a decline in global income. But the same research studies suggest that at lower costs we can avoid dangerous climate change.
The question is then: what steps do we need to take? How can we take responsible decisions and assess the consequences of climate change? Research will play a crucial role in addressing these questions. Public expectations are high and rightly so; answers are expected.

The **global dimension** of climate change and natural hazards has initiated a number of international research efforts and collaborations, in which Europe has played and continues to play a key role.
The international dimension and collaboration in climate research in the 6th Research Framework programme is certainly one of the highlights. Just to give you a few examples: a European research consortium including African partners studies the change and impact of the West African monsoon on global climate as well as the social and economic impacts on this region; an international consortium with strong European contribution observes the shrinking Artic Ocean sea-ice cover in order to understand past climate and forecast changes; tropical experiments over Australia are carried out to increase our understanding of the changes in the atmospheric composition. These are just examples but they show that European research is present and has established an excellent reputation.

Let me now briefly comment on the **close relationship between environmental research and policies including the environment**. I believe that environmental policies need to be built on sound scientific knowledge. Indeed it should be noted that policy actions such as the Montreal and the Kyoto Protocols arose from the work of scientists.
We see with great satisfaction that the Montreal Protocol (a ban on ozone depleting substances) is functioning. The atmospheric load of chlorine components should further decrease in coming years. We can therefore expect that the ozone hole will slowly recover within the coming decades, although climate change may delay the recovery process.
The Kyoto Protocol is based on the scientific consensus that there is a balance of evidence for human-induced climate change. This has been formulated by the Intergovernmental Panel on Climate Change, established by the United Nations Environmental Programme as an independent body for scientific advice. I know that many of you here today have contributed to its work.
However we all know that the Kyoto Protocol is only a first step to stabilising our climate, and greater efforts are necessary to achieve the ambitious goals. I will even go one step further - climate change is unavoidable. Society needs to be prepared for the coming changes in order to minimise their socio-economic impact.

This leads me now to **the 7th Research Framework Programme**, where we have taken the necessary steps to include climate change research to make Europe fit for the expected challenges. I can assure you that we will further promote scientific excellence and cooperation in these fields at European and international levels.
The programme will address major unanswered scientific questions and advance our understanding of the earth system functioning and changes. It will tackle the problems which are most important for society such as the future climate change impacts from local to global scale and determine optimum mitigation and adaptation strategies. Certainly, the commitments on research and systematic observation as formulated in the Treaties and international initiatives like the Group on Earth Observations are taken seriously by the European Commission.
This is one of the many reasons why earth observations will continue to be an integral part of the FP7 allowing early detection of changes and the development of response options. The combined use of observation and models should help us to detect thresholds and eventually points of no return, which our society should know about.

I would not like to end this speech without thanking the representatives of the Royal Academy of Science and Art for their noble support making these nice facilities available. The ambience of this magnificent place establishes the frame for the event.
But I would also like to thank you [*the participants*] for your personal support to the European research and the European Commission in the different panels and advisory groups. It is indeed my hope and wish that the successful work you have done so far will continue and that Europe will keep its leading position in Climate Change research. It is something we can be truly proud of.

I wish you a successful Symposium!

PRESENTATIONS AND SUMMARY REPORTS

SESSION I
CLIMATE CHANGE AND OBSERVATIONS

Keynote on Climate Change

Hartmut Grassl
Max Planck Institute for Meteorology, Hamburg, Germany
Meteorological Institute, University of Hamburg, Germany

I. INTRODUCTION

Climate is a key resource for mankind. Given the size of our planet and the distance to the sun the question "What are the most important parameters for our life and for climate?" gets the same three priority parameters:

- Energy from the sun or solar radiation flux density
- Precipitation or clouds and precipitation
- Photosynthesis of plants or vegetation

Therefore, politicians have to deal with climate also without our intervention into the climate system. In a world with anthropogenic climate change we need a climate change policy. Climate research thus became a prerequisite for more intelligent decision making that has as its goal the dampening of the anthropogenic climate change rate in the 21st century.

II. A FEW FACTS

All three natural long-lived greenhouse gases show a concentration increase caused by human activities: Carbon dioxide (CO_2) rising from 280 (1750) to 380 ppmv (2005), methane (CH_4) from 0.7 to 1.75 ppmv and nitrous oxide (N_2O) from 0.28 to 0.315 ppmv. The CO_2 increase is still growing, CH_4 is recently levelling off, and N_2O grows continuously.

Global mean air temperature close to the surface has risen by 0.6°C in the twentieth century and the 10 warmest years on record since 1856 came all after 1994, with 1998 and 2005 standing out as the two hottest, 2005 without El Niño, thus indicating further warming. A major part of this warming is anthropogenic, i.e., is due to the enhanced greenhouse effect of the atmosphere.

The consequences of this strong recent warming are numerous, a few mentioned here are:
- Arctic sea ice extent shrinks strongly;-7%/decade in late summer and -3%/decade in late winter;
- nearly all mountain glaciers have lost mass, especially within the last decade;
- sea level rises by ~3 mm per year since 1992, well above the long-term mean of ~1.5 mm per year in the twentieth century;
- precipitation decreased in many semi-arid areas increased in most high northern latitudes and in many parts of the mid-latitudes during winter in the twentieth century;
- precipitation amount per event has increased in most areas including those with slightly less total amount, i.e., frequency of extreme amounts has increased;
- many ecosystems show signs of rapid change: tree-line moves upward and pole-ward, vegetation period length grew, damage due to tropical storms, whose strength has increased on average, has grown drastically.

III. THE ABSENCE OF DIRECT ANALOGUES IN CLIMATE HISTORY

We can expect a very long interglacial due to Earth's orbital parameter changes (see contribution by André Berger), i.e. the Eemian interglacial about 125 000 years ago lasting only about 10 000 years with global mean temperatures well above those in the holocene, before our strong impact has started, is no suitable analogue.

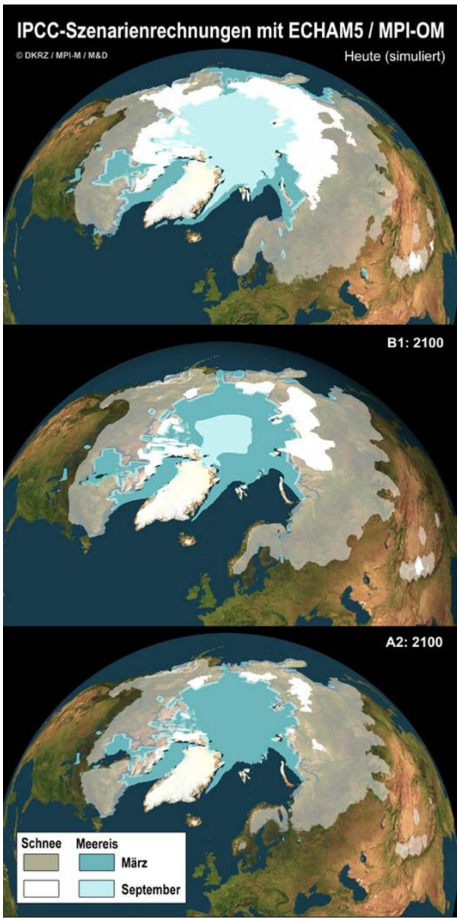
As orbital parameters, solar luminosity, volcanic eruptions and distribution of continents all change at their proper timescales not periodically, no clear analogue in climate history will emerge for the climate of the near future. It will be characterized by CO_2 levels well beyond 300 ppmv, a situation which never occurred over millions of years during the existence of two major ice sheets (Antarctic and Greenland).

The way forward is applying numerical climate or Earth system models, which have been evaluated by comparison to climate history, to given scenarios of human behaviour. These scenarios should span a wide range as we do not know the probable behaviour of humankind in view of the global climate change threat.

IV. CLIMATE CHANGE SCENARIOS

The recent new coupled atmosphere/ocean/land-model runs for IPCC with improved models, for example the ECHAM5/MPI-OM1 combination, do not lead to major changes in comparison to earlier coupled model climate change runs; hence they confirm earlier model runs with major climate change within the 21st century, if no major climate policies are introduced on global scale: changes of mean air temperature equivalent to the differences between a glacial and an interglacial but “squeezed” into one century with all its consequences for the precipitation belts. Even the complete disappearance of the Arctic multi-year sea ice is forecast (see Figure 1). However, they also show the strong influence of different behaviour of humankind.

Figure 1: The shrinking cryosphere in two scenarios of climate change for 2100 together with present-day simulations. Please note the partial survival of multi-year sea ice in September for Scenario B1, standing for a more environmentally conscious global community than Scenario A2 without any attempt to establish a global environmental policy. Warning: the changes in A2 go well beyond the tested range of the models; source: Climate Projections for the 21st Century, Max Planck Institute for Meteorology, Hamburg, January 2006.

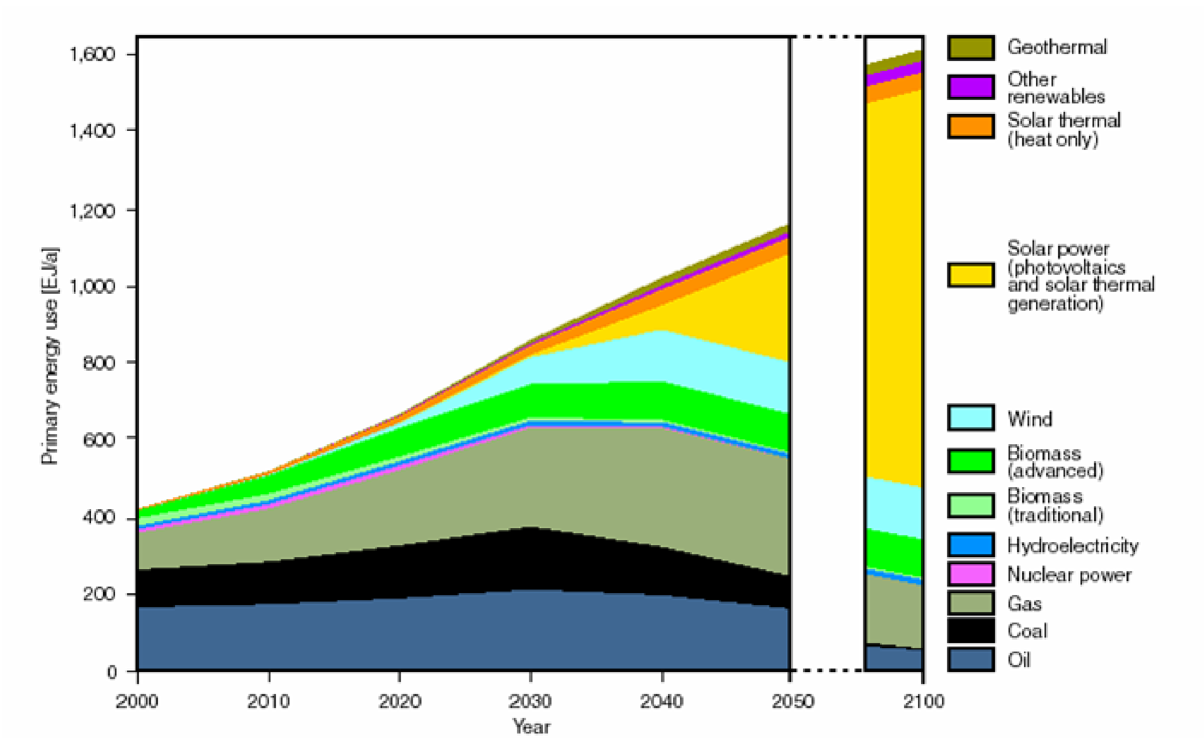


V. CLIMATE POLICY NEEDED TO REACH THE EU GOAL "LESS THAN 2°C WARMING"

Climate change policy cannot neglect other major issues for mankind. Combining the development of developing countries – another key goal – with the dampening of anthropogenic climate change leads to the sustainability challenge, which can only be met by a new global energy supply system. This has to drastically increase total energy throughput by a factor of 3 until 2100, even at major energy efficiency gains, but has to lead to climate protection as well. In an attempt to respond to both challenges at once the Global Change Advisory Council of the German Government (WBGU = Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen) has recommended a 450 ppmv CO_2 concentration limit in order to reach the +2°C goal of the European Union (EU). It has adopted a high economic growth scenario (A1T) within a technology friendly environment (T stands for it) and assuming a global attempt to reach true multilateralism (1 stands for it) since the fulfilment for A1T would make it even easier for other scenarios with a more environmentally conscious humankind, e.g. B1.

The result in short (see Figure 2 and www.wbgu.de): A1T (450 ppmv) is in the long run cheaper than any other scenario, can reach the +2°C goal if climate system sensitivity is below +2,5°C for 2 x CO_2, carbon sequestering into former gas and oil deposits is taken as an option in the coming decades, before massive direct solar radiation use becomes the pillar of a global energy system. A1T-450 implies major renewable energy research investments, takes into account many guard rails like at least 500 kWh electrical energy per person per year in developing countries and is eased by giving up early in the 21st century fossil fuel subsidies and by internalising external effects within an agreed international climate policy.

Figure 2: The Energy Scenario for the 21st Century; source: www.wbgu.de.



The GEOSS Challenge: What Role for the Scientific Community?

José Achache
Director, GEO Secretariat

I. THE GEO PARTNERSHIP TO BUILD GEOSS

The Group on Earth Observations (GEO) is leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS) over the next 10 years. GEO involves 60 countries, the European Commission, and 43 international organizations.

The GEOSS vision, articulated in the 10-Year Implementation Plan, represents the consolidation of a global scientific and political consensus: the assessment of the state of the Earth requires continuous and coordinated observation of our planet at all scales.

Consistently, GEO has defined a series of objectives to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behavior of the Earth system.

- Build a sustainable, comprehensive and coordinated observation system of systems
  As a "system of systems," GEOSS will work with and build upon existing national, regional, and international systems to provide comprehensive, coordinated Earth observations – in situ, airborne & space-based - from thousands of instruments worldwide, transforming the data they collect into vital information for society.
- Provide open and easy access to data anytime and anywhere
  The societal benefits of Earth observations cannot be achieved without data sharing. GEOSS will help ensure that the quality data required by users reaches them in a timely fashion and in an appropriate format. There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation.
- Increase the use of Earth observations
  Building GEOSS will require the development of scientific research and will stimulate the development of operational products, services and tools. It will, in particular, facilitate the transition from research to operations of observing systems and techniques and enable partnerships between research and operational communities. Most critically, achieving the vision of GEOSS will require GEO to facilitate substantial capacity-building efforts in human resources, institutions and observational infrastructures, particularly in developing countries.

II. A TRANSVERSE APPROACH

The approach of considering the Earth as an integrated system facing major common challenges represents a significant breakthrough, an intentional departure from earlier approaches looking at individual components of the Earth's system.

Nine Societal Benefit Areas
GEOSS is designed to enhance delivery of benefits to society in nine areas:

- Disasters: Reducing loss of life and property from natural and human-induced disasters
- Health: Understanding environmental factors affecting human health and well-being
- Energy: Improving management of energy resources
- Climate: Understanding, assessing, predicting, mitigating, and adapting to climate variability and change
- Water: Improving water-resource management through better understanding of the water cycle
- Weather: Improving weather information, forecasting, and warning

- Ecosystems: Improving the management and protection of terrestrial, coastal, and marine ecosystems
- Agriculture: Supporting sustainable agriculture and combating desertification
- Biodiversity: Understanding, monitoring, and conserving biodiversity

The rationale for adopting a user-driven transverse cross-cutting approach is three-fold:
First, there are significant synergies among user requirements and addressing these common requirements is central to the efficient implementation of GEOSS.
Second, some Earth observations are relevant to many societal benefit areas. For instance altimetry-derived observations have benefited geodesy, oceanography, hydrology, climatology, and ice-sheet monitoring and even tsunami detection. Maps of topography or land cover and land use, or even a geodetic reference frame for Earth observations represent products of common interest to most societal benefit areas.
Third, most societal benefit areas are interdependent. Weather and climate changing patterns for instance have important implications for many areas, including human health, water availability, food security, and energy management.

III. WHAT ROLE FOR THE SCIENTIFIC COMMUNITY ?

Scientific research is crucial to (i) optimize the use of GEOSS observations, (ii) ensure the transition from research to operational systems, and (iii) generate new applications in existing and emerging fields. Moreover achieving the GEO objectives will require:

1. Improving our understanding of basic Earth processes in and across all societal benefit areas.
2. Connecting scientific communities to (i) facilitate access to, and eventually assimilation of, any relevant data whether in-situ, airborne or space; (ii) encourage the development of coupled models and Earth system models; and (iii) expand the use of specific methodologies to other disciplines, e.g. “reverse tracing of precursors” also known as “pattern recognition” from earthquake prediction to epidemiology.
3. Developing new observation methodologies such as radar altimetry, Doppler lidar wind measurements and Synthetic Aperture Radar (SAR) Interferometry
4. Linking existing methodologies to end-user applications (e.g. multi-model ensemble weather and climate predictions to predictions of crop yield and malaria incidence).
5. Adapting to new processing technologies (Web 2.0) such as distributed grid-computing and remote processing using Web services. GEONetcast – a GEO initiative to develop Earth observation data broadcasting worldwide – could build upon progress in this area.

Efforts in the foregoing areas will be supported by GEO activities to engage with the global scientific research and technological community. GEO will work through the International Council for Science (ICSU) and the GEO Committee on Science and Technology to form linkages to major scientific research enterprises in each societal benefit area, and to ensure that relevant scientists and technical experts are involved and contributing to GEOSS in a truly participatory and meaningful way.

Why Paleoclimates ?

A. Berger[1]
Université catholique de Louvain, Institut d'Astronomie et de Géophysique G. Lemaître, Chemin du Cyclotron 2, 1348 Louvain-la-Neuve, Belgium

Paleoclimatic reconstructions help to discover the natural variability of the climate system over times scales ranging from years to hundreds of thousands of years. They are fundamental in climate research, especially now, because they provide a unique set of data to validate models over climatic situations largely different from those of the last 150 years. The climatic situations of the last century are indeed available in great detail, but with a very poor diversity. According to IPCC, the global average air surface temperature has increased by about 0.8°C from the end of the 19th century, but is expected to increase above the 1990 level by another 1.4°C to 5.8°C by the end of the 21st century. 1998 bet the record of the last 150 years and 2005 is the second warmest year (or first according to the selected data bank) with more than 0.5°C above the 1961-1990 average. It must be pointed out that 2005 is beating records without the help of El Niño, which was the case for 1998. The last decade is the warmest of the last century and what is expected for the end of the 21st Century is unprecedented over the last million years.

This is even more true for the atmospheric CO_2 concentrations. The present-day 380 ppmv is already well above the natural variability of the last million years (Siegenthaler et al., 2005). The projected values for 2100 are ranging between 500 and 1000 ppmv, requesting to look back millions, tens and maybe hundreds of millions of years in the past.

It is expected that reconstructions of past climate will help not only to validate the models used for predicting the climate of the 21st and 22nd centuries, but also to provide best analogues and description of what might happen in the next future.

In relationship with this, we have tried to see what would be our climate also at the geological time scale without and with human intervention in order to analyse whether our responsibility is also involved over the next millennia and not only for the few next generations.

The astronomical theory of paleoclimates aims to explain the climatic variations occurring with quasi-periodicities situated between tens and hundreds of thousands of years. Such variations are recorded in deep-sea sediments, in ice sheets and in continental archives. The origin of these quasi-cycles lies in the astronomically driven changes of the latitudinal and seasonal distribution of the energy that the Earth receives from the Sun. These changes are then amplified by the feedback mechanisms which characterize the natural behavior of the climate system like those involving the albedo-, the water vapor-, and the vegetation- temperature relationships. Climate models of different complexities are used to explain the chain of processes which finally link the long-term variations of three astronomical parameters to the long-term climatic variations at time scale of tens to hundreds of thousands of years. Sensitivity analyses to the astronomically-driven insolation changes and to the atmospheric CO_2 concentration have been performed with the LLN 2-D paleoclimate model over the Quaternary. Assuming a CO_2 concentration decreasing linearly from 320 ppmv at 3 Myr BP (Late Pliocene) to 200 ppmv at the Last Glacial Maximum, the model simulates the intensification of glaciation around 2.75 Myr BP, the late Pliocene-early Pleistocene 41-kyr cycle, the emergence of the 100-kyr cycle around 900 kyr BP, and the glacial-interglacial cycles of the last 600 kyr (Berger and Loutre, 2004). Simulations with different CO_2 reconstructions over the last 1 Myr have confirmed that the model can sustain the glacial-interglacial cycles of the late Pleistocene (Berger et al., 2004), although improvement of the model performance is still expected.
This 100-kyr cycle, one of the most striking features of the Quaternary, is linked to the future of our climate. As each cycle is characterized by a long glacial period followed by a short interglacial (~ 10-15 kyr long) and as our interglacial, the Holocene, is already 10 kyr long, paleoclimatologists were naturally inclined to predict that we are quite close to the next ice age. Simulations using our climate

[1] International Symposium on Climate Change Research Challenges, in memory of Anver Ghazi, EU DG Research, Belgian Royal Academy of Sciences and Arts, Brussels, 2-3 February 2006.

model show, however, that the current interglacial will most probably last much longer than any previous ones (Berger and Loutre, 2002), an entrance into glaciation being highly improbable (confirmed by Vettoretti and Peltier, 2004). We suggested that this is related to the shape of the Earth's orbit around the Sun which will be almost circular over the next tens of thousands of years. As this is primarily related to the 400-kyr cycle of eccentricity, the best and closest analogue for such a forcing is definitely Marine Isotopic Stage 11 (MIS-11), some 400 kyr ago, not MIS-5e (Loutre and Berger, 2003). Modeling results with the LLN model (Berger et al., 2003) and EPICA reconstruction (EPICA, 2004; Raynaud et al., 2005) confirm a similar behavior of the climate response during MIS-11 and MIS-1 with a length of 30 kyr or more.

Because the latitudinal and seasonal distributions of insolation will not change any more over the next tens of thousands of years, changes in greenhouse gas concentrations are expected to play a more and more important role. This is particularly important in the context of the already exceptional present-day CO_2 concentrations (unprecedented over the past millions of years) and, even more so, because of even larger values predicted to occur during the 21st century due to human activities (IPCC, 2001; Crutzen and Stoermer, 2000). According to the experiments made with the 2-D LLN climate model, there seems to be a threshold in the CO_2 concentration (~ 700 ppmv) above which the Greenland ice sheet melts (see also Gregory et al., 2004; Ridley et al., 2005) and disappear totally within 10 000 years roughly. Finally sensitivity experiments made with the LLN model show that only a CO_2 decreasing even more rapidly than just after MIS-7 would allow an early end of our interglacial (Crucifix et al., 2004), leaving open the question that if this would have been the case the anthropogenic greenhouse era might have begun thousands of years ago (Ruddiman, 2003).

Anver Ghazi was very clever in understanding, already in the 1980's, the importance of paleoclimate reconstructions to improve our understanding of the climate system behaviour. It is to be expected that the policy- and decision-makers will be as perceptive and perspicacious as he was when they will build the 7th Framework Programme allowing the scientific Community to understand:

1. why the climate entered into an ice age, 2.7 Myr ago;
2. why the amplitude of the glacial-interglacial cycles increase markedly around 400 kyr BP, going from cool to warm interglacials although the glacials remained equally cold;
3. but also why the East Asian monsoon was exceptional during these cool interglacials (much stronger than during the following warm ones; Yin and Guo, 2005; Rousseau, 2006);
4. why the atmospheric CO_2 concentration remained situated between 180 and 280 ppmv over the last 1 Myr;
5. why was the meridional overturning ocean circulation during glacials weaker than during interglacials as opposed to what is expected for the global warming now;
6. what were the world climates when it was much warmer than to-day and/or the concentrations of greenhouse gases were much larger.

This is simply a sample of questions which will undoubtedly help us to better understand the climate system sensitivity and behaviour.

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Climate in the future

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Director, Met Office Hadley Centre

The presentation will discuss the future challenges in improving predictions of climate change. The talk will focus on three specific areas:

1) The need for increased resolution of climate models in order to resolve important small scale processes

2) The need to increase the complexity of climate models through the introduction of important processes currently not incorporated in these models

3) The need to quantify, and ultimately reduce, uncertainty in climate predictions though the use of ensemble techniques.

The implications of these requirements will be discussed.

Avoiding Dangerous Climate Change

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According to the British Prime Minister Tony Blair, “Climate Change is the most important long-term issue we face as a global community. A sound understanding of the science must be the basis for action.“ This view is reflected in the design of the 7^{th} Framework Programme, where the problem of anthropogenic global warming ranks high on the agenda. Many important research questions remain to be answered in the field, yet the most crucial one is *how to avoid dangerous climate change.*

The rationale for this prioritization comes in two pieces: First, we need to know with sufficient certainty whether anthropogenic interference with the natural climate system has indeed the potential to generate disastrous impacts – otherwise humankind should better focus its efforts on poverty reduction or education campaigns and leave adaptation to global warming to market forces and ingenious social actors. Second, we need to make absolutely sure that we adopt the best possible strategies for solving, or alleviating at least, the problem – otherwise humanity runs the risk of doing too little too late in the wrong places. Political and operational decisions made over the next couple of decades will, in fact, determine the planetary environmental conditions for the next thousands of years.

A state-of-the-art account of the pertinent aspects associated with the master question formulated above is provided by a recent book consolidating the results of the 2005 Exeter Conference on the dangerous-climate-change issue (Schellnhuber et al. 2006). From the material presented there and a host of international deliberations addressing the topic, I infer the following shortlist of overarching research challenges for the scientific climate-change community in the next 5–10 years:

1. Identifying & Monitoring the “Tipping Elements” in the Earth System;
2. Spotting & Analyzing Key Regional Vulnerabilities;
3. Quantifying the Efforts for Containing Climate Change within a Sub-Dangerous Domain; and
4. Appraising Portfolio Strategies Integrating Mitigation and Adaptation Measures.

In the following, I will briefly address a few salient features of these challenges.

First things first: Limiting anthropogenic climate change to a “tolerable” excursion of Earth System dynamics means, above all, not to transgress critical thresholds that separate different modes of operation of main elements of the planetary machinery. Such a transgression might be irreversible on civilization time scales and/or transcend the adaptive capacity of the affected regions.

Fig. 1: Tipping Points in the Earth System

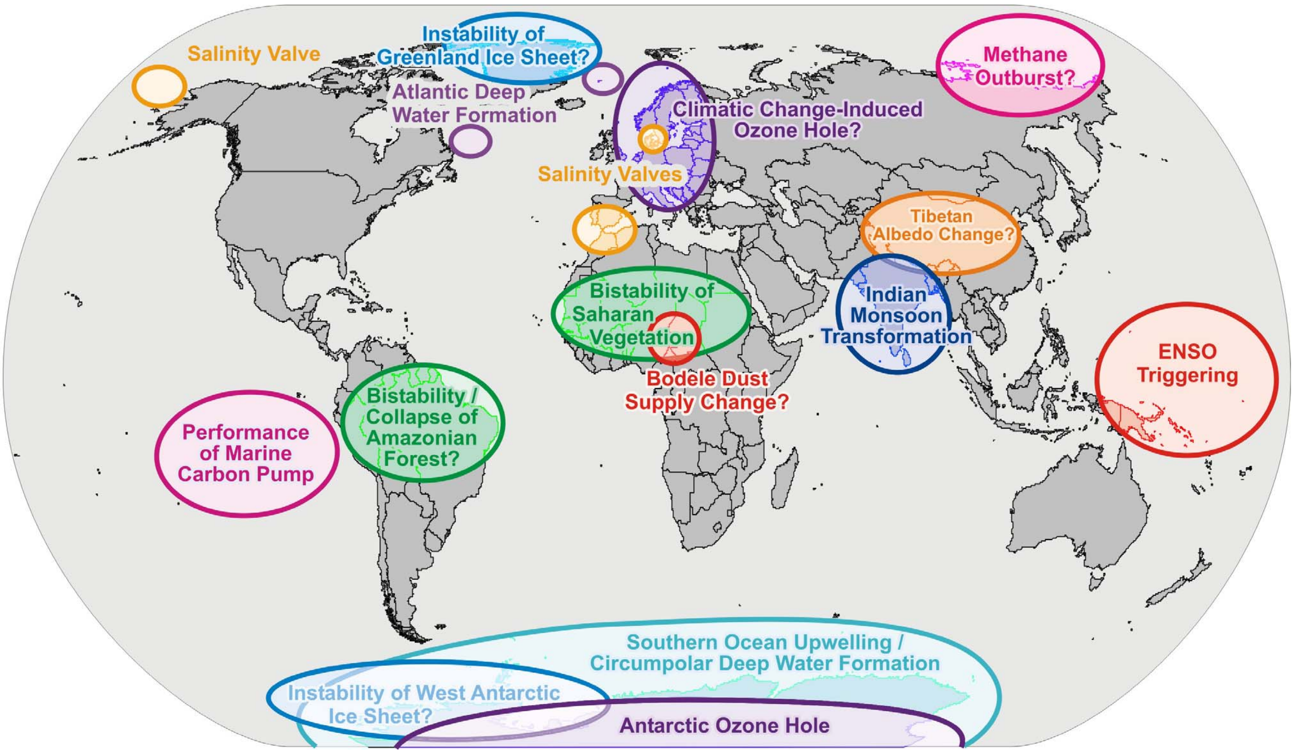


Fig. 1 (see, for instance, Kemp 2005) summarizes in cartoon form potential "Achilles Heels" in the Earth System such as the North Atlantic Deep Water Formation, the Greenland and Westantarctic Ice Sheets, the Indian Monsoon, the Amazon Ecosystem and the Marine Carbon Pump. All those items may be prone to destabilization by global warming, particularly under Business-as-Usual scenarios projecting planetary average temperature increases of 5 and more degrees Celsius. A crash research programme of the Manhattan Project calibre seems necessary for inspecting all tipping candidates of Fig. 1 (as well as others not yet (dis)covered) one by one to clarify, as soon as possible, whether they are amenable to switching by human interference and, if yes, whether there are still ways to avoid the activation. The development of novel monitoring techniques for evaluating precursor signals for imminent phase transitions should be a vital part of such a programme (Held and Kleinen 2004).

Apart from triggering large-scale discontinuities in planetary dynamics, climate change may threaten a range of important systems and regions. Recent studies suggest that global warming transcending 1.5 - 2º C with respect to pre-industrial levels could wreak havoc on quintessential ecosystems like the Great Barrier Reef (Leemans and Eickhout 2004) and heavily reduce ecosystem services in Europe (especially in the Mediterranean, the mountain and the boreal areas; see Schröter et al. 2005). Some progress in understanding ecosystem vulnerability has been made in recent years, yet the analysis needs to advance much faster.

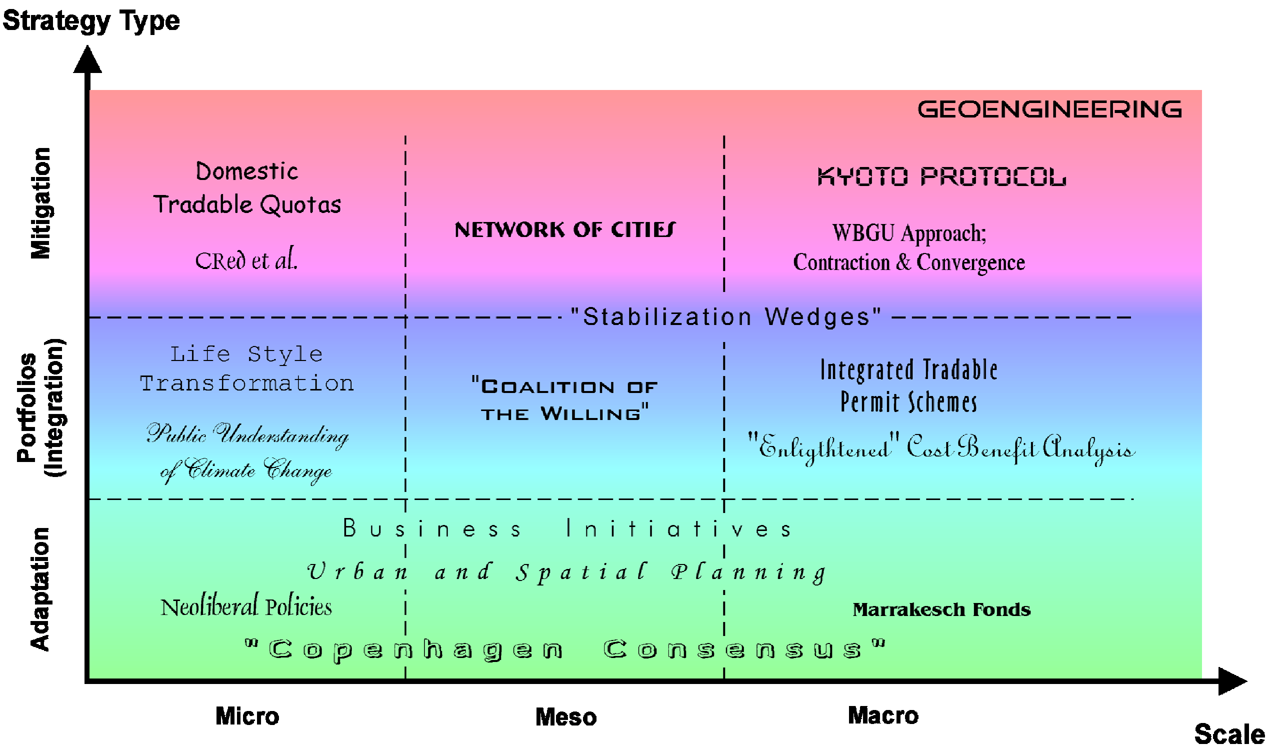
The last statement also applies to the issue of regional "hot spots", i.e., sub-continental areas which will be heavily impacted by even moderate degrees of global warming and are particularly ill-prepared for coping with the emerging challenges. For the sake of illustration, let me mention the Caribbean that was struck by an unprecedented hurricane season in 2005 and may cease to be manageable – as a sociopolitical system – in the present way if the storm regime becomes even worse.

No less bleak appear the longer-term sustainability prospects for the Sahel zone, which suffered tremendously during the 1970ies drought and enjoys a slight increase in water availability at present. Unfortunately for this region, which embraces several of the world's least developed countries, computer simulations predict further dramatic reductions in precipitation towards the end of the 21st century under several SRES scenarios (Held et al. 2005). The possible collapse of Sahel societies under this and other environmental pressures would undoubtedly send multiple migration tsunamis to

Europe. Finally, the Arctic Climate Impact Assessment (www.acia.uaf.edu) has recently revealed the vulnerability of a region that is characterized by the opposite type of geographical marginality as the Sahel. Who ever wishes to define dangerous climate change needs to account also for these regional challenges associated with global warming. Yet very little is known about the true resilience of areas such as the ones mentioned here.

Let us assume, however, that pertinent research allows to specify convincingly what degree of climate change we should try to avoid. This could mean, in particular, that the 2º C target of the European Union is re-confirmed as a reasonable benchmark for climate protection. Then the questions still remain, how to hold that temperature line and how to cope with the (significant) residual climate change (not to speak of the ocean acidification directly induced by atmospheric CO_2 enrichment). The available response strategies, ranging from pure mitigation measures under the UNFCCC to pure adaptation measures on the ground of tiny communities is sketched in the 2-dimensional tableau of Fig. 2.

Fig. 2: Climate Solutions Space



Given the realities of life and politics, a question of overriding importance concerns the economic costs of stabilizing greenhouse gases in the atmosphere at sub-dangerous levels (i.e., in the 450-600 ppm CO_2-equivalent range). Following pioneering work by IIASA (see, for instance, Gritsevskyi and Nakicenovic 2000), an international intercomparison project involving about a dozen of coupled energy-economy-climate models just finalized an attempt to calculate the global GDP losses associated with various mitigation targets. This attempt distinguished itself from former ones by explicitly endogenizing technological innovation as induced by climate protection policy (Edenhofer et al. 2006). The results strongly indicate that the necessary emissions reductions to avoid dangerous climate change might be achieved with economic costs in the range of only 0.5 % of gross world product! This is an encouraging finding, but just a first step on a long research avenue. Further studies with more sophisticated models are urgently needed to corroborate the outcome.

And yet this is only the beginning of a thorough exploration of the strategy space as depicted in Fig. 2. So far, almost all research efforts have been fixated on the top-row right-column corner of the matrix, with the Kyoto Protocol issue as the main pièce de résistance on the menu. Managing anthropogenic climate change effectively and efficiently will require a much broader approach through robust portfolios that blend mitigation and adaptation options at the appropriate scales. The search for "climate solutions" may be guided by two sweeping formulae:

Climate Damage = Climate Vulnerability x Climate Change; (1)
Climate Protection Benefits = Avoided Damages – Adaptation Costs – Mitigation Costs. (2)

While the first equation highlights the principal intervention choices, the second equation lists the principal gains and losses involved. It should be mentioned here that there is no solid scientific basis available today for calculating the global (or regional) damages avoided by different climate stabilization paths. This is just one of the yawning research gaps characterizing the state of the response issue.

Fortunately, an FP6-Integrated Project with the acronym ADAM (Adaptation and Mitigation Strategies for Europe) will be launched this spring that has the potential to break new ground in this area (as from 1.3.2006: www.adam.eu).

I would like to emphasize that the integration of climate change management measures should be analyzed and implemented particularly for urban territories: cities contribute heavily to greenhouse gas emissions, on the one hand, and will suffer in many devastating ways from climate change impacts, on the other. Also, their relationships to their hinterlands need to be revised in the ages of global warming – just think of biomass production + carbon sequestration as a potential formula for the next industrial revolution. In other words, novel research roads need to be pursued for re-inventing urbanity and rurality in the 21^{st} century and beyond.

In a nutshell, science needs to support the following key elements of an overall climate change management scheme:

I. Avoiding the Unmanageable;
II. Managing the Unavoidable;
III. Accelerating the Transition to Sustainability.

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The role of the biosphere in the carbon cycle

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The present concentration of carbon dioxide (CO_2) in the atmosphere is higher than in the past 420,000 years or maybe even in the past 20 million years, and it continues to rise. The primary causes are fossil fuel combustion and deforestation. Globally, the land biosphere (excluding the part subject to deforestation) takes up 30% of the fossil fuel emissions and thus is presently reducing the speed of anthropogenic climate change. Yet our understanding of this carbon sink, which is mainly located north of the Tropics, its partitioning between Europe, North America, and Asia, its controlling mechanisms and its vulnerability to changes in climate and land management are still uncertain. Coupled climate models indicate that, in the near future, carbon (C) release from existing C pools in the biosphere could be large enough to offset any attempts of technical CO_2 emission reduction. Meeting the scientific challenge of establishing the full carbon budget of a continent with acceptable accuracy has also high political relevance because the Kyoto Protocol includes carbon sources and sinks in the terrestrial biosphere.

CarboEurope-IP aims to understand and quantify the present terrestrial carbon balance of Europe and the associated uncertainty at local, regional and continental scale.
The key innovation of the CarboEurope-IP is in its conception as to apply single comprehensive experimental strategy, and its integration into a comprehensive carbon data assimilation framework. The observational and modelling programme will run at unprecedented spatial and temporal resolution. This will allow for the first time a consistent match of bottom-up and top-down estimates of the regional variation in carbon sources and sinks.

In order to achieve these aims, CarboEurope-IP addresses the three major topics:

1. Determination of the carbon balance of the European continent, its geographical patterns, and changes over time. This is achieved by (1) executing a strategically focused set of surface based ecological measurements of carbon pools and CO_2 exchange, (2) further enhancement of an atmospheric high precision observation system for CO_2 and other trace gases, (3) execution of a regional high spatial resolution experiment, and (4) integration of these components by means of innovative data assimilation systems, bottom-up process modelling and top-down inverse modelling. The key innovation of the CarboEurope-IP is in its conception as to apply single comprehensive experimental strategy, and its integration into a comprehensive carbon data assimilation framework. It is solving the scientific challenge of quantifying the terrestrial carbon balance at different scales and with known, acceptable uncertainties. The increase in spatial and temporal resolution of the observational and modelling program will allow for the first time a consistent application of a multiple constraint approach of bottom-up and top-down estimates to determine the terrestrial carbon balance of Europe with the geographical patterns and variability of sources and sinks.

2. Enhanced understanding of the controlling mechanisms of carbon cycling in European ecosystems, and the impact of climate change and variability, and changing land management on the European carbon balance. This is achieved by (1) the partitioning of carbon fluxes into their constituent parts (assimilation, respiration, fossil fuel burning), at local, regional and continental scales, (2) the quantification of the effects of management on net ecosystem carbon exchange based on data synthesis, and (3) the development, evaluation and optimisation of ecosystem process models.

3. Design and development of an observation system to detect changes of carbon stocks and carbon fluxes related to the European commitments under the Kyoto Protocol. This is achieved by (1) atmospheric measurements and a modelling framework to detect changes in atmospheric CO_2 concentrations during the time frame of a Kyoto commitment period, and (2) the outline of a carbon accounting system for the second Commitment period based on measuring carbon fluxes, stock changes by soil and biomass inventories, vegetation properties by remote sensing, and atmospheric concentrations.

Climate change impact on the water cycle and resources, link to extreme events

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Changes in the hydrological cycle induced by global warming may affect society more than any other changes, especially with regard to flood and drought risks, changing water availability and water quality. Increasing levels of greenhouse gases are expected to significantly affect the global water cycle leading to large changes of rainfall. Unlike temperature, however, precipitation is strongly determined by the detail of the atmospheric circulations and it has proved difficult to reach a consensus on how the patterns of rainfall will change in space and time. The details of how catchments respond will depend on both the regional climate change and the characteristics of the catchments. The climate system is a global, coupled system, thus tele-connections link seasonal and inter-annual climate variability between regions (often associated with ocean anomalies, such as El Niño or the North Atlantic Oscillation). It is therefore important to consider the water cycle globally.

To date, the projection of potential impacts of climate change on the hydrological cycle has relied on projections from global, and nested, regional climate models (GCMs and RCMs). In these models hydrological processes are currently only crudely represented. Thus, future changes in some components, such as precipitation, evaporation, runoff, and precipitable water content can be captured in only a general fashion, i.e. for large areas and basins. Detailed changes, in the regional components of the hydrological cycle, such as groundwater, snowmelt, permafrost and wetlands, are poorly resolved. In addition, several anthropogenic influences on the hydrological cycle are generally not considered within current climate models, such as irrigation, large water storage & regulation facilities like dams and agricultural land use changes and management. This limited physical representation of the hydrological cycle precludes the realistic simulation of all of its components in full detail in space and time. As a result, the current practice of assessing the impacts on water resources involves, in most of the cases, a one-way linking of the outputs from the climate models to 'off-line' local hydrological models. This causes many inconsistencies in both scales (of time and space) and process descriptions; the impacts of the interactions and feedbacks between the components are also lost. There is therefore a need to develop a new conceptual and modelling framework which would connect the climate, hydrological and water resources assessment models in a consistent way, to consolidate this framework with the observed patterns of the hydrological and water resources system in the past, and finally to provide a comprehensive assessment of the current and future global water cycle and water resources vulnerability.

The presentation will cover the hydrological and climate aspects of the present and future global water cycle, and related water resources status, by explicitly addressing:

- the current global water cycle, especially causal chains leading to observable changes in droughts and floods
- how the global water cycle and the extremes may respond to future drivers of global change
- feedbacks in the coupled system as they affect the global water cycle
- the uncertainties in the predictions of coupled climate-hydrological- land use models
- the future vulnerability of water as a resource, and in relation to water/climate extremes related risks

SESSION II

CHANGES IN ATMOSPHERIC COMPOSITION AND OZONE DEPLETION

Atmospheric Chemistry and Climate in the 'Anthropocene'

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Abstract:

Despite their relatively small mass, 10^{-5} of the earth biosphere as a whole, generations of ambitious 'homo sapiens' have already played a major and increasing role in changing basic properties of the atmosphere and the earth's surface. Human activities accelerated in particular over the past few hundred years, creating a new geological era, the 'Anthropocene', as already foreseen by Vernadsky in 1928: "…the direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater influence on their surroundings."

Vernadsky's predictions were more than fulfilled. Human activities are affecting, and in many cases out-competing, natural processes, for instance causing the 'ozone hole', the rise of greenhouse gases with their impact on climate, urban and regional air pollution, 'acid rain', with all their consequences for human and ecosystem health. These problems are also increasingly affecting the developing nations of the world. Despite the tremendous progress that has been made, major questions remain and much research needs to be done.

There are major uncertainties regarding future human activities and their impact on climate and environmental chemistry. Some examples are given. Because major impacts, for instance global warming beyond the 'tolerable window', > 2°C or 0.2°C/decade, cannot be excluded, it is proposed that research on climate engineering should not be tabooed anymore, for instance through enhancing earth's albedo by injection of H_2S in the stratosphere. An alternative is injection of soot particles. The albedo enhancement should only be conducted if research shows that it leads to positive results.

Stratospheric ozone depletion and UV-B radiation

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The stratospheric ozone layer is a crucial, and fragile, component of the global environment system. Ozone filters potentially harmful solar UV radiation; it is an important greenhouse gas; stratospheric ozone is an important source for the troposphere. Changes in ozone in the stratosphere could therefore have a damaging impact on surface biological processes, could directly affect climate change and could influence changes in the tropospheric oxidizing capacity, with potentially important feedback consequences.

During the last 15 years, a programme of European research, coordinated through the European Commission, has played a major role in advancing our understanding of stratospheric ozone. In particular, Arctic ozone depletion has been documented in detail and many of the major chemical, dynamical and microphysical processes have been elucidated. Similarly, understanding of the processes responsible for middle latitude ozone depletion has also advanced considerably. This has only been possible because of European-wide collaboration which enabled major field campaigns, on a scale greater than individual European countries could contemplate, to explore the fundamental processes. A balanced programme of field and laboratory measurements, complemented by numerical modelling, is an essential part of this strategy.

Major progress has been made, but much remains to be done. In particular, we now understand that questions about the future state of the ozone layer (‘*ozone recovery*’) are not simply atmospheric chemistry questions but are fundamental to the debate about chemistry-climate interactions. Furthermore, these are no longer specifically questions about the stratosphere but are now seen also to relate directly to the tropospheric system – they are ‘whole-atmosphere’ questions.

Specific research activities must continue to focus on the lower stratosphere and upper troposphere. This is the region where there has already been large ozone change, where changing chemical and dynamical processes both play a role and where the change in ozone has its largest impact on climate and (because most ozone resides here) on surface UV. The ongoing IP SCOUT-O3 is addressing some of these questions. The atmospheric chemistry modelling community in Europe is strong, having led the way in the development of chemistry-transport models (chemical models whose transport is based on analysed wind fields), and this expertise is now leading to a strong chemistry-climate modelling programme. SCOUT-O3 is thus playing a leading role in international programmes (e.g. through WCRP SPARC and its initiative in process-oriented validation) and international assessments (e.g. the ongoing WMO/UNEP assessment of the state of the ozone layer) and is expected to lead to new knowledge in this area.

SCOUT-O3 has also just completed a major tropical field campaign, aimed at understanding the role of tropical clouds and aerosols as well as investigating the exchange of air between the tropical troposphere and the lower stratosphere. Central to the latter issue is an improved understanding of the tropical tropopause transition layer (TTL), only recently recognised as being fundamentally important for the evolution of the coupled chemistry-climate system. The SCOUT-O3 field data are now being analysed in detail. First complementary theoretical investigations suggest that our earlier ideas about transport to the stratosphere will require important revision. In particular, it is becoming clear that transport into the bulk of the stratosphere may be quite different, and much slower, than transport to the extratropical lowermost stratosphere (one of the crucial regions for ozone, and climate, change). Transport of water vapour, for a long period a primary research focus, may not be the most useful paradigm for the transport of other chemical tracers.
A number of inter-related scientific questions, all central to the chemistry-climate issue, are currently highly relevant. These include:

1. The recovery of the ozone layer. We still do not understand the detailed future evolution of the ozone layer, both in middle and high latitudes. In particular, might future cooling in the Arctic lower stratosphere lead to periods of increased threat to Arctic ozone before recovery

commences? How will changes in temperature, transport and composition in the lower stratosphere affect the middle latitude ozone development?

2. Stratosphere-troposphere exchange. Our understanding of the fundamental processes is still incomplete. Much remains to be done, especially in tropical latitudes. Are there preferred regions, and periods, for transport to the extratropical lowermost stratosphere *and* to the bulk of the stratosphere? Will transport from the stratosphere to the troposphere increase with climate change and what will be the impact on tropospheric oxidizing capacity?

3. The role of the troposphere. How will changes in the troposphere affect the stratosphere? Will tropical convection increase in a future climate, leading to increased troposphere-to-stratosphere transport? What are the potential impacts on the stratosphere? How will wave forcing of the stratosphere change?

4. Very short-lived substances. The importance of very short-lived halogenated substances is currently a topic of heated debate. What is the quantitative role of these compounds? It is clear that some brominated species must play a role in the lowermost stratosphere. Are short-lived chloro- or iodo-compounds also important? How might their role change in the future? For example, could a climate-induced change in biospheric emissions be important?

These issues are related and require a combined measurement (field and laboratory) and modelling approach. Many of the open questions concern the tropics where population and emissions are expected to increase rapidly during the coming century. One important question is how we should address scientifically the issue of increased Asian emissions. If our current thinking on troposphere-to-stratosphere exchange is correct, the Asian monsoon could lead to the rapid transport of surface pollution into the upper troposphere and then into the lowermost stratosphere, with important consequences for the ozone layer and climate. A fundamental, interdisciplinary international approach is required.

Changes in tropospheric composition

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Changes in atmospheric composition directly affect many aspects of life, determining climate, air quality and atmospheric inputs to ecosystems. In turn, these changes affect the fundamental necessities for human existence: health, food production, and water availability. It is now well recognized that human activities have perturbed the chemical composition of the atmosphere on local, regional, and global scales. These perturbations arise from i) emissions from fossil fuel/bio fuel combustion and other industrial processes; ii) anthropogenic enhancements of biomass burning; iii) human-induced land-use changes. On regional scales, air pollution is a serious and growing problem in many parts of the world. In the industrialized mid-latitudes of the Northern Hemisphere, elevated concentrations of ground-level ozone and particulate matter are of concern from a human health perspective. Moreover, since the world's major agricultural regions are co-located with industrialized regions in the northern mid-latitudes, the impacts of regional air pollution on world food production can be significant. In other regions of the world, such as tropical and extra-tropical Asia, Africa and South America, anthropogenic emissions, which are already quite high, are projected to increase substantially in the coming decades as a result of the increasing energy and food demands of a growing population. In addition, the development and growth of mega-cities and urban conglomerations will necessitate their consideration in studies of regional and global atmospheric chemistry. The past decade of international research has clearly revealed a large number of atmospheric chemistry issues facing society as well as the challenges of studying and managing an integrated Earth System.

I. INTRODUCTION

Over the past century, humanity has been altering the chemical composition of the atmosphere in an unprecedented way, over an astonishingly short time. In many respects, the influence of mankind on the environment justifies the definition of a new geological epoch: the Anthropocene [Crutzen, 2002]. World-wide emissions from growing industrial and transportation activity and more intensive agricultural practices have caused widespread increase in atmospheric concentration of photochemical oxidants, acidic gases, aerosols, and some toxic chemical species. Many of these air pollutants are known to have detrimental impacts on human health and/or natural and managed ecosystem viability. Furthermore, higher fossil fuel consumption coupled with agriculturally driven increases in biomass burning, fertilizer usage, crop by-product decomposition, and production of animal-based food have led to increasing emissions of key greenhouse gases, such as carbon dioxide, methane, and nitrous oxide. The net effects of the build up of radiatively active trace gases and the changing burden of atmospheric particles appear to be responsible for much of the climate trend observed during the 20th century, particularly the warming over the last few decades [IPCC, 2001]. Predicted impacts of climate change include disruptions of agricultural productivity, fresh water supplies, ecosystem stability, and disease patterns. Significant increases in sea level and changes in the frequency of severe weather events are also forecast. The resulting effects of all these stresses on biogeochemical cycles could exacerbate changing atmospheric composition and result in further effects on climate. If current trends are unchecked, much more significant warming is predicted, potentially driving a wide range of perturbations in other components of the climate system.

II. STATE OF THE ART IN ATMOSPHERIC COMPOSITION CHANGE

The notion has emerged in recent years that the Earth is operating as a single system in which the biosphere has an important active role. The Earth System can be represented as an ensemble of compartments among which a constant exchange of matter and energy occurs (Fig. 1). The atmosphere is the gaseous envelope surrounding the globe, while the hydrosphere includes all oceans and freshwater bodies on the planet. The lithosphere defines all rocks on Earth exposed to the atmosphere or underwater, while a further compartment comprises soils and sediments. The most important characteristics of the Earth System is however the existence of the biosphere which comprises all living organisms on the planet, including us humans, and which exists in all other compartments: the atmosphere, the oceans, the soil.

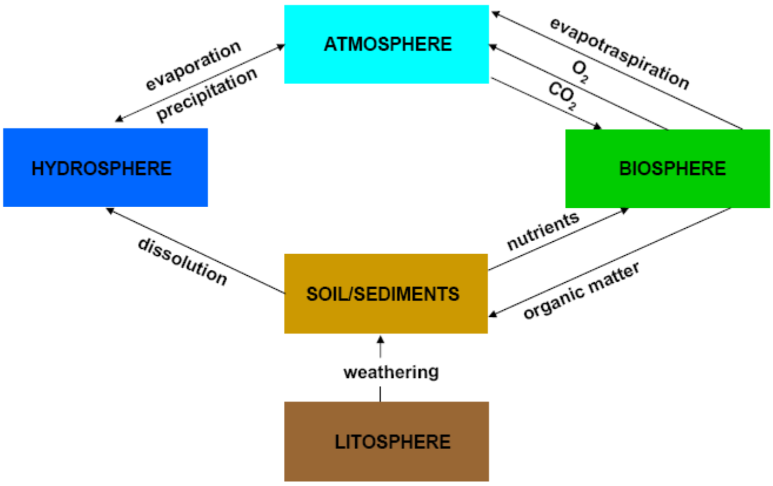

Fig. 1 – The compartments comprising the Earth System and some main transfer processes among them. The biosphere, being present within all other compartments, has an important and regulating role of the whole System.

Understanding the Earth System is crucial to achieving sustainable development. Improved knowledge on global change processes and the interaction with human activities is required to implement policy objectives on human welfare and safety, protection of the environment and economic development [Steffen *et al*., 2004].

Within the Earth System, the atmosphere has a central role since it is the most sensitive compartment where changes induced by anthropogenic activities show up first and most clearly. Considerable progress in knowledge has already been achieved in the area of atmospheric changes and the past decade has seen global atmospheric chemistry research blossom. We have learned much about the global cycles (sources, transformations, and sinks) of the most important atmospheric chemical species. Existing satellite observations have provided a wealth of data regarding the chemical composition of the atmosphere, and new satellite instruments have recently been or are about to be launched. Multi-platform studies of atmospheric chemical processes have been conducted on an unprecedented scale. Global chemical transport models can now simulate with some success the distribution of key tropospheric chemical species, and are capable of simulating future global atmospheric composition scenarios. Furthermore, short lived, radiatively active substances such as ozone and aerosols are now incorporated as active constituents in most global climate models. As scientific understanding of the elements of atmospheric chemistry has been developed, the necessity of understanding the linkage between atmospheric composition and other components of the Earth System has been realized more explicitly. Ten years ago, the concept of having an Earth System level view was a rather abstract idea. Feedbacks between, for example, changing climate and changing terrestrial emissions, or changing climate and atmospheric chemical composition, were not included in models. Now, we are on the threshold of a more quantitative understanding of the role of atmospheric chemistry in Earth's System processes and of developing strategies to integrate that knowledge into a predictive capability [Brasseur *et al*., 2003].

Although substantial advances have been made in understanding fundamental processes in the chemical system of the atmosphere, our predictive capability remains limited in spite of its importance for informed decision making. The uncertainties in our forecasts of air quality and climate change are still high. In addition, new and challenging problems at the chemistry/weather, chemistry/climate, and chemistry/ecosystem interfaces are emerging and will require much attention in the future.

European research in the past decade has made considerable progress in studies of atmospheric changes through international programmes supported by the EU Framework Programs. Important achievements of EU projects involve issues such as tropospheric ozone changes, emission sources of air pollutants and greenhouse gases, aerosols, clouds and climate research. European scientists also contributed strongly to innovations in satellite remote sensing. These research activities are often part of larger international efforts such as the International Global Atmospheric Chemistry Project (IGAC) of the International Geosphere-Biosphere Program (IGBP) and the Global Atmospheric Watch (GAW) of the World Meteorological Organisation (WMO). Many European atmospheric scientists have key coordinating roles within these International Programmes.

Among the various European programs in this field it is worthwhile to mention the Network of Excellence ACCENT (Atmospheric Composition Change: the European Network of Excellence), presently operating within the 6th Framework Program (http://www.accent-network.org/). The overall aim of ACCENT is to promote a common European strategy for research on atmospheric composition change, to develop and maintain durable means of communication and collaboration within the European scientific community, to facilitate this research and to optimise two-way interactions with policy-makers and the general public. ACCENT provides a framework for co-ordination and communication among the European research community and will thereby have the effect of restructuring European research on the sustainability of atmospheric composition, leading to a durable integration.

III. FUTURE PERSPECTIVES

A more quantitative understanding of the role of atmospheric composition change in Earth's System processes and the development of effective strategies to integrate this knowledge into a predictive capability require that the atmospheric chemistry community is capable of:

i) accurately determine global distributions of both short and long lived chemical components in the atmosphere and document their changing concentrations over time;
ii) providing a fundamental understanding of the processes that control the distribution of chemical components in the atmosphere and their impact on global change and air quality;
iii) improving the ability to predict the chemical composition of the atmosphere over the coming decades by integrating the understanding of atmospheric processes with the responses and feedbacks of the Earth System.

This knowledge will provide decision-makers with the tools necessary to develop appropriate, science-based policies to manage the health of our atmosphere and its role in global change. Enhanced outreach to the public will be vital to ensure that the new knowledge results in changes in public attitude, policy and legislation.

The Science Panel on Atmospheric Research, appointed by the European Commission, has recently suggested some key research areas to be developed with the aim of advancing understanding of the Earth System (Lelieveld *et al*., 2005).

- *Biogeochemical cycles and climate:* First, anthropogenic perturbations of the nitrogen cycle are vast owing to energy use as well as planned and inadvertent fertilisation of agricultural land and natural ecosystems. This has a multitude of consequences, e.g. for the carbon cycle. Second, emissions of volatile organic compounds from the marine and terrestrial biosphere, and their role in atmospheric composition, the carbon cycle and climate are poorly understood.
- *Atmospheric self-cleansing capacity:* Tropospheric ozone and the hydroxyl radical play a central role, and large global concentration and distribution changes may have taken place in the past. Although the tropical troposphere may be regarded as the key area for atmospheric oxidation processes, our knowledge e.g. about the role of the biosphere as well as the observational data base for this part of the globe are insufficient to assess future developments.

- *Lower-middle atmosphere interactions:* Changes in the composition in both the troposphere and stratosphere have previously unanticipated consequences through intimate dynamical coupling mechanisms. A better understanding is important to monitor and predict the state of the ozone layer, and also has the potential to improve medium to long-range weather and climate forecasting.
- *Aerosols, clouds and the water cycle:* Anthropogenic aerosol particles perturb radiation transfer and heating rates in the atmosphere, surface warming, evaporation, clouds and precipitation. This contributes to climate change and likely has substantial effects on the water cycle, including the development of severe storms and lightning.
- *Global change and radiation transfer:* Atmospheric radiation transfer is controlled by the sun, the atmospheric composition, clouds and surface properties, which undergo natural variability and anthropogenic changes. Their quantification is of key importance to assess present and future levels of ultraviolet radiation and climate forcings.
- *Air quality, megacities and global change:* The growth of large urban conglomerates with more than ten million people largely takes place in the developing world, in particular Asia. The rapid global urbanisation is associated with new environmental problems, however, it also presents new opportunities to decrease local, regional and global air pollution.

In order to foster the scientific agenda in global change science, investment in top-level research infrastructures is needed. Laboratory infrastructures, long-term monitoring networks, research aircrafts, super-computer facilities, satellites are among the priorities in this field.

Last but not least, global change science implies collaboration among scientists of different disciplines such as chemistry, physics, biology, and other applied sciences. In addition, since the concept of Earth System takes into consideration the human society in the functioning of the system itself, this approach tends to shade the barrier between natural sciences and social sciences (economy, sociology, history, law…) and this is a further challenge that atmospheric scientists shall not miss.

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SESSION III

NATURAL HAZARDS:
PREVENTION, RISK MANAGEMENT,
MITIGATION AND FORECASTING

Natural hazards and economic impact in Europe: some concepts for the 7FP

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Human and economic losses due to natural disasters (e.g. floods, storms, earthquakes etc.) continue to increase world-wide. According to Munich Re, in 2004 more than 180.000 people died world-wide as a result of natural and technological catastrophes. The number of Natural Hazard events came to around 650, economic losses rose to over 120Bn Euro.
The high importance of disaster reduction policies was highlighted at the UN-World Conference on Disaster Reduction, organized by UN-ISDR on 18-22 January 2005 in Kobe, Japan. As a consequence there is a need to integrate knowledge and to update the state of art into a disaster management approach that reflects the complexity of the modern society in a realistic way and therefore can better support actions for disaster and vulnerability reduction. This is of paramount importance since the European Commission is in the process of launching the new 7th framework programme, which has to be adapted to the current social and economic European situation.

Currently disaster management approaches at European level suffer from four main restraints:

1. There is no common shared strategy at European level for the prevention and mitigation of natural disasters, especially when dealing with the integrated and combined impacts of natural hazards on modern society including secondary social effects. Main initiatives in progress are on regional or national level (i.e. landslides and floods risk maps adopted by river basin authorities in Italy, Plans d'Expositions aux Risques at municipality scale in France). As disasters are often affecting several countries, with heavy cross-boundary effects originated in one country and impacts in others, there are some EU initiatives (e.g. the current preparation of an EU Action Programme on flood risk management) but these generally focus on a very specific target and are often mono-disciplinary. This aspect is now becoming more and more important since the new 7th framework programme should incorporate and address the gaps in previous programmes, which have certainly been more oriented to solving single problems than to integrate knowledge, technology and prevention/mitigation policies.

2. The theoretical approach of "natural and induced technological disaster management cycle" does not reflect the complexity of reality. There is the need for a modern "disaster science" which can better deal with complexity and dynamic systemic interactions. The commonly accepted and standard "natural and induced technological disaster management cycle", including stages of prevention, mitigation, preparedness, response and recovery is a theoretical view that is usually marginally working in practice. This is especially the case in the context of a modern European society that is more and more characterised by complex impacts and secondary societal-economic losses. The major critical uncertainties of the ongoing model (Figure 1) are:
   - Scientific gaps (e.g. in risk assessment including understanding of frequency and trigger mechanisms for a specific typology of hazard and problems of data production and availability);
   - Cultural gaps (i.e. disregarding of vulnerability, disasters domino effects, NaTech scenarios);
   - Technological availability, demands and constraints (e.g. integration between remote sensing and ground based instruments for early warning – for a specific typology of hazard);
   - Plurality of approaches for different mitigation and management contexts (e.g. spatial planning, structural engineering, emergency planning, community preparedness and vulnerability);
   - Scale issues and institutional arrangements (e.g. local and regional spatial planning and emergency management for a specific type of hazard);
   - Conflict between long-term (e.g. sustainable development) and short-term strategies (e.g. emergency management).

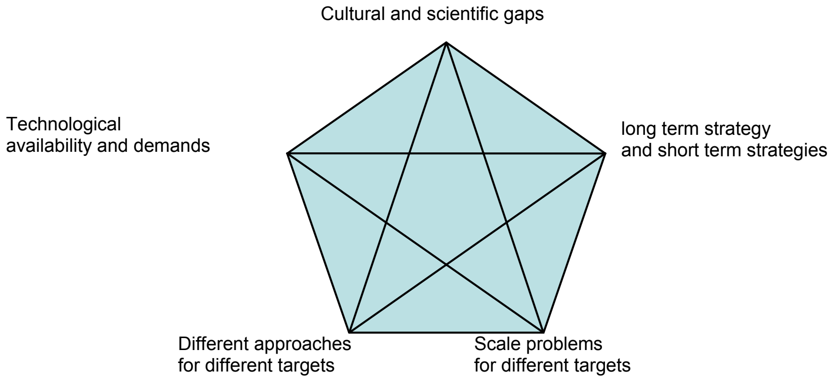

Figure 1 – Uncertainties in the natural and technological disaster management cycle

These points are all interlinked. The cycle of disaster management largely starts from scientific knowledge that is limited to a single form of hazard/risk assessment (mostly by Earth Scientists). So far, only a few studies and applications have been dedicated to merging the various hazards and risks into a multiple analysis and understanding their synergistic interactions and implications. In addition, some hazards are still poorly developed in specific sectors of risk assessment (i.e. vulnerability analysis for landslides). On the other side, the various scales of analysis affect approaches and methods (being data dependent) for the same target of the exact definition of risk. The frequency and magnitude of events influence the implementation and adoption of sustainable mitigation strategies. The effective use of available technological tools in the field of disaster management by stakeholders and end-users is not common in many European countries, especially some of the new member states. Finally, the necessity to have real-time tools and technology is largely claimed by spatial planners and policy makers. This is especially important for the crisis and response phase, however much more information should be enriched with data.
A new approach for the harmonization and further development of all components of the "disaster cycle" is needed.

3. It is clear that most knowledge is existing in the first dimensions of the Logic Value Chain on natural disaster analysis and risk management and the least about the third (Figure 2).

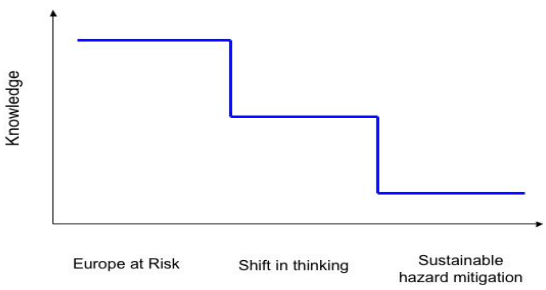

Figure 2 – Potential distribution of knowledge on the three steps of the Logic Value Chain

Sustainable hazard mitigation programmes addressing both the short and long term consequences of their implementation in a holistic manner and building greater resilience, have not been adequately included in the agenda of European stakeholders and scientific research. Coping with natural hazards and disasters today require a refinement of the process, in order to minimise and/or redistribute losses and reducing environment, social and economic disruption. The impacts of natural hazards on modern society today will cause more losses than in the past. Europe needs to be ready to prepare a more resilient society for future generations (sustainable hazard mitigation).

Geological hazards (Earthquakes, Volcanic Eruptions, Landslides and Tsunamis)

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While half of the world population is living in a zone where at least one natural hazard exists, research and operational investigations are difficult to achieve considering the long-term issues natural hazards may induce in our more and more fragile society.

We essentially consider hazards related to the solid envelop in this presentation although tsunami hazard is included because it often comes from submarine landslides and/ or earthquakes and because its impact is when waves hit the coastline. Moreover, most research issues are coming from the initial excitation and from the final run-up. Finally, inundation hazard is often tackled through the fluid envelop community although water saturation of the ground is a key issue of inundation estimation. We may certainly suggest that this natural risk should be partially included in the item of geological hazards somehow in the future.

These hazards are complex to estimate because time scales for building up them are much longer than for the ocean and atmosphere envelops ranging from 1000 years over 1 Ma. Moreover, the event may last few seconds for earthquakes without no warning we do detect up to now to years for volcanic reactivation before the sudden eruption. Landslides may be built over a century before the final collapse. Finally, tsunamis may travel in hours and predicting where the wave will hit coastlines is possible when a fast and coherent alert is performed.

Because of specificities of each geological hazard, presenting issues in a single run is very challenging. One must underline that in-situ measurements through long-term monitoring are still not achieved although new technologies are available to both record signals, store them and analyze them both for operational issues and research investigations. As recommended by GEMS, combining dense and repeatable spatial measurements as well as in-situ measurements is a key for success.

Challenges in the future will certainly require a combination of dense high-quality measurements with more and more realistic modelling using assimilation techniques through inversion techniques.

Estimation of impact zones of these catastrophes requires mitigation which can be achieved only with well-coordinated societies and with well-educated population. This will be certainly the most challenging aspect of the risk mitigation which should be tackled modestly by small steps.

Let us consider more specifically the four different geological hazards we investigate

Seismic Hazard: this hazard is difficult to estimate both in its amplitude and in its impact. Therefore, its difficult mitigation requires intensive research activities concentrated on different aspects as

- Signals prior an earthquake: heavy instrumentation (spatial and in-land ones) and better understanding of fluid/rock interactions are necessary
- Characterization of the event in real time: recording seismic signals is no more an issue and collecting seismograms in real time is no more the exclusivity of seismologists. Time responses of modern networks should be measured in seconds and provide information for better mitigation and management. It has also impact on tsunami mitigation eventually. Because the time window we have from paleoseismology, historical seismology and instrumental seismology is so short compared to characteristic times of building up stresses before failure in the crust, we still face the problem of precise possible earthquakes in seismic zones. One may say that this investigation is a on-going process which will never end and on which we should proceed using both geological and seismotectonic information. We need information for extended-finite sources making the physics of earthquakes an challenging and exciting field.
- Characterization of ground shaking moves from probabilistic towards deterministic approaches and one may question where is the boundary between them. In other words, what is the

knowledge of the medium required for such evaluation of ground motion. Up to now, it is not at the scale of the precision we achieve for reservoir monitoring. Characterization will be performed by dense networks of instruments whose records may be used as a remedy when describing the medium becomes too difficult. Although modelling has moved to 3D geometries, the introduction of complex rheology with non-linear behaviour is still an issue and certainly where the modelling will have to make a break-through by considering porous media with fluid interactions. With better constraints on expected seismic earthquakes spatially and in intensity and with better descriptions of the crustal model where waves propagations.

We shall expect in the future procedures for assimilation of more and more dense records in a way to mimic the meteorological strategy for better fitting observations by improving models of sources and media. Therefore, dense and affordable networks as performed in Japan should be deployed using new technologies.

Of course, we have restricted our analysis to hazards but one should mention vulnerability estimations and issued in order to reduce this vulnerability at a cost affordable by the society.

Volcanic Hazard: this hazard is spatially easier to investigate than the previous one although it may be more difficult to follow a crisis period because it may last for years when first geochemical signals demonstrate a change in the volcanic behaviour. The complexity of the different interactions between fluid, gas and rocks makes this hazard difficult to quantify and, therefore, predict the paroxysm of the crisis is difficult if not uncertain. In Europe, volcanoes are mainly equipped for surveys and seem to be under-instrumented for research issues as understanding magma transfer, fluid penetration, structure stability and so on.

Through geochemical analysis of traces, one may investigate residence times and significant improvement has been performed along these lines, while depth and geometries of associated reservoir are still poorly determined.

Monitoring the deformation of these instable structures is of key importance and both inclinometers, GPS measurements and SAR images should be promoted. Understanding mechanical behaviours require characterisation of the volcanic structure and significant effort should be performed for better and better description of each dangerous volcano as done for an oil reservoir. This requires electric, gravimetric and seismic surveys at a scale not yet achieved.

Eruption should be modelled more and more quantitatively and information collected for initial particle conditions at the top of the volcano are essentially as well as a fine description of gas particles for better fluid modelling.

Understanding how a geographically well-defined zone is behaving is not unreachable: with new technologies, dense monitoring of volcanic areas is possible for both survey and both research investigation.

Landslide Hazard: this hazard is quite insidious because only careful investigation always detection of instable zones. Interaction between fluids and rocks is a key issue and monitoring should be performed at different scales.

Again, it requires characterisation of the medium using geophysical investigation. Geochemical analysis will help understanding what is the water circulation, a key element in landslide evolution. Rockfall may come from temperature constrast and any mechanical constraint of the material may speed up degradation and, therefore, instability.

Understanding what is the best description for better mechanical behaviour of landslides is a key issue and efforts for coupling hydro-thermo-mechanical features both for measures and for modelling will be necessary in the future.

In case of failure, the impact zone estimation is difficult and requires more complex modelling than only a fluid transportation. Quite dense materials may be transported along large distances with mechanisms to be better understood.

Tsunami Hazard: this hazard is well defined in terms of geographical zones (the coastline) along which necessary and careful quantification of impacts is necessary taking into account that these zones are often of economical interest. Bathymetry at all scales is a key ingredient while wave simulation could be improved for tuning precisely run-ups.

Modelling by including more and more features as attenuation, wave interactions and so on are essential keys of quantified impacts.

Near-field event as a local landslide and/or a local earthquake inducing a tsunami should be investigated because time is short for warning. Precursory event detection as well as periodic bathymetric surveys should be performed in order to preamp any anomalous feature.

Far-field event requires both research and operational efforts because effects are predictable, manageable and simple measures of protection are possible.

Confirmation of the wave excitation should be performed by real-time tide gauges and microbarometric deep-water sensors. Early warning system is possible for tsunamis and coastal storms in the future by combining warning systems of earthquakes and tide detection.

Climate Related Hazards: Prevention, Risk Management, Mitigation and Forecasting

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I. THE HAZARDS

Much of this contribution to the symposium is written from the perspective of flood management but issues on risk management are common to natural hazards more broadly.

Here we define a hazard as a situation that has the potential to cause harm. Hence we take an anthropocentric viewpoint (no humans, no hazards and certainly no risk). Hydro-meteorological hazards in their most generic form derive from precipitation, wind speed, thermal conditions and transport of air-borne pollutants and pathogens. Fluctuations in these quantities may occur over a wide range of temporal and spatial scales. Human life, society etc is generally well adapted to the status quo – the climatic average and "normal" variability; it is the variations beyond the normal that mainly give rise to the natural hazards such as:

- floods (flash-floods, extensive floods of lowland plains, groundwater floods),
- avalanche (snow / rock),
- landslide, mud and debris flows – often in conjunction with floods
- storm surge, storm wave leading to inundation of coasts and estuaries
- windstorm and tornado
- drought

This contribution to the symposium concentrates on issues associated generally with short-term precipitation extremes at a variety of spatial scales. In flooding, the greatest risk to life occurs in unexpected flooding whether from flash flooding from rainfall or from large waves close to the shoreline. Heavy rainfall also can trigger land instabilities, with landslides posing a substantial risk to life and property in certain areas of Europe. Economic and property damage is often most severe for events with a large spatial scale – major basin floods or coastal surges. However, triggering mechanisms for floods can also depend upon longer term climatic conditions such as seasonal accumulations of snow or, for landslides, the season-scale accumulation of rainfall. The social and economic impacts of natural hazards are well documented elsewhere; see for example the recent report of the European Environment Agency (2003).

II. PREVENTION AND MITIGATION

The word "prevention" perhaps should not be used for climate related natural hazards since technologies are not available to influence the meteorological conditions that cause the hazards and any actions to reduce human-induced climate change will only have an influence in the long-term. Nevertheless, "flood prevention" for example was a widespread policy aim in the last century. In Hungary the national concept of "flood fighting" portrays the struggle between the community and the natural forces of the river and this is similar to the notion in many countries of providing flood defence, protection or prevention. All these terms indicate a philosophy of human control over nature and the protection of property against the "common enemy" of the elements.
Now the position is that of flood risk management (Samuels *et al*, 2005); this builds on the developments in the research community, sponsored nationally and at a European level. Typically a strategy for flood risk management will combine a number of mitigation measures. The design of effective mitigation measures requires a sound understanding of the physical and social factors which contribute to the overall risk. For example, the recently completed IMPACT project of FP5 examined

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processes which operate in extreme floods (www.impact-project.net); the outcome of the research on the failure of embankments is that the best performing models are now available from Europe. The FP5 Action MITCH extracted commonalities from completed FP4 research on floods, droughts and landslides (see Fuchs (2006) or www.hrwallingford.co.uk/Mitch/default.htm). The FLOODsite project is undertaking research on both physical and social issues to provide tools and techniques for risk management with training and dissemination strategy to facilitate implementation and uptake of the research outcomes.

III. RISK MANAGEMENT

The benefit to society from research on climate related hazards will come through better risk management. In discipline of risk management, "risk" is no longer taken as a synonym for "hazard" but is a combination of both the hazard and the consequences that follow from that hazard happening.

Over the past decade or so concepts around hazard and risk have been clarified, providing a clearer picture of the roles in risk management of the natural hazard processes and the social aspects of the impact of hazards on people, property and the environment. There are many common themes to risk management regardless of the type of hazard that causes the risk. Principal amongst these are

- Applying the analytical model of source, pathway, receptor and consequences
- Describing the hazard in terms of frequency and quantified physical measures
- Identifying areas, communities, physical or environmental assets, social structures, etc (the "receptors") which are exposed to the hazard
- Quantifying the vulnerability of the receptors to harm in terms of susceptibility to various types of damage and a "value" for that damage.

For climate related hazards little can be done with current technologies for affecting the source in terms of strength or probability of occurrence. Thus risk management measures are directed at other aspects of the overall risk through

- altering the characteristics of the pathway
- reducing the exposure of the receptors to the hazard or
- reducing the vulnerability of the receptors to experiencing damage.

These actions collectively are termed "risk management measures" in the FLOODsite Language of Risk (FLOODsite, 2005). Measures which address risk through controlling exposure and vulnerability will be largely non-structural in nature whereas altering the pathway will usually be through structural intervention in the system. Research in FLOODsite has identified the importance of understanding the nature of the risk management process and the roles and responsibilities of all the actors in the decision making (Müller & Schanze, 2005). The portfolio of risk management measures may be classed broadly as those applied in preparation for any event (e.g. spatial planning, contingency planning, and defence infrastructure), emergency measures during an event, and, support and recovery measures after the event.

Understanding and identifying climate-related hazards and aspects of risk management has been undertaken in many EC research projects, see the projects to FP5 listed in Samuels (2003) and the summary by Fuchs (2006) with research continuing in FP6 particularly in the FLOODsite IP and the Armonia STREP on multi-hazards.

IV. FLOOD FORECASTING

Current research on flood forecasting at a European level has a long patrimony, building on projects in FP2, FP3, FP4 and FP5. The ACTIF Accompanying Measure in FP5 acted as a "Cluster" of eight FP5 projects on flood forecasting. The projects represent the state-of-the art in their areas with innovations in a variety of topics including:

- innovative technologies for space-borne and ground-based monitoring;
- the estimation of precipitation in near real time at a global scale

- assimilation of data from a variety of sources with different characteristics into numerical weather prediction and hydrological models
- new and improved modelling techniques;
- the linkage between meteorological and hydrological models;
- spatial recognition and indicators for current state of natural hazards;
- improvements in the dissemination of forecasts and warning;
- practices for emergency awareness, preparedness and operations at both the institutional level and with the individual citizen.

Three projects, ACTIF, FLOODMAN and Flood Relief sponsored a common end-of-project international conference in October 2005. The proceedings of this event cover current issues in flood forecasting worldwide and are available through the ACTIF website (www.actif-ec.net).

V. RESEARCH INFLUENCES ON POLICY AND PRACTICE

Policy and practice on risk management (flood risks in particular) is responding in a variety of ways to knowledge and new techniques arising from research and the need to continue to invest in knowledge; three examples are given below.

The European approach on Flood Risk Management has undergone significant development since 2001. In September 2003 the European Environment Ministers produced the document “Best practices on flood prevention, protection and mitigation”. In July 2004 a Commission Communication was published from the Commission relating to flood risk management and subsequently an Action Programme is under development. The action programme includes: legislative proposals for a new Directive requiring flood risk management plans, research and information exchange activities and funding possibilities for the proposed actions. The action programme and the directive now being drafted recognise the importance of research in improving knowledge and understanding of the management of flood risks.

At a national level, the UK Office of Science and Technology (OST) commissioned the Flooding Foresight project to inform public policy and expenditure by researching the drivers, responses and scenarios for flood risk over a timescale of about 100 years. Flood risk was analysed at a 10km scale for four socio-economic scenarios, which were linked to global emissions scenarios and simulations of future climate. Drivers of flood risks were identified and ranked under each of these scenarios and the potential flood damages estimated for the 2080s. Substantial differences emerged between the scenarios with the damage increasing in all scenarios if current policies are maintained. Nationally, the current annual flood damage is estimated as about €1 Billion, with this rising to over €30 Billion without additional mitigation strategies in the worst scenario. Future flood risks depend strongly on assumptions on global emissions of greenhouse gases; this provides a clear link between international policy and impacts at the national scale. The report (OST, 2004) poses many questions to policy makers such as:

- Should the increasing levels of flood risk be accepted or actions taken to reduce them?
- How important is managing climate change to the risks faced from flooding and how best can this be achieved?
- How should land be used in balancing the wider economic environmental and social needs against creating a legacy of flood risk?
- What is the balance between societal responses to flood risk and the implementation of bigger structural defences?
- Who should pay for flood defence – the balance between government, developers, the individual and insurance?

In FP6, the ERA-NET coordination actions are bringing further structuring of the European Research Area with actions continuing through FP7. In the context of research on flooding issues, the ERA-NET CRUE aims to provide greater cooperation between national research programmes on flooding which together spend in excess of €30 Million per annum in the 25 Member States. The vision for the CRUE is to develop strategic integration of research at the national funding and policy development levels within Europe to provide knowledge and understanding for the sustainable management of flooding risks at the river basin and coastal process cell scale. CRUE is also addressing the pressing need to improve the dissemination of existing research results to derive public benefit from past investment in the generation of knowledge and understanding.

VI. RESEARCH CHALLENGES

The research needs below concentrate on flooding as others at this symposium contribute topics on landslides and drought. These research challenges were drafted following the workshop organised in Brussels by DG Research on 10 October 2005 in response to the summer 2005 flooding. The overall objective is to support sustainable economic and social development without increasing property or people at risk from climate-related natural hazards. Important research challenges remain on flooding issues and processes which are related in particular to extreme events and combinations of natural hazards that have a common driver, for example, landslides and floods generated by rainfall.

- **Databases**
  - European database (with guidance and protocols) for extreme floods allied with other natural hazards recording processes in operation, damages, human and social impacts
  - European meta database on natural hazards research results (project deliverables, models, publications)

- **Multi-hazard issues**
  - Generation of sediment and debris in extreme floods including
    - indicators of sources, likelihood and quantity of debris and sediment generation
    - sediment load from landslides and mud flows,
    - beach / foreshore mobilisation by storm waves
    - floating debris (for example trees, urban trash and vehicles) and
    - large dense material (including boulders and masonry from failed structures)
  - Propagation and fate of debris and sediments in highly unsteady conditions including
    - Effects of debris and sediments on the performance of flood defence infrastructure, blockage of river structures, or damage to properties
    - Impact of short-term morphological change on estimated extent and magnitude of flood hazard (e.g. major accretion in river systems or loss of coastal foreshore)
    - Means of identifying areas at risk from debris and sediment effects
  - Joint occurrence (incl. uncertainty) of related natural hazards
  - Probabilistic real time risk forecasting of multi-hazard events
  - Feasible flood management options and activities accounting for the multi-faceted nature of extreme events

- **Uncertainty issues**
  - Combination and propagation of all sources of uncertainty
  - Contribution of uncertainty to overall assessment of risk
  - Communication of uncertainty to non-scientists

- **Infrastructure performance**
  - Identification, understanding and parameterisation of failure modes and mechanisms
  - Develop techniques and tools for reliability analysis
  - Non-intrusive technologies to measure defence condition
    - Measurement technologies for defence condition (static)
    - Real-time monitoring technologies for changes in defence strength
  - Forecast pathway performance including
    - probability of failures (using real-time monitoring of condition) and effects of debris on system capacity (including blockage of bridges and structures and deposition)

- **Modelling**
  - Improved probabilistic forecasting of flood sources (precipitation, ocean waves, storm surges) based on coupled modelling
  - Flood prediction in ungauged basins

- **Flooding in urban areas**
  - Storm sewerage system performance under intense rainfall or wave overtopping conditions

- Propagation of floods through urban areas from all sources of flood water
- Land use impacts on flooding
- Fate of flood-borne pollutants and pathogens in the urban environment
- Direct impacts of wave, surge and tsunami inundation on people and property
- "Broad-scale" models of urban drainage systems to enable management strategies to be developed at city scale considering of all flood sources and pathways within the urban area

− **Future scenarios for natural hazards and risk including climatic forcing**
- Improved regionalisation at spatial and temporal scales of interest for natural hazards - both deterministic and statistical downscaling
- Changes in extremes and parameters of probabilistic functions as used for technical / engineering design
- Better coverage of feed backs within elements of the terrestrial system and between the terrestrial and atmospheric systems (e.g., with land-use or water supply)
- Scenarios of future management of natural hazards
  - o governance, social, policy, technology
  - o linkage to climate scenarios

− **Socio-economic and institutional aspects of risk management from natural hazards**
- Driving factors and growth indicators of flood risk
- Influencing public understanding and awareness of direct and indirect water-driven risks and their uncertainty
- Valuation methods and tools for flood risk (socio-economics and ecology)
- Institutional issues arising from flood disasters and failures in flood management
- Identifying "tolerable" flood risk taking account of economic and social pressures and contingency plans for extreme events
- Influence of governance strategies on long-term change and management of flood risks
- Influence of land use and management policies on long-term flood risk
- Adaptive strategies (incl. resilience) to manage risk from floods and associated natural hazards
- Institutional arrangements for disaster management and civil protection
- Account for real-time distribution of exposure and vulnerability of receptors

− **Uptake and implementation of research advances (in FP5, FP6 and FP7)**
- Facilitate uptake of flood risk management methodology developed in FP6 for risk management of all hazards
- Identifying and overcoming barriers to end-user acceptance and implementation of research outputs
- Disseminate European flood RTD outcome in a user friendly web portal linked with information on relevant policy demands and end user requirements
- Moving beyond communication and dissemination to operational implementation
- Demonstration and training of research advances in practice
- Practical risk minimisation methods

VII. CONCLUDING REMARKS

Patterns of settlement, land use, flood defence and drainage in Europe have a significant legacy from previous generations of interventions in the natural systems of rivers and flood plains. Seeking the path of sustainable development implies that our generation's risk management practices should not place additional burden on future generations. Hence risk analysis for flood management in current and future conditions should be undertaken to inform policy choices, land use planning and public investment in infrastructure. Past research at national and European level on climate related hazards has brought benefits to European citizens through more reliable means of forecasting and warning, identification of areas at risk of flooding, landslide and avalanche, and, methods for mitigation of the hazards. Scenarios for future climate in many parts of Europe show a significant impact on the hydrological cycle with variations at a range of spatial and temporal scales. Investment in research is essential to provide understanding of climate related natural hazards, whether they arise from trend, regional and seasonal changes or extremes of precipitation and drought.

ACKNOWLEDGEMENT

Dr Anver Ghazi, through his colleagues within his Unit in DG research, guided many of the EC research projects referenced in this paper. In particular, having overseen the negotiations on the FLOODsite project I was delighted that he could welcome us to our launch workshop in July 2004. We miss his wisdom, warmth, friendship and professional support.

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Desertification – Regional Assessment and Monitoring Strategies for a Global Problem

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Desertification is recognised as one of the major threats to the global environment which directly impact on human well-being and social welfare (Millenium Ecosystem Assessment, 2005). It not only affects developing countries but also industrialised nations in semiarid and dry subhumid regions, where land degradation processes cause a severe reduction or loss of the biological and economic productivity. The driving processes are complex, and diverse views exist on the relationship between climatic and anthropogenic causal factors of desertification. Climate sets important boundary conditions, but is not a single or major driver of desertification because typically pulse-driven ecosystems in dry regions have enormous resilience and recovery capacities. Against the background of accelerated climate change, these boundary conditions tend to become more restrictive – although the regional pattern is not yet fully understood. The main drivers of land degradation processes, however, result from the human impact on the delicate balance between the demand for and the supply of ecosystem services in drylands (population pressure, socioeconomic and policy factors, land use practices, globalisation phenomena). Consequently, mitigation is a major component of future research efforts – but it is bound to remain largely inefficient without objective, repeatable and spatially distributed information on the state of ecosystems and available resources. The development of integrated desertification assessment and monitoring concepts therefore remains an important research challenge, as are the improvement of environmental data bases and of terrestrial and space-borne observation systems.

I. INTRODUCTION

Desertification is defined by the U.N. Convention to Combat Desertification as “land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities.” Land degradation is in turn defined as the reduction or loss of the biological or economic productivity of drylands. Desertification takes place worldwide in drylands which occupy 41% of Earth’s land area and are home to more than 2 billion people - a third of the human population in the year 2000 (Millenium Ecosystem Assessment, 2005).

Large areas of the European Mediterranean are affected from transitional processes that cause conflicts between past and present land uses or economic and ecological priorities. The resulting land degradation may be conceived as a process in which disturbances have gone beyond the resilience of the land and have caused an, at human timescales, irreversible loss of the land’s carrying capacity or biological production potential. It embraces all degradation processes which imply a loss of or reduction in potential productivity of the land; assessment concepts must encompass both, physio-geographic and socio-economic, perspectives of the problem (Reynolds and Stafford-Smith, 2002).

II. CLIMATE AND DESERTIFICATION

Desertification can be perceived as result of a long-term failure to balance demand for and supply of ecosystem services in drylands. The pressure is increasing on dryland ecosystems for providing services such as food, forage, fuel, building materials, and water for humans and livestock, for irrigation, and for sanitation. This increase is attributed to a combination of human factors and climatic factors. Although not a single or major driver of desertification, the effect of global climate change on desertification worldwide and in Europe is complex (e.g., Prince at al., 1998; Bolle, 2003) and certainly not sufficiently understood. A major problem arises from the difficulty to distinguish between natural variability and climate change. Although climate models have limitations and uncertainties, they are considered most valuable tools for long-term climate prediction and the construction of regional scenarios. The European research project MICE[4], for example, has analysed temperature extremes and suggests that Southern Europe and the Mediterranean will experience considerable future warming, with prolonged droughts in summer and reduced rainfall in winter. Although most climate models tend to produce somewhat too warm and dry regional scenarios it is important to asses the impact of future predictions on the hydrological system as well as on agriculture and forestry, as it has been done in the European Projects MICE and PRUDENCE[5] with regard to important crops in Spain. Although mostly caused by people, there may also be an increase in the meteorological risk of wildfires. Furthermore, regional climate scenarios might be substantially modified through local circulation systems (e.g. Millán et al., 2005). Major issues to further explore are related to the impact of desertification on global climate change, the regional impact of climate change phenomena, and the linkage between desertification, biodiversity and soil carbon storage.

III. DESERTIFICATION INDICATORS

Understanding the significance of desertification is constrained by many uncertainties. Information gathering - long-term remote sensing and sub-national biophysical and socioeconomic data - enables the development of a baseline and indicators of desertification. Such information helps to reduce uncertainties regarding the relationships among desertification, climate change, biodiversity, ecosystem services, and human well-being; it is the prerequisite for identifying priorities and monitoring the consequences of actions.

The identification of desertification indicators has been substantially supported by continuous research efforts on desertification-related processes and modelling approaches within specific target areas (e.g. in the European Projects MEDALUS, MEDACTION and DESERTLINKS[6]). While earlier research work was more concentrated on the physical dimension of desertification, the focus has been adjusted more on the involvement of local stakeholders and research on social, economic and institutional dimensions of desertification. In connecting these multi-disciplinary dimensions of the desertification problem, much knowledge has been gained on suitable indicators, such that European Research has led to substantial progress in this field; an extensive database on desertification indicators system for Mediterranean Europe has been developed which gives access to around 150 indicators of relevance to desertification in the Mediterranean.

IV. DATABASES AND SPATIAL INFORMATION

European environmental databases have largely improved during the past years (EU Meeting Alghero), and spatial data infrastructures such as INSPIRE will certainly lead to further expansion and refinements. An exhaustive inventory on available regional data sets and information layers (i.e. covering most of the European Mediterranean) which appear useful in the context of desertification research has also been executed within the framework of the European research project LADAMER[7]. A major deficit was identified on the level of accessibility to climate station data with sufficiently long records and adequate spatial distribution, a mandatory prerequisite for desertification assessment and monitoring concepts. Also, meteorological and earth observation satellites have proven of invaluable importance for environmental assessment and monitoring issues. However, there are risks that major satellite missions might not be continued and existing data archives not efficiently maintained. Particularly within the frame of GMES and GEOSS[8], further European initiatives for supporting the continuity of major earth observation and global environmental monitoring satellite missions are more than appropriate.

[4] MICE: Modelling the Impact of Climate Change
[5] PRUDENCE: Prediction of Regional Scenarios and Uncertainties for Defining European Climate change risks and Effects
[6] MEDALUS: Mediterranean Desertification and Land Use; MEDACTION: Policies for land use to combat desertification; DESERTLINKS: Combating Desertification in Mediterranean Europe: Linking Science with Stakeholders
[7] LADAMER: Land Degradation Assessment in Mediterranean Europe
[8] Global Earth Observation System of Systems (GEOSS) is envisioned as a large national and international cooperative effort to bring together existing and new hardware and software, making it all compatible in order to supply data and information at no cost. GMES is a joint initiative of the European Commission and the European Space Agency to bring data and information providers together with users

V. BASELINE DEVELOPMENT, ASSESSMENT AND MONITORING

The existing assessments of the global extent of land degradation all have major weaknesses, and although European Research has already produced substantial advances in this field, the shortcomings of available assessments point to the need for a systematic and standardised approach. Large collections of desertification indicators have been provided, and the integrated use of satellite-based remote sensing with ground-based observations and spatial data can provide consistent, repeatable, cost-effective information on vegetation cover and other surface properties relevant to desertification. Continuity of observations (long-term monitoring) is required to account for the high inter-annual variability of dryland ecosystem services, and to distinguish between the role of human actions and climate variability in vegetation productivity. Valid interpretation of remote sensing imagery for desertification requires careful calibration and validation against ground measurements (such as vegetation cover, biological productivity, evapotranspiration, soil fertility, and compaction and erosion rates).

More than 10 years have passed since the European Commission has launched first attempts to produce exhaustive maps on natural resources and soil erosion risks in Mediterranean Europe (CORINE, 1992). Since then the Commission has funded numerous dedicated research projects in the field of land degradation and desertification which mainly focussed on data collection in specific field sites, detailed methodological studies, assessment and monitoring experiments, and the development of specific modelling concepts (e.g., MODULUS[9]). Some projects, such as DeMon-II and GeoRange[10] have successfully demonstrated how earth observation satellites can be used to trace land degradation processes and to monitor the effects of land management interventions local scales (e.g., Hill, Hostert et al., 2003). However, although substantial scientific progress has been achieved and some projects succeeded to link a considerable number of field sites and case studies across the Mediterranean basin, the scientific community has, apart from few initiatives such as the "Soil Erosion Risk Assessment in Europe"[11] and PESERA[12], so far failed to provide unifying concepts for assessing even specific aspects of land degradation processes on Mediterranean scale.

The LADAMER project was specifically tailored towards an approach more balanced between level of detail and level of generalisation, addressing the major requirements outlined above in two ways. Firstly, it is explicitly based on the integrating of various small-scale datasets that have been partially compiled under the mandate of the Commission in the last years, and which have in many cases only be used separately (e.g., CORINE land cover, European soil database 1:1,000,000, GTOPO/SRTM elevation data, GRID meteorological database, NUTS administrative regions). The conceptual framework of LADAMER together with a regular update strategy of the base datasets forms the basis for a long-term monitoring concept of the environmental status of European desertification-affected areas. Secondly, the perspective of political decision makers is clearly reflected by the concentration on the regional scale and the goal of supplying different categories of maps covering large areas in a consistent and comparative manner rather than exclusively focussing on local case studies.

[9] MODULUS: A Spatial Modelling Tool for Integrated Environmental Decision Making
[10] DeMon-II: An Integrated Approach to Desertification Assessment and Monitoring; GeoRange: Geomatics in the Assessment and Sustainable of Mediterranean Rangelands
[11] initiated by the European Soil Bureau
[12] Pan European Soil Erosion Risk Assessment

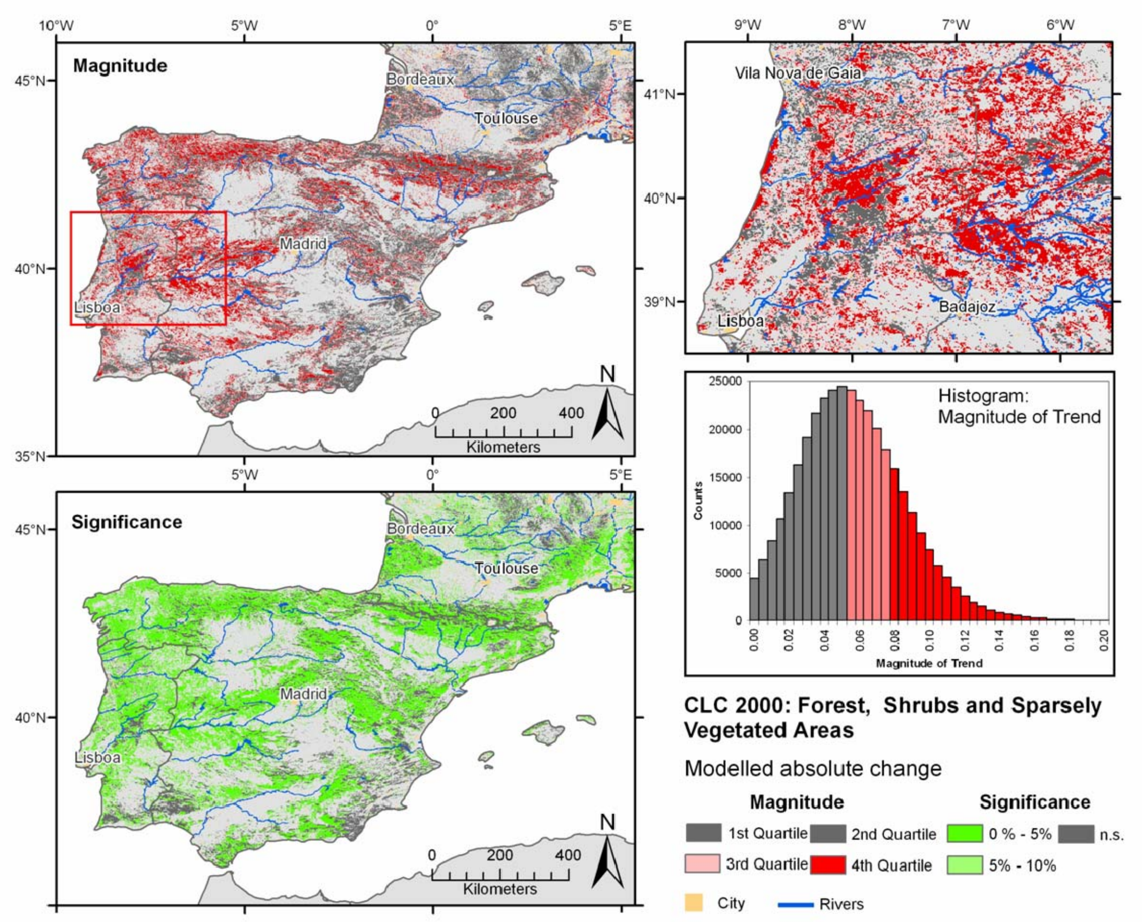

Fig. 1. Significance and Magnitude of the Change in Vegetation Abundance within the semi-natural vegetation communities (CORINE 2000 classes forest, transitional woodland, open spaces) of the Iberian Peninsula within the Period 1989-2004 (Udelhoven & Stellmes, Trier University, Germany).

The results of analysing the calibrated MEDOKADS (Koslowsky, 2003) time series of 1-km-NOAA-AVHRR data over the Mediterranean basin (e.g., Udelhoven et al., 2005) suggest that environmental change over the past 15 years is primarily characterised by increasing vegetative cover within agricultural and semi-natural ecosystems, owing to intensification and irrigation on one hand, and the widespread land abandonment which has already started many decades ago on the other (fig. 1). This is strong evidence for the socio-economic drivers of environmental change in the Mediterranean which trigger substantial changes of the hydrological cycle, shrub encroachment and increasing wildfire risks, as well as an accelerated depletion of ground water resources.

VI. INTEGRATED ASSESSMENT CONCEPTS

Understanding the impacts of desertification on human well-being requires that the knowledge of the interactions between socioeconomic factors and ecosystem conditions are improved. Advanced concepts aim at producing a representation capable of integrating physical, ecological and socio-economic processes at a high level of abstraction, so that an application is possible to member states of the European Communities as well as non-European regions. This would be a major step to support designing and evaluating strategies aimed at lowering the threats for desertification and degradation in affected areas. Needless to say that such approach must to be complimented by an adequate spatial information infrastructure.

Starting from pioneering work of Boer (1999) the aim of the land condition assessment in LADAMER was to explore a method based on implementations of net primary productivity (NPP) ratios. The whole mainland Spain (ca. 494000 km^2) was used as study area at a resolution of 1 km. Input data consisted of monthly surfaces in the period September 1996 through August 2000, containing the following variables: Vegetation Abundance (Stellmes et al., 2005) from the MEDOKADS data base;

Precipitation (P), interpolated from georeferenced meteorological stations; and Potential Evapotranspiration (PET).

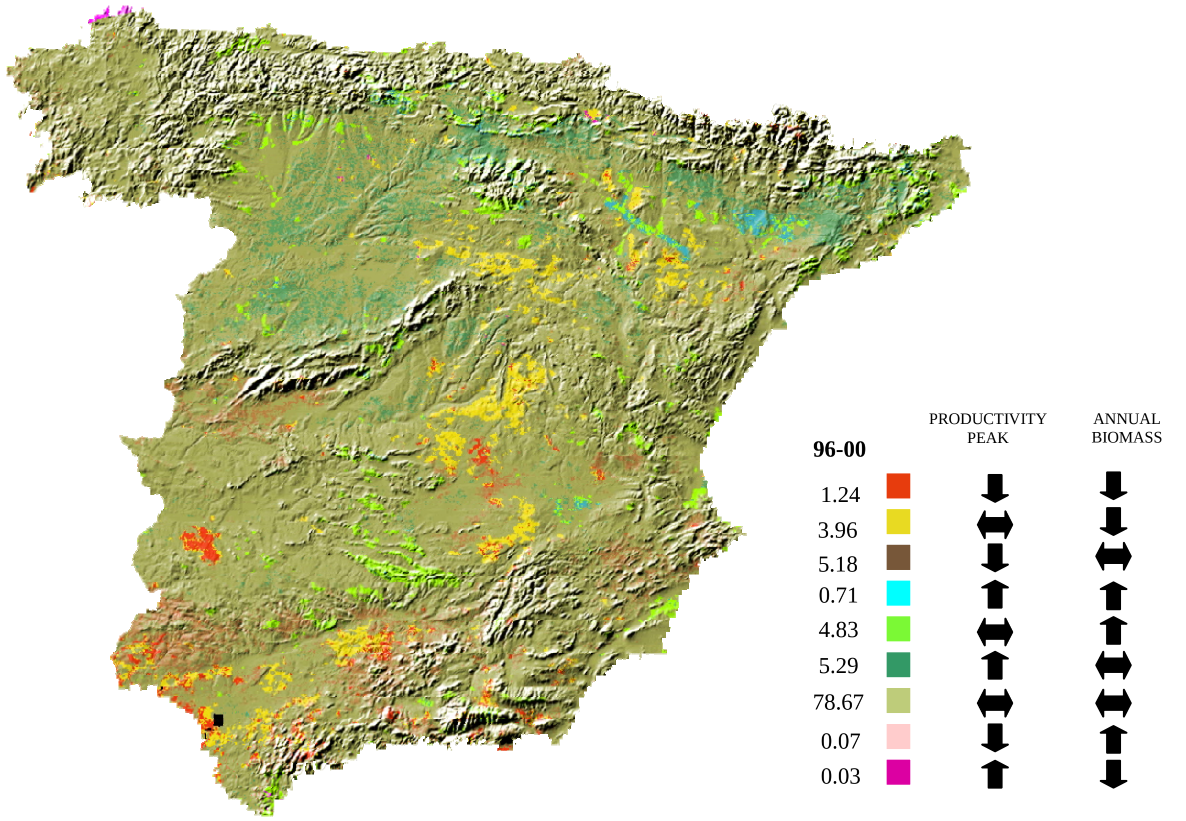

Fig. 2. Vector index of land condition for Spain (Del Barrio & Puigdefabregas, EEZA, CSIC, Almeria, Spain)

Rainfall Use Efficiency (RUE) was originally defined as the ratio of NPP to precipitation (P) over a given time period (Le Houerou, 1984), which can be interpreted as the fraction of rainfall released to the atmosphere through the vegetation cover. A remotely sensed vegetation index was used here as a surrogate to NPP. If RUE is computed over a large area with strong climatic gradients, as it is the case of mainland Spain, drylands often account for the largest values because of their very low P values, which prevent a direct comparison between locations under different climates. To avoid it, the RUE values were plotted against an Aridity Index (AI) that was computed as the ratio of P to PET. The upper and lower boundaries of such a scatter plot are respectively interpreted to convey the maximum and minimum vegetation performance for a given aridity class, which is a first approach to climate de-trending. The resulting functions could then be spatially modelled using the AI layer as the independent variable, to yield two layers showing the maximum and the minimum expected RUE for every map location. The final step was to compute a new layer showing the relative position of the observed RUE within the range formed by the maximum and the minimum expected RUE. The relative RUE (rRUE) is assumed to reflect the vegetation condition as the observed performance (in terms of the satellite-derived vegetation index integrated over time) with respect to the minimum and maximum performance that can be expected for that climate (in terms of AI).
The mean observed RUE reflects the sustained response of vegetation to its local climate, and it is interpreted as a proxy to biomass and maturity. However, the maximum observed RUE reflects the short term response if meteorological conditions are suitable (in terms of seasonal P), and it is better a proxy to productivity and resilience. Those are two independent components of the vegetation performance that capture its condition in ecologically meaningful terms. The resulting regional map of the Iberian Peninsula (Fig. 2) appears to be in agreement with the trend analysis mentioned before: most of Iberia shows evidence of steady-state or increasing vegetation performance within the observation period. The Integrated Project DeSurvey[13] presently provides the platform for extending and optimising these concepts.

[13] Integrated Project DESURVEY: A Surveillance System for Assessing and Monitoring Desertification

VII. MITIGATION, RESTORATION AND INTEGRATED LAND MANAGEMENT

The goal of rehabilitation and restoration approaches is to restore ecosystem services that have been lost due to desertification. This is not only achieved through specific technical approaches (reforestation, soil amelioration, etc.) but a positive change in the interaction between people and ecosystems. Integrated land and water management, as well as protection and restoration of vegetative cover are key methods of desertification prevention. Research projects such as MEDACTION, DESERTLINKS, and GEORANGE had already covered important land management and mitigation issues in the context of their prime objectives. But specific emphasis had been given to improving the efficiency of restoration initiatives through the evaluation and transfer of technologies which are environmentally sound, economically viable, and socially acceptable. The European research project REMECOS had investigated and developed techniques for restoration of degraded natural and afforested areas in Southern Europe, and REACTION[14] approached the evaluation of restoration efforts in the northern Mediterranean from ecological, economic and socio-cultural perspectives; specific aspects are being explored within the RECONDES and INDEX[15] projects. Further research in this field will include actions to explore the efficiency of mitigation and restoration actions.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Besides the specifically targeted research projects and the large structures of so-called integrated projects many smaller actions have substantially contributed to enlarge the understanding of land degradation and desertification processes. The concerted action MEDRAP[16] has substantially contributed to establish better links between the scientific community and the actors in the relevant areas, AIDCCD[17] addressed the issue of the implementation of the United Nations Convention to Combat Desertification and Drought (UNCCD) by co-ordinating the exchange of information and experiences across the world, while SCAPE[18] has organised workshops where specialists on soil conservation and protection, data users and providers and policy makers discussed and reviewed soil conservation and protection strategies in contrasted regions of Europe. Also the dissemination of information has largely improved through developing clearinghouse mechanisms and information portals, such as CLEMDES and EU-MEDIN[19]. In the follow-up of a first scientific meeting (Hill & Peter, 1994), UN-Ambassador Hama Arba Diallo, Executive Secretary of the UNCCD, personally opened the International Conference on “Remote Sensing and Geoinformation Processing in the Assessment and Monitoring of Land Degradation and Desertification” (RGLDD) in Trier (Germany), a Supporting Measure funded under the 5th Framework Programme.

However, in view of much progress that is achieved, addressing desertification continues to be critical and essential to meeting the Millennium Development Goals. The human well-being of dryland people, about 90% of whom are in developing countries, lags significantly behind other areas. Europe itself is facing the risk of further aridification in its southern member states, and the persisting risk of ecological and social disasters in Africa is also casting shadows on the economic growth and development in the Mediterranean. Desertification and land degradation should therefore be a major topic within the seventh Framework Programme; however, it seems important to create possibilities which allow an extension of RTD projects to affected non-European countries. Without diminishing the relevance of other aspects, the improvement of assessment, monitoring and early warning strategies will remain one of the most important challenges.

[14] REACTION: Restoration Actions to Combat Desertification in the Northern Mediterranean; REMECOS: Reclamation of Mediterranean Ecosystems Affected by Wildfires
[15] INDEX: Indicators and Thresholds for Desertification, Soil Quality, and Remediation; RECONDES: Conditions for Restoration and Mitigation of Desertified Areas Using Vegetation
[16] MEDRAP: Concerted Action to support the Northern Mediterranean Regional Action Programme to Combat Desertification
[17] an ENRICH (European Network for Research into Global Change) Accompanying Measure
[18] SCAPE: Soil Conservation and Protection for Europe
[19] CLEMDES: Clearing House Mechanism on Desertification for the Northern Mediterranean Region; EU-MEDIN: Euro-Mediterranean Disaster Information Network

ACKNOWLEDGEMENT

This paper aimed at summarising important aspects of desertification research in Europe, in particular assessment and monitoring strategies. Occasionally, reference to previous and ongoing European research projects is made but it should be noted that due their large number it is not feasible to mention all high quality projects conducted under support of the European Commission within this short summary. An exhaustive listing of projects can be found under in the Catalogue of Contracts in the Area of Land Degradation/Desertification (c/o marie.yeroyanni@ec.europa.eu), and more information can be easily retrieved by submitting the project acronyms to Internet search engines. The author is grateful to many colleagues he had the pleasure to meet within interdisciplinary research projects, and who were all willing to share their expertise; particular thanks go to Gabriel del Barrio and Juan Puigdefabregas for many intense discussions. Last, but not least, sincere thanks go to the scientific officers of DG Research who have been an important component in stimulating the research on this important topic.

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SESSION IV

DISCUSSION ON FUTURE RESEARCH PERSPECTIVES OF CLIMATE CHANGE AND CLIMATE RELATED HAZARDS WITH SHORT SUMMARY REPORTS FROM SESSION CHAIRS

Session I: Climate Change and Observations

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Human induced climate change and its impact on the earth system will be one of the key challenges of the 21st century. In response of alarming climate change projections, European climate policies have already taken action aiming at stabilization of the ever increasing atmospheric concentration of $CO_{2.}$ The goal is to keep the global temperature response to enhanced Greenhouse gas concentrations below 2°C, keeping the atmospheric greenhouse gas concentrations at sub-critical levels (450-600 ppm CO_2 equivalent). The ambitious policy goals are calling for an integrated research program to monitor and detect changes in the earth system, to better understand its dynamics and impacts, and finally to develop sustainable response options to meet the challenges ahead guiding society in a sustainable way through the transition phase.

- **Systematic Observation**
  Climate scientists welcome the initiative of the Group on Earth Observation (GEO) to build a Global Earth Observation System of Systems (GEOSS). Within this initiative a number of societal benefit areas have been defined, facing many common challenges and therefore will be addressed in an integrated fashion. It was recommended to add land degradation to the list, since it is a significant problem for many areas. Furthermore GEOSS should be extended to an end to end system to fully meeting the requirement of the scientists. Progress in earth-system modeling depends to a large extend on the availability of long time series of reliable physical and socio-economic parameter and data. Furthermore the hope has been expressed that systematic observations (GEOSS) will be accompanied by a strong research program that data collected are fully utilized by the research community.

- **Past Climate**
  The understanding of the natural variability of the climate system, its dynamics and abrupt changes remains high priority. Knowledge of climate change in the past helps to understand current trends, developments and regime changes. We still do not know why the climate entered into an ice age 2.7 Mya ago. Astronomically driven forcing changes seem to determine the interglacial cycles but the processes and feed-back mechanisms re-distributing the energy of the sun in the earth system, which are causing an on-set and break-down of an interglacial cycle are still not well understood. It is also not clear why atmospheric concentrations of CO2 within interglacial cycling remain in the range of 180-280 ppm. An ambitious climate hind-cast program should focus on the modeling (re-construction) of an interglacial cycle as an essential contribution to better understand climate dynamics.

- **Carbon cycle**
  Combustion of fossil fuels and deforestation are the primary causes for the ever increasing CO_2 concentrations in the atmosphere, the main driver for climate change. Currently about 50 % of the anthropogenic emissions are taken up by the land biosphere and the ocean thereby reducing the atmospheric CO_2 increase. The estimates provided for the different carbon reservoirs are highly uncertain and might change significantly in a warmer CO_2 rich world which might lead to further surprises. The ocean plays a critical role in the carbon cycle and the impact of a more acid ocean on the marine ecosystem and its feedbacks on the carbon cycle are not well known. There is a need for an integrated carbon observation/assimilation system to better estimate regional carbon budgets which should be linked to soil and ecosystem process studies. The link and possible feed-back between the carbon cycle and climate change deserves high priority. There is a risk that carbon reservoirs reach a saturation level and former sinks might turn into carbon sources.

- **Hydrological cycle**
  Climate change will alter the hydrological cycle substantially with serve repercussions on society. The consequences of changing rainfall pattern, water availability and water quality, increasing risks of draughts and floods will cause tremendous problems for the regions affected. Therefore, the impact of climate change on the hydrological cycle needs to be assessed in an integrated way

studied by coupled hydrological models. Process studies, such as surface emissions of aerosol, its formation and fate, cloud-aerosol interactions, and changes in the earth radiation pattern and budgets should complement model application. The impact of land use and land use change on the hydrological cycle is an important research issue. The human dimension, urbanization and industrialization going along with increasing water demand must also be taken into account with emphasis on water management (challenge of mega cities). Ensemble runs for the assessment of hydrological regimes with different models should be applied as a water management tool at regional and global level.

– **Earth system modeling and projections**
  Human activities interfere with all components of the earth system and have become a major driving factor for climate and global change. To assess the system response related to human pressure, there is a need to better integrate the natural and human components of the earth system. Consequently, the European research challenge is to develop a truly integrated program to observe, analyse and predict the evolution of the Earth System, and its different natural and socio-economic components. These research activities should be complemented by detailed analyses of the individual components. The programme should form a solid basis to better understand the functioning of the Earth System and to study the interaction and feed-back mechanism. This should also help to study the impact of environmental changes on the socio-economic component. Research should focus, beside Europe, on vulnerable regions such as the polar and tropics which are extremely sensitive to changes with potentially large impacts on Europe.

– **Response options**
  The anthropogenic interference with the natural earth system implies high risks of generating potential disastrous impacts. As a guiding principle for environmental policies unmanageable system changes must be avoided, unavoidable changes in a transition phase, however, should be managed in a sustainable way. Actions to be taken should be based on sound scientific understanding of the functioning of the earth system. This indeed highlights the need to fully develop and apply the integrated earth system modeling concept. This (virtual) earth system simulator could provide a catalogue of calculated scenarios that would allow testing of hypotheses regarding the natural and socio-economic consequences of e.g. climate change adaptation and mitigation measures and help to formulate policies response options to challenges of globalisation, from climate change to social security. Urban territories contribute significantly to the environmental problems and climate change and need special attention regarding management decisions from greenhouse gas emissions to water supply.

Session II: Atmospheric Chemistry

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Strategic directions regarding atmospheric chemistry within the Framework Programme 7 cannot be dissociated from the overall directions to be adopted by the EC for climate change and Earth system science. It is important that the FP-7 Programme on Earth system questions be broad and integrative. Atmospheric chemistry must be seen as a component of the broader Earth system science concept.

Three directions should be emphasized:

1. **Global, regional and local air quality**, including biogenic, pyrogenic, volcanic, oceanic and anthropogenic emissions of chemical species, biosphere-atmosphere interactions, as well as the coupling between chemical, biological and micro-meteorological processes in the vicinity of land surfaces. The changes in land cover and specifically the impact of mega-cities on regional and even global air quality should be addressed. Air pollution resulting from the emissions of road traffic, aircraft and especially commercial ships should receive increasing attention.

   Fundamental studies on the nature of multi-scale transport of gas phase compounds and aerosols should be encouraged. This includes long-range transport, convective exchanges, boundary layer ventilation, cross-tropopause exchanges as well as dry and wet deposition processes. The commission should encourage the organization of field campaigns and modeling activities that address issues related to air quality at different scales. Research supporting the development of a fully integrated system capable of monitoring and predicting chemical weather should be a priority.

2. **Chemistry-Climate Interactions** including the impact of the changing atmospheric composition on climate forcing, and conversely the impact of climate change on the chemical composition of the atmosphere.

   Many of the climate-related processes that need to be considered are observed in (or related to) the upper troposphere and lower stratosphere (UTLS). The physical nature of the tropopause, the conditions under which irreversible exchanges are taking place, the role of cirrus clouds especially in the tropical tropopause layer (TTL), the injection of water from the troposphere to the stratosphere, the convective transport of chemical species including halogens from the surface to the TTL, the production of nitrogen oxides by lightning, etc.

   More detailed studies should be performed on the formation of aerosols and their fate in the atmosphere. This includes studies on the sulphur cycle in the Earth system, the chemical nature of the different types of aerosols, the interactions of these particles with gas-phase oxidants, their role in the formation of cloud droplets. Studies on the indirect effects of aerosols on climate should be accelerated. Aerosol studies should be considered in the broad Earth system context: the impact of these particles on the hydrological cycle, and on the land and ocean biosphere should be considered.

   The relation between stratospheric chemistry and climate should be further studied. Among the key questions to be addressed are the ozone recovery and its dependence on future climate conditions, the effect of stratospheric dynamics on tropospheric weather, the response of stratospheric composition and dynamics to solar variability. Tropospheric sources of stratospheric waves should be better identified. Processes that contribute to temperatures trends in the stratosphere and mesosphere should be further investigated. The global budget of middle atmosphere water should be better quantified.

3. The Need for Adequate Facilities

The European Commission should facilitate the development of the community facilities that are required to better observe the evolution of the atmospheric composition. These include monitoring stations, airborne platforms, etc. A strong laboratory programme to elucidate some fundamental issues related to chemical kinetics or radiative properties of chemical compounds (incl. Aerosols) needs to be supported.

Access to supercomputers must be facilitated for advanced chemical transport models and for climate (or earth system) models and their chemical and biogeochemical components. The development of a European supercomputing facility for capability-type applications and dedicated to geosciences should be facilitated by the European Commission.

Finally, the Commission should support projects that attempt to assimilate, analyze and make use of space observations of chemical compounds. A special effort should be made to use space observations to evaluate chemical transport models of the atmosphere.

Session III: Natural Hazards

Stavros A. Anagnostopoulos, Professor and Head of Structural Engineering
Department of Civil Engineering, University of Patras

This is a brief report summarizing the presentations and discussions on natural hazards that were made during the above stated Workshop. In dealing with the problem of natural hazards, one must distinguish between Hazard and Risk so that a common terminology is adopted to avoid confusion and misunderstandings. Hazard can be defined as the probability of occurrence within a specific period of time in a given area, of the potentially damaging natural phenomenon. Risk on the other hand is the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to the occurrence of the catastrophic natural phenomenon. In other words Hazard expresses the natural phenomenon and Risk its consequences. In somewhat mathematical terms one can write:

[RISK]=[HAZARD]*[VULNERABILITY].[elements at risk]

Obviously risk is more difficult to estimate than hazard because it involves, in addition to the hazard, estimation of the the vulnerability of the elements at risk. As far as mitigation is concerned it becomes obvious from the above definitions that it is the risk and not the hazard that can be mitigated, mainly through the reduction of the vulnerability of the elements at risk. Hazard cannot in general be mitigated except for some climate related hazards (e.g. extreme temperatures, desertification) that may be moderated through long term measures affecting the clima itself. Therefore research for natural hazards must be targeted primarily towards risk mitigation, aiming at two broad directions: The first towards better understanding the physics and mechanisms generating the natural hazards and hence towards more accurate quantification, probabilistic or deterministic, of their expected intensities, times and affected locations, and the second towards measures for reducing the vulnerability of the elements at risk for each type of hazards. Obviously the first direction is more scientific while the second is mostly engineering.

This gives us now a more clear perspective to address research needs for individual hazards, that as explained above such needs must be distinguished to research on hazard generation mechanisms and quantifications and to research for risk mitigation methods, technologies and measures. Under the above perspective, we will list below a summary of ideas presented or discussed for the various hazards during the workshop.

I. GEOLOGICAL HAZARDS

- <u>**Earthquakes**</u>

  a. **Hazard mechanisms-quantifications**: Extend previous studies for the most important seismotectonic zones in Europe to model earthquake generation mechanisms and predict expected ground motions in such zones for engineering purposes, paying special attention to near fault motions. Support the European data base for strong motion data and its use for the development of a European seismic hazard maps in terms of spectral ordinates, along the lines of the USGS, using uniform criteria and data quality. Such maps should be made available on line and allow the dissagragation of the hazard so that an engineer can consider ground motions for specific potential events (i.e. events of specific magnitude at specific distances that most significantly contribute to the seismic hazard) in his analyses of significant structures. Such an effort would entail the development of regional "*source spectra*" and their respective "*scaling laws*".

  b. **Risk mitigation**: Earthquake engineering R&D in general for reducing the vulnerability of new and old construction.

- <u>**Volcanic activity**</u>

  a. **Hazard mechanisms-quantifications:** Support monitoring of volcanic activity using a varietry of methods. Eruption models and factors triggering eruptions. Monitoring precursory phenomena and improving accuracy in the prediction of time "windows" for eruptions.

b. Risk mitigation: Predictions of areas to be affected by eruptions and lava flows. Early warning systems

– **Landslides**

a. Hazard mechanisms-quantifications: Improved models for landslide predictions and for triggering mechanisms due to heavy rainfalls and earthquakes. Mapping landslide hazards.
b. Risk mitigation: Research on the effectiveness of various engineering interventions reducing the landslide potential.

– **Tsunamis**

a. Hazard mechanisms-quantifications: Development of real time monitoring systems and also hazard maps for threatened coastal areas.
b. Risk mitigation: Risk estimation in the threatened areas as function of the wave height. Development of warning mechanisms utilizing real time data.

II. CLIMATE RELATED HAZARDS

– **Floods and flush floods**

a. Hazard mechanisms-quantifications: Generation, propagation and fate of sediment and debris in extreme floods with joint occurrence of these related natural hazards. Improved regionalisation at spatial and temporal scales of interest for natural hazards - both deterministic and statistical downscaling. Changes in extremes and parameters of probabilistic functions as used for engineering design. Monitoring systems
b. Risk mitigation: Identification, understanding and parameterisation of failure modes and mechanisms for flood defence infrastructure and real-time monitoring of defence condition. Influence of land use and management policies on long-term flood risk. Early warning systems

– **Storm surges**

a. Hazard mechanisms-quantifications: Maximum height estimations, relation to storms and real time monitoring
b. Risk mitigation: Risk estimation in the threatened areas as function of the wave height. Development of warning mechanisms utilizing real time data.

– **Forest Fires**

a. Hazard mechanisms-quantifications: Quantification of the effect of forest growth on carbon sequestration, in conjunction with the increase in fire hazard. This should take into consideration forest fire regimes (including forest flammability) currently and in the future, under climate change scenarios.
b. Risk mitigation: Tree species selection for future forests under global change scenarios, taking fire hazard development into consideration. Evaluation of forest fire protection needs (fire prevention, pro-active forest management and firefighting), on large scale, with examination of future scenarios and alternatives in order to determine the best mix for sustainability and optimum cost. Development of decision making frameworks about the criteria and the specifications for creating and protecting new forests. Early detection systems for quick mobilization of firefighting mechanism.

– **Extreme weather conditions**

a. Hazard mechanisms-quantifications: Effects of long term climatic changes on extreme weather conditions.
b. Risk mitigation: Measures to alleviate long term climatic changes. Socioeconomic infrastructures to mitigate effects of extreme weather conditions.

– **Desertification**

a. Hazard mechanisms-quantifications: Regional impact of climate change. Linkage between desertification and biodiversity. Linkage between carbon storage in vegetation and soils. Continuity of major earth observation and global environmental monitoring satellite missions. Further explore the hierarchy and standards of desertification indicators. Integrate Earth-observation data and products with other data and information layers, for a more complete view and understanding of problems and derived solutions, including the physical and socio-economic dimension of the desertification processes. Comparative analysis and inter-calibration of existing remote sensing archives from global environmental monitoring satellites to improve the perspectives in the field of desertification retrospective monitoring, trend analysis and early warning capacities in relation to ongoing climate change processes.

b. **Risk mitigation:** Impact of desertification (soil and vegetation losses) on global climate change and vice versa. Establishment - improvement of geo-spatial data infrastructures (also in third, i.e. affected, countries) as a basis for mitigating and abating desertification. European initiative for facilitating the free access to national climate data archives for non-commercial scientific endeavours. Development and evaluation of strategies for a mid- to long-term evaluation of restoration projects and land management strategies in areas affected from land degradation and desertification. Raising public awareness, capacity building for transferring robust desertification assessment and monitoring strategies to affected countries in Europe and beyond.

As a final remark it must be pointed out that the idea of integrated research projects may be appropriate only for natural disasters that have common origins and hence the same generation mechanisms and perhaps mitigation measures, e.g. climate related hazards. On the other hand, risks that come from hazards caused by entirely different generation mechanisms and which have entirely different effects, e.g. earthquake versus flood risks or even landslide risks caused by excessive rainfall, get no advantage by including them in an integrated project, as the expertise, methods and technologies required for each type of risk are different. Thus the result of such “integrations” is bound to be negative and money will be wasted. The most successful projects in earthquake risk mitigation research in the past have been small projects with well defined objectives that addressed specific practical problems and produced tangible and measurable results.

EVENING PROGRAMME AND SPEECHES FROM DISTINGUISHED COLLEAGUES AND FRIENDS OF ANVER GHAZI

Invitation to the Symposium Dinner

2 February 2006 at 20:00

Building Charlemagne
Salle de réception, 2ème étage
Rue de la Loi 170
1000 Brussels

Evening Programme

The evening session is dedicated to the memory of Anver Ghazi. Distinguished colleagues and friends from the research community and the European Commission, as well as close family members are invited.

"Anver Ghazi's contribution to European Research in Climate Change"
Achilleas Mitsos, European Commission

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"Hommage à Anver Ghazi"
Philippe Busquin, European Parliament

• • •

"Anver Ghazi, Wanderer zwischen den Welten"
Christian Patermann, European Commission

• • •

"A requiem to a 30 year friendship"
Christos Zerefos, University of Athens

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"Anver Ghazi's contribution to European Research in Climate Change"

Achilleas Mitsos, Director-General, DG Research (2000-2005), European Commission

It is an honour for me to testify on the contribution to European Research of a remarkable man – my colleague and my friend Anver Ghazi. And I am glad to do this now and in the presence of members of his family, some of his closest collaborators in our Directorate General, and a selection of the best experts of the scientific community with whom he worked throughout his professional life.

Anver Ghazi was a very highly regarded man with whom it was an enriching experience to work. He was a true reservoir of scientific knowledge on Climate Change within our Directorate General and the European Commission; he was very prominent in the establishment of a strong European research Community on this important topic.

He contributed, less than no single person within or outside the European Commission, to the development of international research strategies on Climate Change, not to mention Earth Observation and natural hazards, for the European Union.
Anver was passionate about Earth sciences.

- He received his PhD in Natural Sciences in Geophysics and Meteorology in 1968 from the University of Cologne where he stayed as a researcher and as an Assistant Professor for 10 years
- He had spells in the US, at NASA in 1973 and 1974 and as a Visiting Scientist at the University of Boulder in Colorado, a renowned institution in the domain of atmospheric research.
- He joined the European Commission in 1980 as a Principal Scientific Officer and became Head of Unit in the Directorate General for Research and the Joint Research Centre in the areas of space and the environment, particularly in global climate change and natural hazards.

I think you can all testify how respected Anver was outside the Commission and the many friends he had all around the world. I can add how very much appreciated Anver was by his team and his colleagues in DG Research and other Commission services.
His views and his experience were simply indispensable when a decision was to be taken in the area. As a small testimony on that I want to add that during the period I was Director General, Anver was the only colleague I had requested to prolong his working life beyond the normal retirement age and until the end of 2005 in order to help the Commission to build a strong position in the Group on Earth Observations (GEO) initiative, a field in which he was a specialist, had an unrivalled memory of the whole history of the discipline since its very beginnings and he was known and recognised by the entire global scientific community involved in this domain.

The Earth Observation Summit in Brussels a year ago was the last professional engagement of his distinguished career and I know that by participating Anver showed, on top of all his well-known qualities, an immense courage.

His professional achievements went side by side with his human qualities. Born in Hyderabad, India he managed to embrace strongly the ideals of the European Union, demonstrating how much Anver was a man at the crossroads of the great cultures of the world. This international conference about the research on Climate Change and Impacts, Ozone Depletion, Earth Observation and Natural Hazards is addressing all the challenges for which Anver dedicated his professional life. It is certainly an excellent initiative in memory of Anver Ghazi.

But we, his colleagues in the European Commission, we owe Anver also something else. Anver Ghazi contributed a lot to the upgrading of the image that the scientific community and even the society at large have for the European Commission officials.

I feel privileged to have worked closely for many years with colleagues who combine wonderfully and uniquely professionalism and passion and Anver Ghazi was such a man, "par excellence". I feel privileged for having met, worked together and share experience, knowledge and friendship with Anver Ghazi.

"Requiem to a 30-year friendship"

Christos S. Zerefos, Professor of Atmospheric Physics,
National and Kapodistrian University of Athens, Faculty of Geology & Geo-environment

When I first met Anver, 30 years ago at NCAR in Boulder, Colorado, while he was visiting me at the Advanced Studies Department, he was enrolled in a summer school for upper atmosphere. By then he had completed his PhD at the University of Cologne, and he was 35. He was born in Hyderabad, India and I was born in Cairo, Egypt and in addition to scientific issues, as young researchers by then, we did find common cultural interests, for example we both had read parts from the Koran and from the Bible. We both admired Alexander the Great, the Eastern Philosophy and the roots in science which originated in Far East, India, Athens and Alexandria. Gradually we became friends and have been discussing several issues of importance at that time that had to do with the ozone layer. By then I was a developing ozone man in the scientific community and Anver continued to be interested in the Physics of the Upper Atmosphere. However, we have both been interested also in Climate Change and particularly in Global Change issues. When Anver, in 1980, was appointed by the European Commission as a Scientific Officer and later replaced Roberto Fantechi as Head of Unit, he boosted issues of Global Change and together he created a little spiritual baby called "ENRICH" with the Director General Contzen and Pierre Mathy. ENRICH stands for the "European Network for Research in Global Change". He was also deeply involved with Climate and Natural Hazards, as well as in Space and the Environment, in issues which are now in the forefront of Science. In 1984 we have jointly organized a Quadrennial Ozone Symposium and published together a thick book on Atmospheric Ozone which included the Proceedings of the Symposium. We have published together other books and other publications. However I consider that Atmospheric Ozone was historic in the sense that it was the Symposium where the new Bass and Paur ozone absorption coefficients have been adapted and more importantly where Professor Chubachi, from Japan, discovered first an ozone hole in the Japanese ozonesonde measurements at Syowa in Antarctica, a finding that a few years later became a joke with Anver, Rumen Bojkov and other eminent colleagues since Professor Chubachi did not link his discovery to any ozone destroying mechanism and everybody thought in September 1984 that something was wrong with the Japanese measurements. It was not until early next year (1985) when Joe Farman and other eminent colleagues from the British Antarctic Survey discovered the ozone hole as a springtime phenomenon in Antarctica and tried to link it with human activities.

Anver was respected not only in Europe but also internationally for his devotion in research in Global Change. I still remember his face when we first heard about the Nobel Awards given to our colleagues and friends Paul Crutzen, Sherry Rowland and Mario Molina. He told me "now it is time to boost Paul's research and Global Change research in Europe". I remember also when we have been discussing with my other friend, late Heinz Ott, on the importance of establishing a European UV-B network. Both Anver Ghazi and later Christian Patermann, all helped to vitalize such a network which has flourished faster than the corresponding at the US. The vision of a European Arctic Experiment created in the late 80s by Hans Ott, continued in the 90s and served so faithfully by Christian Patermann and particularly George Amanatidis it was also in the focal interest of Anver. I remember when polar stratospheric clouds were dominating the northern skies of Europe, Commissioner Busquin, expressing his deep appreciation for the success of such a pan European experiment. These experiments have shown that the threat in the protective ozone layer was not confined in Antarctica but could occur also in the Arctic and over more populated areas. Anver was there. Anver has been rapidly moving in the various summits and I remember the last time I saw him, it was in Brussels, 16 February 2005, where in spite of his health problem has fully attended the meetings. Anver succeeded as a professional, scientist in administration and by his fine character and social qualities. Of course his Indian origin and his long lasting studies and work in Germany together with his beloved wife, Renate, all helped to that image. Anver survives with his two daughters. I remember Sheila and Yasmine, which were too small, haven't seen them since a long time but always Renate was telling my wife, Effie, the family news. Some of the pictures that I could get have to do with cultural heritage from Hyderabad where he was born and finished the high school in 1958 and at the lobby of the Hotel in Halkidiki where we had the 1984 Quadrennial Ozone Symposium and, the two figures in the Sibelius monument at the UV-B Conference organized by Petteri Taalas in Helsinki a few years ago. Last, there are two pictures from the Opening Ceremony of the Quadrennial Ozone Symposium held in Kos, Greece in June 2004.

At this point, I would like to congratulate Elisabeth Lipiatou, Pierre Valette and Claus Brüning for organizing this important climate conference and dedicating it to the memory of Anver Ghazi.

Dear Renate, Yasmine and Sheila, Anver will live on for a long time in our hearts and we shall always remember him as a fellow in Science, in life and in culture, which we are all going to miss. On behalf of my colleagues back in Greece we pay to you our most sincere condolences and we wish you Health and Prosperity to remember a fine man, a fine personality who is not with us any more.

AGENDA

2nd February 2006

Room: Salle du Trône

12.45 Registration

13.45 Welcome

14.00 Opening Remarks:
- Commissioner J. Potočnik
- DG Research representative
- Representative of the Royal Academy of Belgium

Climate Change and Natural Hazards Research in the 7th Framework Programme
European Commission (EC)

Session I - Climate Change and Observations
Chair: H. Grassl [Max-Planck-Institut für Meteorologie - Hamburg]

14.30 Keynote on climate change
H. Grassl

15.10 Keynote on global earth observation systems of systems
J. Achache [WMO]

15.50 Coffee Break

16.30 Climate in the past
A. Berger [Université Catholique de Louvain]

16.55 Climate in the future (prediction and scenarios)
D. Griggs [British Met Office]

17.20 Climate change impacts, adaptation and mitigation, and its economic consequences
J. Schellnhuber [University of East Anglia/Potsdam-Institut für Klimafolgenforschung]

17.45 The role of the biosphere in the carbon cycle
R. Valentini [Università degli Studi delle Tuscia]

18.30 Reception [Marble Room]

20.00 **Dinner for invited guests**
Speeches from distinguished colleagues and friends of Anver Ghazi
Restaurant of the European Commission,
Charlemagne Building, 2nd floor, rue de la Loi 170, Brussels

3rd February 2006

Room: Auditorium Baron Lacquet

Session I (continuation) - Climate Change and Observations
Chair: H. Grassl

08.30 Climate change impact on the water cycle and resources, link to extreme events
P. Kabat [Alterra]

Session II - Changes in Atmospheric Composition and Ozone Depletion
Chair: G. Brasseur [Max-Planck-Institut für Meteorologie, Hamburg]

09.00 Keynote on changes in atmospheric composition
P. Crutzen [Max-Planck-Institut für Chemie, Mainz]

09.40 Stratospheric ozone depletion and UV-B radiation
J. Pyle [University of Cambridge]

10.05 Changes in the Troposphere
S. Fuzzi [CNR, Istituto di Scienze dell'Atmosfera e del Clima]

10.30 Coffee Break

Session III - Natural Hazards: Prevention, Risk Management, Mitigation and Forecasting
Chair: S.A. Anagnostopoulos [University of Patras]

11.00 Keynote on natural hazards and economic impact
C. Margottini [ENEA, Roma]

11.40 Geological hazards (seismic risks, volcanoes, tsunamis)
J. Virieux [UNSA-CNRS, Valbonne]

12.05 Climate related hazards
P. Samuels [HR Wallingford]

12.30 Desertification
J. Hill [University of Trier]

13.00 Buffet Lunch

Session IV - Discussion on future research perspectives of climate change and climate related hazards with short reports from session chairs
Chair: E. Lipiatou [European Commission]

13.45 Session I: Climate change and observations — *H. Grassl*
Session II: Changes in atmospheric composition — *G. Brasseur*
Session III: Natural hazards — *S.A. Anagnostopoulos*
Summary and conclusions

16.30 End of symposium

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