EUROPEAN SCIENCE FOUNDATION

SETTING SCIENCE AGENDAS FOR EUROPE

LESC SCIENCE POSITION PAPER

LESC Strategic Science Position: The View Ahead

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European Science Foundation

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This LESC Science Position Paper has been prepared by the members of the Standing Committee for Life, Earth and Environmental Sciences (LESC), with support from the ESF office.

Acknowledgement:
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This Paper is published under the responsibility of the ESF Standing Committee for Life, Earth and Environmental Sciences (LESC). It does not necessarily represent the position of the European Science Foundation as a whole.

Published by the European Science Foundation
August 2009
Printing: IREG, Strasbourg
ISBN: 2-912049-99-7

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Floating icebergs in proglacial lake
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Wildflower field (© A. Kallio)

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Mankind is facing some major challenges related to the natural environment. Atmospheric concentrations of greenhouse gases are increasing, leading to changes in the energy balance of our planet and resultant warming of the climate, the oceans and the Earth's surface. Acidification (resulting from elevated atmospheric CO_2) is changing the composition of ocean water, affecting many marine organisms. Biodiversity is generally declining, which will have significant impacts on the functioning and resilience of many ecosystems, perhaps added to by the threats from invasive species.

The speed of these processes is such that most ecosystems cannot adapt and major turnovers are to be expected. Even if life on Earth survives for many millions of years to come, and ecosystems renew themselves over the long term as they have done in the geological past, there is no doubt that the human species and its current life style are threatened.

The present challenge is to mitigate the impacts and to adapt to environmental crises on local, regional, and global scales. Many of the societal problems are essentially ecological in nature, involving natural resources such as water, energy and food, or natural capital such as waste treatment services, in the context of a rapidly increasing human population. Efficient strategies have to be found and need to be rapidly implemented. Food security, for example, is of major concern and has an impact on the survival of millions of people. Emerging diseases and the spread of previously unknown diseases can also cause the death of millions. Our society is intimately linked to the consumption of energy. Yet reliance on limited resources of coal, gas and oil creates problems of energy supply, and the recovery and burning of these fossil fuels have considerable negative environmental impacts. Searching for alternative and renewable energy sources and creating a wealthy society based on lower energy demand should become and remain top priorities.

The Standing Committee for Life, Earth and Environmental Sciences (LESC) of the European Science Foundation (ESF) is well qualified to participate in the identification of current and future fields of concern and in the development of research strategies to tackle these challenges. LESC's mission is to advance, catalyze and develop integrative, multidisciplinary research and networking within the European science arena. LESC also aims to encourage independent research in life, Earth, and environmental sciences at both national and

Melting icebergs on a lagoon

Introduction and framework

European levels, and to enhance knowledge transfer, training and scientific understanding across Europe. The ultimate aim is to advance knowledge of planet Earth as a complex, interacting system.

Understanding and characterising the dynamic interactions between the geosphere, hydrosphere, atmosphere and biosphere, and the anthropogenic impacts on them, clearly requires transnational and interdisciplinary collaboration. Consequently, LESC deals with the entire continuum of processes over all temporal and spatial scales: from molecular biology and genomics to cellular and organismal physiology to community ecology and biodiversity studies; from isotope geochemistry to geohazards such as landslides or volcanic eruptions; from nutrient cycling and radiative balance to global scale tectonics and global climate change scenarios.

Fundamental research is needed to develop science based mitigation and adaptation strategies. By advancing such knowledge, LESC helps to secure a sustainable future for the planet and its inhabitants. LESC identifies research areas that are currently ignored or emerging, and promotes activities that operate at the boundaries between the life, Earth and environmental sciences. In this way, LESC sets the agenda for research at national and international levels, signposting areas that urgently require support.

To help the Member Organisations achieve a coherent European Research Area, LESC advocates strategic use of the ESF instruments and seeks new partnerships. LESC has made optimal use of ESF instruments, namely Exploratory Workshops, Research Networking Programmes, EUROCORES, and Forward Looks. Our efforts in recent years have yielded a substantial amount of initiatives and coordinated actions. Some have already led to research funding schemes, others have set the agenda for future activities. For instance, the Forward Look on *Systems Biology* and the recently published Forward Look on *European Food Systems in a Changing World* both present action plans addressing the complex challenges ahead. The Forward Look dealing with *Responses to Environmental and Societal Challenges for our Unstable Earth (RESCUE)* will take a similar approach. For these activities, LESC seeks financial commitment of the Member Organisations and strives for synergetic actions with other ESF Standing Committees, COST Domain Committees and external partners.

In the context of concern about the future of our planet and our society, this document identifies the main issues that LESC believes warrant the highest priority for research and international cooperation in the coming decade. It presents neglected or emerging topics and unifying themes in the life and environmental sciences as well as in the Earth sciences.

The topics are presented sequentially, starting with molecules and proteins, going through individual organisms, populations, ecosystems, biogeochemical cycles and Earth-surface processes, and finally to climate and the global environment. The paper concentrates on research activities in the natural sciences, but also integrates economic, industrial, societal and political issues. The examples given serve to illustrate the key issues. They are not exclusive.

Finally, LESC describes its vision of how the available strategic instruments will be implemented over the next five years (2010-2014) to achieve maximum impact and benefit.

From molecules to organisms: the molecular level

The RNA world

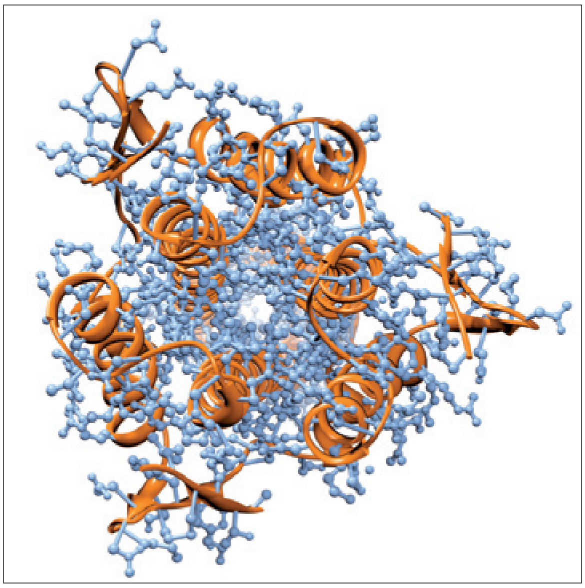
A large proportion of the genome, either in eukaryotes or prokaryotes, produces both sense and antisense transcripts. Although some recent models, such as transcriptional interference, RNA masking, RNA editing and RNA interference, have been proposed, the mechanisms underlying gene regulation by diverse sets of antisense RNA remain largely unknown. Gene regulation by endogenous small interfering RNAs (siRNAs) has been described mainly in organisms possessing RNA-dependent RNA polymerase. Although endogenous siRNAs driven from transposable elements have also been identified in mammals, the number of siRNA molecules so far identified is small. Moreover, the increasing information on the diverse biological roles of non-coding RNAs suggests that our knowledge on the information content and organisation of eukaryotic genomes is highly incomplete.

The ESF Forward Look on the RNA World – a joint activity of LESC and European Medical Research Councils (EMRC) – will be published during 2009 and will further define the most urgent research questions in the field of non-coding RNAs.

Vast research efforts are needed to refine our knowledge on how genetic information is encoded, used and transmitted. This can be performed by developing new methods of ribonucleo-proteomics on model organisms in animal, plant and marine biology. Increases in genomic data, supported by sophisticated bioinformatics approaches as well as emphasis on epigenetics and chromatin remodelling themes will also be major inputs for the future. Recent developments in DNA research, such as DNA repair, chromosome stability and related issues should not be omitted from future research efforts in life sciences. Moreover, they also have medical implications.

The protein world

In order to expand the paradigm for regulating gene transcription, protein translation, protein degradation and many other cellular processes, a better understanding of the protein world is essential. This area of research includes proteomics, structural analysis of proteins, membrane proteins, glycoproteins, protein-protein and protein-ligand complexes, as well as bioinformatics tools for the prediction of protein function. The next level of research would include detailed investigation of the identity, diversity and biological roles of metabolites in cells and organisms, employing metabolomics and metabonomics, again supported by sophisticated bioinformatics.



A model of influenza virus Hemagglutinin

The glycosylation world

If one considers DNA/RNA as the 'first language of life' and proteins as the second one, glycosylation (carbohydrate structures) can be considered as the 'third language of life'. The number of potential glycan structures is higher than the potential number of DNA, RNA or even protein structures by several orders of magnitude. Therefore, a better understanding of 'complex carbohydrates' is crucial for many fields of biology, medicine and biotechnology. Glycosylation processes or glycan structures (linked to proteins or lipids or in various free forms) are involved in a great variety of important biological processes, such as development, growth control, immune systems and host-pathogen interactions. In Europe, a strong scientific community has been developing in the various fields of glycosciences. What is needed now is a strengthening of the existing networks and better connection with other biological disciplines, including biomedical research. Within ESF, a very successful Exploratory Workshop was held on glycosciences in 2007 and a Research Networking Programme started in 2009.

From molecules to organisms: the cellular and organismal levels

Understanding evolutionary questions

More advanced genomic techniques can provide a deeper appreciation and understanding of evolutionary questions across a range of taxa. New technological developments such as association mapping are enhancing the potential of quantitative genetics, molecular paleontology and evolutionary genetics. Important research questions in the biomedical, agricultural and environmental disciplines include: What is the genetic basis for specific phenotypic traits? How can we interpret genotype-phenotype interrelationships? What is the basis for genetic diversity amongst individuals and populations? Answering these questions might now become possible due to the fast development of sequencing methods. Within ESF, a new EUROCORES Programme, *Ecological and Evolutionary Functional Genomics (EuroEEFG)*, has recently been initiated (spring 2009) and will tackle some of these questions.

Analyses of Phylogenetics and Evolution (APE)

Over the last few years, the freeware package APE for evolutionary studies, written in the R language, has become a primary tool in taxonomy. R is widely used for statistical analysis and is of interest to any biologist. APE is specifically dedicated to phylogeny, population genetics and evolution. Phylogenetic analysis covers a wide range of methods from reconstructing gene trees and estimating divergence dates, to analysing diversification. APE provides functions for reading, writing, plotting and manipulating phylogenetic trees, analysing comparative data in a phylogenetic framework, analysing diversification, computing distances from allelic and nucleotide data and reading nucleotide sequences. It includes several other advanced tools, such as the computation of minimum spanning trees or the estimation of population genetics parameters. All these diverse tasks rely heavily on computational statistics.

Until recently, most of these methods were only available in specialized software. APE provides them all in a single, free package. In taxonomy, it is important to have access to this broad range of analyses from macroevolutionary processes to population genetics, because we are looking at the genetic effects of environmental change over very long periods of time.

APE is under constant development. New methods are gradually implemented in the package and can be adapted to the need of the users. It provides a flexible framework for developing and implementing new statistical methods for the analysis of evolutionary processes and its ongoing maintenance is expected to be fruitful.

Analysing integrated reponses from molecules to behaviour

The neurosciences have developed very rapidly over the past decades. Conceptual and technological progress have occurred in neurogenetics, microscopy of living neurons, neurophysiology, neuroimmunology, *in vivo* networking analysis, brain (molecular and cellular) imaging and the study of animal behaviour (ethology). A once descriptive science has evolved fast into a quantitative biology of causal links, where dynamic processes take centre stage. The availability of neurogenomics, transgenesis in rodents, improved imaging and neurophysiological techniques have made it possible to study the neuronal system from molecules to behaviour in an integrative way. This brings new opportunities for the biological and psychological description of the brain. It improves insight into brain processes and enables, for example, medical treatments of brain-disorders to be developed. The range and amount of information that is needed to get better insight into complex neuronal processes demand an integrated international approach, and further integration of traditionally separated areas such as genetics, neurobiology, informatics, ethology, psychology, and medical sciences will be indispensible.

The contribution of systems biology

The concept of systems biology remains a challenging framework for research in various life science disciplines. Questions that need to be answered in the next decade(s) include: What can realistically be expected from systems biology, in terms of input to: basic biomolecular research; environmental research (stress responses or host-pathogen interactions, for example)? How can systems biology approaches be efficiently organised?

Applying new tools to help understand the environment

Using the new tools and techniques mentioned above to develop comprehensive and integrated studies in the traditional 'black boxes' would be a major stepping stone. Detailed studies of oceanic phyto- and zooplankton populations have, for example, been difficult so far. By combining new genomics tools – which can identify suites of genes with key functions – with cellular imaging, the diversity and function of planktonic populations can be established. This is also true for the soil ecosystem, where an integrated analysis is desperately needed. These developments provide substantial opportunities to identify organisms in previously unexplored habitats (such as the soil) and to enhance our understanding of functions, processes and conservation, at the ecosystem level.

Bacteria

Microbial diversity

Research using metagenomic approaches is urgently needed to explore the evolution and functional diversity of microbial communities in the soil and marine environment, and in the mammalian body.

There are more different organisms per unit of soil than in any other environment on Earth, with major differences in species composition in different places. Soils are exceptionally complex, highly dynamic systems, a result of biotic and abiotic interaction processes. Microbial populations in the soil play key roles in carbon fluxes in soils. Different functional groups, such as bacteria, degrader fungi and mycorrhizal fungi, co-exist and interact with each other. One challenge not yet resolved experimentally is to reveal the molecular mechanisms by which the physiological activities of algae, fungi, bacteria and archaea determine the nutrient stream to and from different nutrient pools, under ever changing nutrient, temperature, moisture and oxygen conditions.

Similarly, the microorganisms living in close association with the human body outnumber its own cells by about one order of magnitude. It is well known that microbial populations living in the gut and other epithelial surfaces of the mammalian body have important biological functions, such as in immunology and the digestion of food. But there is ample scope to explore our co-evolution with these organisms.

Anemone nemorosa

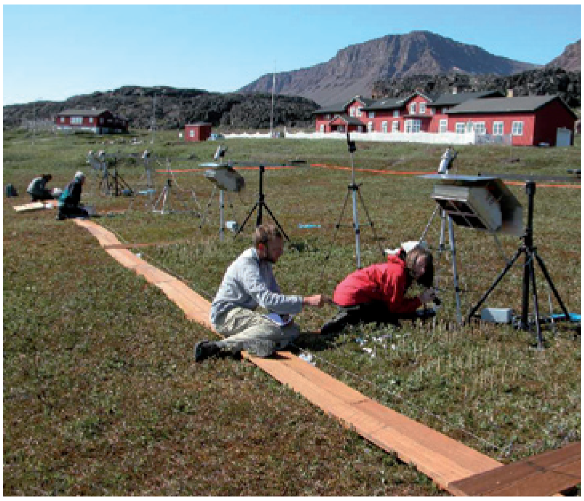
From populations and communities to ecosystems

While the study of ecosystem processes has been the focus of much attention over the past decade, exploration of extreme events and environments has been limited.

Studies on the possible effects of climate change on fauna and flora have increased in recent years. But one aspect that has been largely ignored is that small climate shifts result in a disproportionate increase in the number and probability of extreme climatic events, such as extreme heat, drought, storms and intense precipitation. An exceptionally hot and dry summer, such as 2003 in Europe, statistically only occurs every 9000 years, but General Circulation Models predict that by 2100 one in two summers will be comparable, or even hotter and drier. Less extreme events will obviously become more frequent too. Studies of the impact of such extremes on, for example, plant communities, are scarce. Drought tends to affect plant growth negatively, mostly because of stomatal closure and the associated reduced gas exchange. It is, however, unclear whether the same precipitation deficit has comparable effects in different seasons. Moreover, knowledge on the interaction of drought and heat waves is scarce, and responses to each of these extremes are not necessarily additive.

The study of invasive species is of high importance, because it links extreme events with climate change, ecosystem science, global trade and ecology. A number of Exploratory Workshops have already been funded by ESF in this area. Changes in community composition caused by extreme events may create opportunities for invasive alien species to establish. Climate change will also shift species' relative abilities to compete and may result in new possibilities for invasive species. Invasive species are themselves a contributing factor to global ecosystem change, additional to climate change, with international travel and trade playing a major role. Using advanced modelling techniques to assess invasibility and invasiveness, it may become possible to predict which species may threaten native and managed ecosystems, in both terrestrial and aquatic environments. Such modelling also offers potential for planning restoration and remediation.

The role of nitrogen is important in the interaction between extreme events, climate change and the rate at which ecosystems are affected. The natural abundance of useable nitrogen is low, and considerable human input is already required to produce food for the world's population. This will almost certainly increase, as will the release of nitrogen oxides into the atmosphere from fossil fuel combustion. Changes in the nitrogen cycle have already exacerbated aquatic, coastal and terrestrial eutrophication, acidification, climate change, photochemical smog, poor urban air quality and stratospheric ozone depletion, all of which have impacts on humans and ecosystems on regional and global scales. Understanding the cascade of nitrogen in an ecological context, its effects and its interaction with other environmental concerns must be at the vanguard of the next decade's environmental research strategy.



Infrared heating systems to study the effects of climate warming on tundra ecosystems

Finally, although much attention has been given to the consequences of climate change for ecosystems, there is a dearth of information on how to manage ecosystems to mitigate global change effects and provide sustainable delivery of environmental services. There are many possibilities: using terrestrial ecosystems to sequester carbon in the soil, or to produce bioenergy, and using wetlands for water-cleaning are examples. This area of study deserves urgent and robust investigation. To understand the effects of anthropogenic pollutants on ecosystems, attention must be directed towards the rate of pollutant uptake, rather than pollutant concentration in the air, water or soil. This flux-based approach will eventually provide a deeper understanding, and permit us to assess the effects of pollution on organisms, communities and ecosystems.

Atmosphere, hydrosphere and biosphere

The atmosphere partly escaped as steam from the Earth's crust, additional water was imported by bolide collisions, and more gases were released by volcanoes. Its present composition, however, is a direct result of the photosynthesis process, which uses sunlight and vast amounts of CO_2 and water to produce organic molecules, and releases oxygen as a waste product. Oxygen provided by plants induced corrosion of the Earth's surface, but at the same time it enabled the formation of life as we know it today. Atmosphere and hydrosphere thus inseparably link Earth with life, so that the life, Earth and environmental sciences are tightly interconnected. Climate variability and environmental change on the Earth's surface – natural or man-made – have profound effects on life.

Atmospheric CO_2, irrespective of its origin, is absorbed by seawater, where chemical changes occur that reduce seawater pH and the concentration of carbonate ions, in a process commonly referred to as ocean acidification. Carbonate ions are a basic building block in the skeletons and shells of a large number of marine organisms, including corals, shellfish and calcifying plankton. The latter represent the basis of the marine food web. Increased acidity of the oceans may hinder these species from producing their skeletons and drastically reduce their abundance, leading to the marine food web being cut off at the base. The implications for marine life as a whole, and for human societies, could be dramatic and more research is urgently needed.

A large number of studies have improved our understanding of gas phase and aerosol chemistry in recent decades, but many fundamental atmospheric chemistry processes are still poorly understood and need to be described in greater detail. Exchanges between the biosphere and the atmosphere, in particular of Biogenic Volatile Organic Compounds (BVOC), play a critical role and are key constraints of the physical and chemical properties of the atmosphere and climate. Yet despite their recognised and wide significance in ecology, in the climate system and for atmospheric composition, the knowledge of biotic and abiotic control of BVOC emissions can only be called rudimentary. Consequently, spatial and temporal variation in BVOC emissions and their responses to changes in vegetation cover, the terrestrial carbon cycle and climate are one of the chief uncertainties for projections of the past, present and future role of the terrestrial biota in the Earth system.

Over half of the world population now lives in urban areas and the number of megacities is growing rapidly. The understanding of atmospheric chemistry is therefore of crucial value to a range of economic and policy issues. It has become clear that atmospheric chemistry is intimately linked to climate and global environmental changes. The science behind atmospheric chemistry is interconnected and plays a pivotal role in understanding other key atmospheric problems such as air pollution. Regional impacts are particularly poorly understood and the way climate change will affect local air pollution in urban areas remains an open question.

Measurements of Biogenic Volatile Organic Compounds (BVOC)

Tower for ecosystem flux measurements

Earth sciences: the global level

Geological processes operate on different time scales

Why do we know so little about the planet we live on? In our rapidly changing world it has become imperative to understand better the functioning of our planet. Geological processes operate on many different timescales, from seconds (meteoritic impacts, earthquakes) to minutes (landslides, volcanic eruptions) to hours (tsunamis) / days / months / years to centuries (rapid uplift or subsidence) to millennia (denudation, plateau uplift, plate movements, core processes, magnetic reversals). The future challenge for Earth scientists is not only in learning how these processes operate, but also understanding their rates and how these rates can change. This is crucial when using current understanding of past geological records to evaluate the magnitude and timing of future events. Climate changes, ocean effects and Earth processes shaped the Earth's surface, forming a variety of sceneries and enabling life to flourish in unprecedented diversity. But they have become issues of major concern, as their current speed and impacts might threaten life in all its forms.

The Earth is a highly complex interrelated system, with which man interacts. We are gaining considerable appreciation of how our actions affect the climate and oceans, but we also need to understand how our actions affect the planet itself, and how the Earth's processes affect us.

Erosion and transport of geological materials occur naturally, carried out by rivers, ocean currents, wind and organisms. Materials accumulate in sedimentary basins and are recycled on time scales of thousands to millions of years. Human activity has accelerated many of these processes through mining and transportation of raw materials, extraction and combustion of hydrocarbons, fertilizing and pollution. Over the industrial era, the volumes of geological materials being redistributed worldwide are considerable, and in many cases the rates are far higher than those of natural processes. Future research should quantify these volumes and rates, and evaluate their impacts on ecosystems.

There are some specific areas that demand attention from researchers. For example, we are burying nuclear waste material in regions that are geologically unstable on the time scales of the half-life of the waste. Intensive burning of fossil fuels has not only increased the atmospheric CO_2 concentration, but also changed the natural ratio between CO_2 release and storage, with consequences already affecting the global ecosystem. Petroleum derivates are distributed worldwide: some decompose very slowly, others are toxic and quickly enter the food chain. Finally, we are promoting CO_2 sequestration into bodies that may catastrophically release it due to fracturing and fissuring. All these areas raise questions that can only be answered by careful, detailed research.

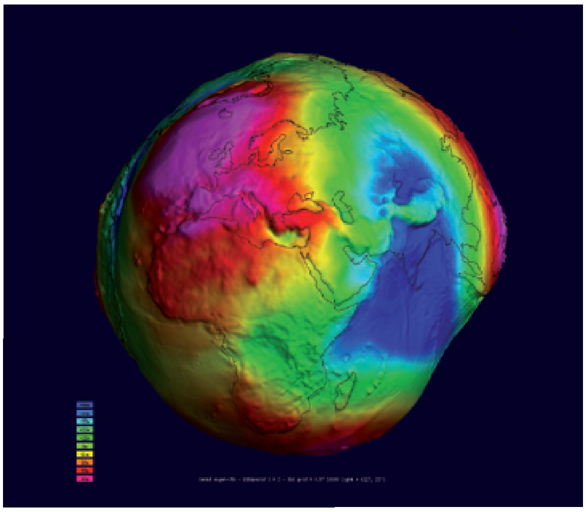
Paleoclimatic studies

Reconstructions of palaeoclimates reveal a broad climatic diversity over the history of the Earth. Such reconstructions help us to understand how the climate system operates and offer the possibility of testing the reliability and robustness of models used to predict future climate scenarios. The global environment is changing continuously. Evidence is accumulating of rapid climatic warming in the past (10°C of warming in three years, for example, 11,700 years ago), due to poorly understood processes in the solid and liquid Earth. What caused warming at such a rate, which would now be considered an unprecedented disaster?

What influence does solar activity have on the climate? Controlled by the orbital parameters, the maximum insulation on Earth in the Holocene was reached about 6,000 years ago. During the Middle Ages there was a relatively short-lived 'Little Ice Age' during a long hiatus in sunspot activity (the Maunder Minimum, lasting some 70 years). Another global warming of the atmosphere has been recorded during the last few decades, with increasing CO_2 concentrations attributed to the excessive burning of fossil fuels.

Within the shallow sedimentary layers beneath the ocean-continent boundaries and polar regions, a huge quantity of methane lies trapped in a solid form, stable within a narrow range of pressure and temperature. Ocean warming has the potential to release some or all of this methane, an important greenhouse gas, into the atmosphere. Two very important questions are how much methane is trapped and how can we ensure it remains so?

If positive feedbacks such as methane release from the ocean floor and melting permafrost, or loss of albedo because of melting ice kick in, a run-away greenhouse can be envisaged, with dramatic consequences for most of today's ecosystems. Will this warming be sufficient to overcome the orbital forcing and flip the Earth into a greenhouse mode, ending the Quaternary icehouse period? Earth history demonstrates that such changes have happened before. Consequently, research should focus not only on global warming scenarios for the coming decades but also on a longer time scale in the past and into the future. More studies are needed to reconstruct past climates using different well-dated and calibrated proxy records and to model climate and climate variability at different time scales. Initial efforts have brought together leading European marine, terrestrial and ice-core communities on these cross-cutting issues and have created



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Shape of the Earth's Geoid after the EIGEN-05C – model.

a momentum that must be better exploited, to advance our understanding of climate variability and the underlying physical, chemical and biological processes.

Remaining questions

Our knowledge about geological and geomorphological processes is steadily increasing but remains weak and fragmentary in too many cases. Some unanswered questions concern extreme geological events affecting the environment on a very short timescale. For example, working out why and how outlet glaciers surge in a single event is important in estimating the rates of ice mass decline and rising sea level. Are slow ice flow dynamics interrupted by a lubricating hydrological drainage system at the ice-rock interface? How do changes in the physical properties of ice with depth affect ice dynamics?

Another geological enigma: why do some volcanoes yield clear precursory signs in the lead up to an eruption, whereas others erupt without warning? Perhaps the answer lies in the configuration of sub-surface magma plumbing systems, on which exogenous and endogenous processes interact. Why do some earthquakes occur in unexpected locations with unexpected magnitudes? How can such events be apprehended? Mantle processes can lead to rapid subsidence with rates in excess of 1cm/year, comparable to horizontal plate movement rates. What drives these processes and could these rates accelerate, creating worse problems with flooding?

On a longer timescale, we have known since the middle of the last century that the Earth's magnetic field reverses, or flips, regularly on average four to five times every million years. Yet we have scant evidence of what happens during a flip. Does the magnetic field reduce to zero or do the magnetic poles move from one geographic pole to the other? If the former, then we temporarily lose the protection of the magnetic field and are irradiated by high-energy cosmic rays. During such times, have the species on Earth undergone an enhanced mutation rate, accelerating the evolution of species?

On a longer timescale still, there are outstanding questions about the Earth's origins. The seismic D' layer at the core-mantle boundary, which is thought to feed mantle plumes, may have formed in the first few percent of Earth's lifetime. But primitive meteorites such as chondrites, thought to have condensed out of the solar nebula, do not reflect the Earth's composition and so our model for the formation of the Earth may be wrong. Extinct radionuclides of terrestrial and extra-terrestrial rocks could reveal the answer.

Extreme events are likely to be understood only by acquiring a solid understanding of a system's behaviour under normal conditions, through inspecting very carefully the geological record, and the way external or internal parameters slowly or catastrophically force new behaviour.

To advance this knowledge, Earth and atmospheric sciences must reach towards communication technologies and physics, striving for a synergistic use of remote sensing data and ground measurements. Observation satellites can provide the data for monitoring our environment over short, medium and long time scales. Using these advanced techniques, for example, it is possible to construct a long time series of surface-mass-balance in non-floating glaciers and link this with observations of sea level rise. Multi-parameter signals of volcanic eruptions and the corresponding transfer of gaseous mass to the atmosphere can be studied in detail. Ground-based observations are also essential. Space- and Earth-based data are complementary and only rarely cover the same spatial and time scales. Full exploitation of space data relies partly on information obtained on the ground for calibrating and validating remote (airborne and space-based) observations. Monitoring our planet will provide constraints to models that could help policy makers to take action for mitigating natural hazards. Improved understanding of active processes, better dating techniques and proper evaluations of uncertainty will lead to better interpretations of the geological record and, therefore, more precise future provisions.

Science and society

For decades, a fundamental methodological incompatibility of the arts and humanities on the one hand and the so-called 'hard' sciences on the other has been perceived. Recently, however, academics have increasingly seen that this division masks a complex field of differences and interfaces within and between the two cultures. There is much to be gained by constructively overcoming disciplinary boundaries, but there is often strong resistance in academies and universities, funding agencies, and research institutes to genuine trans-disciplinary collaboration in either teaching or research.

Who needs science? We all do. The relationship between science and society has become a political issue recently. Policymakers ask questions about the relevance of science for society, and need science to answer specific questions relevant for policymaking. Mankind is currently facing unprecedented changes in the Earth system because of its own activities, based on intensive exploitation and consumption of natural resources and marked perturbations of natural processes. These changes present new challenges and risks for society. Relevant research agendas need to evolve very rapidly, as the scale and urgency of the socio-environmental challenges grows. Strategic responses require a full integration of efforts to achieve sustainable governance, through the interdisciplinary contribution of social and human sciences, in addition to natural sciences.

Once seen as entirely beyond the human domain, the climate is now known to be profoundly influenced by decades or centuries of human activity. Continuously increasing water scarcity at the global scale is making us re-think global water management. A better exploration of the role of human society (the 'anthroposphere') in the integrated and evolving Earth system could contribute towards defining anthropogenic effects such as these, on water and life.

Several other fields, such as aging, natural resource management and urban studies might also benefit from a meeting of the natural and social sciences with the humanities. Adaptation to global environmental change may require deep changes in our behaviour and society structure. The systemic understanding of global change has expanded markedly, but societal drivers and consequences are still to be fully explored through problem-oriented approaches.

The development of transdisciplinary approaches, based on an active dialogue with decision makers and other stakeholders, is not an easy task. Interdisciplinary science is essential to distinguish between the natural variability of elemental cycles and the anthropogenic perturbations of those cycles, as both are part of the Earth system. Similarly, human responses to global change are not simple. Their study requires contributions from natural and physical sciences (for example, in geo-engineering or water management) and from social and human sciences (such as social anthropology and cognitive science).

In the post-modern era, societies need an honest and solid discussion on issues raised by the extremely fast progress of biological sciences, which is poorly understood by the general public. Facing the growing influence of various kinds of creationism in Europe, for example, it is high time to explain better the theoretical backbone of modern biology and ecology evolution. Genetically modified organisms or stem cell research may also be considered neglected in terms of the public understanding of their pros and cons. More emphasis on these important, interdisciplinary areas may be used as an excellent vehicle for increasing the European visibility of ESF.

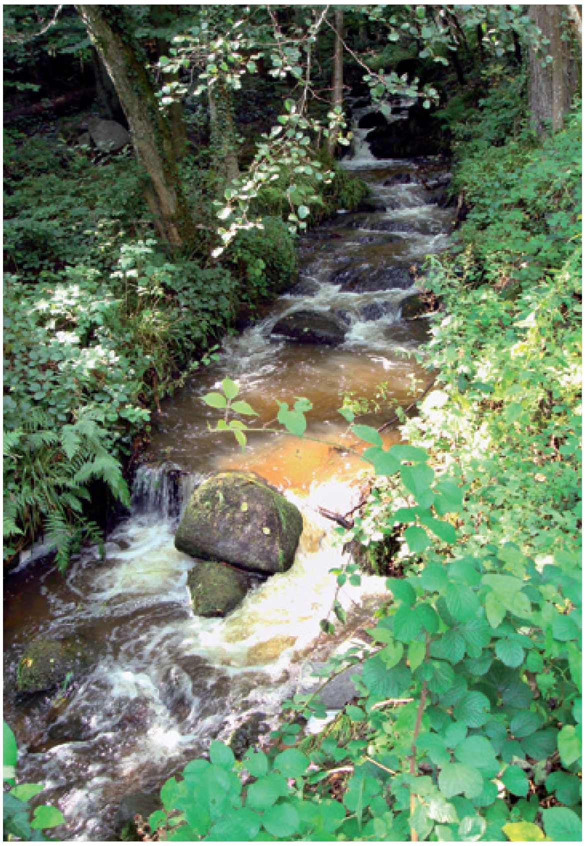
Overall, the extensive knowledge base that scientific research has created should contribute to the development of sustainable responses. Natural, social and human sciences need to improve their ability and capacity to work together so as to respond to the pressing societal and policy needs.

Implementation

This document highlights neglected and emerging areas in the life, Earth and environmental sciences. LESC would like to encourage the scientific community to initiate activities in the strategically identified science fields. The action to be taken will depend on the status of each topic. The science community should take advantage of the support available through the LESC science officers and work in close collaboration with the LESC members to fine-tune the subject and timing of their proposals, and make use of the best instruments.

The current set of ESF instruments aims to meet demands for further exploration and development of initiatives. The openly competitive theme selection process for EUROCORES Programmes, Research Networking Programmes (RNPs), and Exploratory Workshops maintains a high degree of flexibility and safeguards high quality through competition.

Monitoring the progress and impact of achievements through the new initiatives should be a main component of the implementation plan. The mid- and end-term reports currently required by the EUROCORES Programmes and RNPs serve as a feedback to the Standing Committee. This approach should be extended and internalised for all instruments to serve as input for new ideas in future strategy papers. More targeted actions are possible through Forward Looks, Science Policy Briefings and Strategic Workshops. A new instrument could be developed to serve as a targeted *à la carte* funding solution for fast emerging fields that need immediate support.



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Print run: 1000 – August 2009