

## **Earth System Science Revised Theme report June 2010**

### **Note about the revisions:**

The current NERC strategy *Next Generation Science for Planet Earth* is intended to be dynamic and will be regularly refreshed so that NERC is able to respond to new opportunities and priorities. NERC has recently refreshed its strategy and one key outcome is an update to the ESS Theme Report.

The changes to the ESS Theme Report were primarily based on the observation that the scope of the theme, as written in the original Theme Report was too broad, as it encompassed all timescales and all parts of the Earth system. The aims were to:

- (1) Define the boundaries between the ESS and other strategy themes, particularly Climate Systems
- (2) More clearly define the focus of the theme

The revised theme now focuses on biogeochemical cycles and the interactions between the surface and deeper parts of the Earth System on all timescales. The physical components of the Earth System are now within the Climate Systems theme. Paleoenvironmental studies remain an important component of the ESS theme but could also be important to the Climate Systems and Biodiversity themes, depending on how they contribute to the challenges within those themes.

As a result of improving the focus of the ESS theme, the previous challenge 3 (“Understand the forces and feedbacks that drive the Earth System”) has been removed.

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## BACKGROUND

The Earth operates as a complex biogeochemical and physical system with feedbacks between the various components that serve to regulate present and future habitability and long term evolution. These processes operate on timescales from less than seconds to billions of years and on spatial scales from microscopic to planetary.

Traditionally, research has been undertaken in individual components of the Earth system, for instance the ocean, atmosphere or mantle. However, it is now clear that we cannot understand and ultimately manage the Earth's environment without considering it as an inter-connected and highly complex system. This theme therefore aims to encourage research that tackles this issue directly. This will require research that crosses the boundaries of individual Earth system compartments and processes, and is framed in the context of the interactions between particular compartments, processes and the system as a whole, from the core to the upper atmosphere. The timescales of cycling within the crust / mantle / core component of the Earth are usually on the order of millions of years and much longer than in the cryosphere / ocean / atmosphere / earth surface component where processes generally operate on timescales of 10,000 years or less. Hence, for some purposes these are better treated as separate parts within the Earth system.

## SCOPE OF THE THEME

This is best described as fundamental research into drivers and feedbacks in the Earth system from its core to the upper atmosphere. The research can be divided into two broad areas:

- A. biogeochemical (including rock and sediment) fluxes and feedbacks in the cryosphere / ocean / atmosphere / earth surface system,
- B. the crust / mantle / core system to understand those processes that created it, control its continued evolution and define and govern its interaction with the cryosphere / ocean / atmosphere / earth surface processes of (A).

Biogeochemical processes relate to other facets of the Earth system for example ecological and climate systems. Therefore, natural connections exist with the Climate System Theme, which is focused primarily on physical and chemical regulation of weather and climate, and the Biodiversity Theme, that deals primarily with interactions between species. Collaborations between these themes will yield a complete Earth system approach.

## KEY DRIVERS

This theme aims to provide the underpinning science to understand the Earth system, and how the components affect each other at present and over geological time. This understanding will inform all the other themes, as well as providing key scientific understanding to help manage the environment in the face of current global change pressures.

## SCIENCE CHALLENGES

Challenge 1 Understanding the biogeochemical forces and feedbacks that drive the Earth System.

*Scope*

The Earth's environment is regulated in part by complex biogeochemical cycles of key elements (C, N, P, S, Fe, trace metals) which affect atmospheric, aquatic and soil composition, and ultimately the climate system. These forces and feedbacks occur mainly in the cryosphere/ocean/atmosphere/earth surface component of the Earth system, but on longer timescales are influenced by tectonic processes that may alter, for example, sea level and weathering. The multitude of interacting chemical, biological and physical processes within the Earth system leads to the possibility of abrupt non-linear change in components of the system, even in response to smooth changes in the forcing of the system. Such abrupt responses to contemporary anthropogenically-induced global change have potentially serious implications for human wellbeing. As an example, biological productivity on land and in the oceans is regulated by climatic variables and the availability of nutrients, while itself regulating atmospheric composition and hence climate. However, we do not understand even the present day cycle of many of the key nutrients, and hence cannot adequately predict the impact of large anthropogenic perturbations of the major nutrient cycles on the Earth System.

#### *NERC contribution*

**Acquire the key data and modelling needed to provide a rigorous and quantitative understanding of the biogeochemistry, fluxes, interactions and drivers of the Earth system and how the various compartments interact and evolve over geological time.**

These interactions span many components. For example the transport of poorly understood critical nutrients, such as iron, from land to the oceans will alter ocean productivity and hence lead to changes in atmospheric composition and climate, leading in turn to feedbacks with terrestrial cycles and hence to changes in nutrient fluxes to the oceans. Research activity into such cycles needs to recognise the importance of key interactions, and the development of the parts of ice/ocean/atmosphere models that incorporate these interactions. The geological record can offer important information, such as, for example, how biogeochemical cycles contributed to glacial-interglacial and longer-term climate change, or to the Paleocene-Eocene thermal maximum. It also provides us with insights into the basic nature of these cycles, how they have changed over time and the relationship between these changes and the physical environment.

#### *Desired deliverables*

A quantitative understanding of present day global biogeochemical cycles, allowing predictions of the impact of future changes in these cycles on the Earth system. This will require research focussed on key components and processes within particular biogeochemical cycles, studies focussed on the overall cycles now and in the past, and the development of biogeochemical cycle models embedded within physical Earth system models.

### Challenge 2 Understanding the long term development of the Earth and its habitability.

#### *Scope*

The origin and differentiation of the Earth and the ongoing interactions between the resultant mantle, core and crust have created a habitable environment that is unique in the solar system. How this happened is unclear but it culminated in the evolution of advanced lifeforms that continue to shape its development. Special features include the presence of water in the deep solid Earth that has profound implications for its long-term evolution, as well as that of the hydrosphere, and may be the crucial lubricant that distinguishes its mantle dynamics from those of other planets. Tectonic and volcanic processes influence both climate and biogeochemical fluxes but these too are under-constrained at present. While representing only a small fraction of Earth's mass, the continental crust provides the unique repository of nearly all of its history. Unravelling the processes that produced the crust from the mantle is

of particular importance because at present there is no consensus over why a reservoir of this composition was formed on Earth but not on other planets. We think it relates to the special and perhaps changing role of water in silicate melting but it could also relate to the history of weathering. The magnetic field is also different from that of any other solar system object reflecting poorly understood core-mantle boundary dynamics that lead to a surface cosmic ray shield. Through most of the four billion year history of the Earth, life has been present as a major force influencing the atmosphere, oceans, the surface environment and the crust. Major transitions in evolution have driven, and been driven by, climate and environmental change. Improved knowledge of the properties of this coupled system will help us to better understand the history of our remarkable planet.

### *NERC Contribution*

**Develop a deep understanding of the reasons for the uniqueness of Earth.** Research should focus on how the chemical and physical evolution of the Earth has driven change that affects the surface environment; on how water, and possibly life, have affected the chemistry and dynamics of the crust and mantle; and how the complex interplay of biology, geology, ocean chemistry and climate has driven, and was driven by, major transitions in evolution.

### *Desired Deliverables*

Provide an improved knowledge and understanding of:

- the controls on subduction and mantle convection, melting and volcanism,
- how deep-Earth processes influence the surface environment, such as by the generation of the magnetic field and volcanic degassing leading to global change,
- the links between biological evolution and environmental change, in particular in climate, and atmospheric and oceanic chemistry ,
- the ways in which past change can be used to predict the future development of the Earth system.