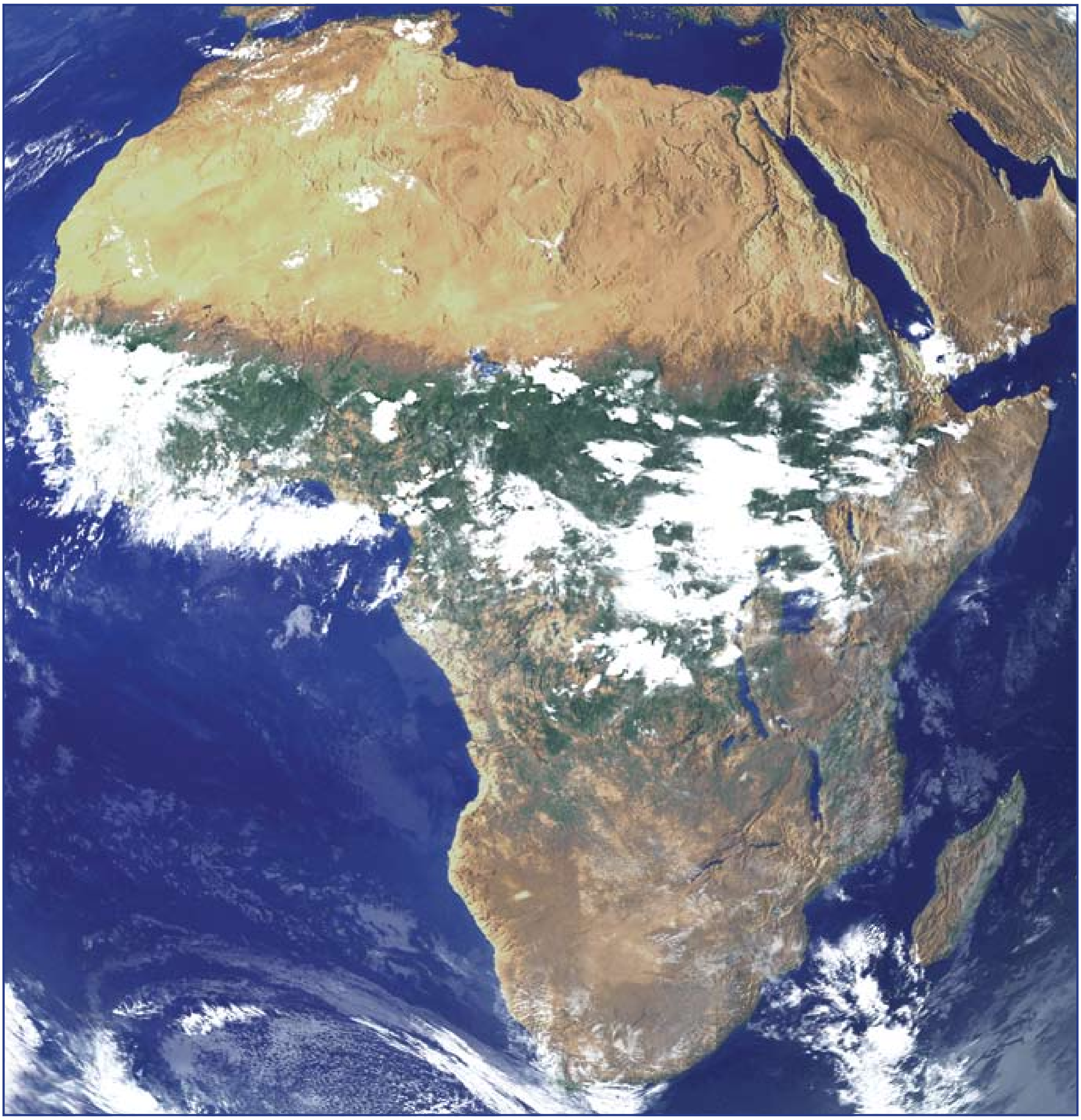
A Strategy for Global Environmental Change Research in Africa



Science Plan and Implementation Strategy

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Executive Summary

Global Environmental Change (GEC) refers to the set of transformations of land, oceans and atmosphere, driven by an interwoven system of socioeconomic and natural processes. Concurrent with the modern phenomenon of *globalisation* (the growing and accelerated interconnectedness of the world) and, to some extent, as a consequence – humans have begun to induce planetary-scale changes in Earth's life support systems.

We now know that human activities match (and often exceed) the natural forces that regulate the Earth System. Recent ice core data show that current levels of carbon dioxide and methane are well outside the range of natural variability over the last 800,000 years (1). Roughly half of the world's ice-free land surface has been altered by human actions(2). Humans now fix more nitrogen than nature does(3). Particles emitted by human activities alter the energy balance of the planet, as well as have adverse effects on human health(4). These may seem to be unrelated issues; however, over the last decades, we have gained a deeper understanding of the degree to which all of these separate issues are linked. The Earth System is a very complex system with myriad feedbacks, and it has and presumably can still exhibit rapid, global-scale responses to changes in environmental conditions.

A consequence of the interconnectedness of the coupled human-environmental earth system is that no region is independent of the rest of the world. In the case of Africa, processes at work in the region (e.g., desertification, biomass burning) can have global consequences, and processes occurring in other regions can have influences in Africa (e.g., the possibility that particulate emissions from other continents affect rainfall patterns in sub-Saharan Africa). This interconnectedness manifests itself as well in the fact that global environmental research requires the involvement of African scientists, and global environmental change research in Africa needs the input of scientists from outside the region; we are all interdependent.

The overall purpose of this document is to describe the areas of global environmental change research that are of particular importance and interest for Africa, to describe the basic research needed to support cogent decisions about adaptation and mitigation, and to provide reasonable options for the support structure needed to facilitate and implement the research.

This science plan was prepared in wide consultation with African global environmental change researchers, and also with the international research community outside Africa. It reflects the collective views of this research community as to the needs and special interest areas for African GEC research. The plan is stratified into three levels of increasing detail; the intention is to clearly describe the large-scale issues of particular importance for Africa, outline the kinds of international, multidisciplinary research approaches necessary to approach these issues, give examples of specific questions and projects that could be part of an African GEC research initiative, and finally to propose a mechanism through which these initiatives could be realized. This initiative is called **AfricanNESS:** the African Network for Earth System Science.

AfricanNESS concentrates on four top-level issues that are the focus of concern with respect to global environmental change and its impacts in Africa:

- **Food and nutritional security,** including crops, wild-gathered resources, livestock resources and fisheries;
- **Water resources,** particularly in the water-limited sub-humid, semi-arid and arid regions;
- **Health,** especially in relation to the biodiversity-linked, environmentally-mediated and vector-born diseases that are responsible for the high disease burden in Africa; and
- **Ecosystem integrity,** on which the persistence of biodiversity and the delivery of ecosystem services depends.

These focal issues find expression, for instance, in the Millennium Development Goals.

These four focal issues are directly and indirectly influenced by a number of interconnected drivers of change, the 'Global Environmental Change Syndrome', including **land cover change** resulting largely from agriculture, forest clearing and infrastructure development; **atmospheric composition change** as a result of human-induced emissions of greenhouse gases, aerosols and nitrogen- and sulphur-containing trace gases; the **climate change** that they together cause; **biodiversity change** resulting from over-harvesting, loss of habitat and pollution; the interconnected economic and political factors involved in **globalisation;** the **demographic** changes in the size, composition, and distribution of populations; including the tendency towards **urbanisation;** and the changes in resource consumption and waste production that accompany **issues of equity**, **increasing wealth** and **novel technologies.**

Between the 'focal issues' and the 'global drivers of change' are a series of causal links, processes and feedback loops. Since it is these interconnections that determine the specific outcome of global environmental change in Africa, the research programme outlined in this document focuses on this connecting layer. It prioritizes those issues that are most critically important for human well-being in Africa; that lend themselves to adaptive actions; or that are of global importance, but best-studied in Africa.

The researchable topics in such a wide-ranging area are unavoidably many and interconnected. To achieve a degree of focus and clarity, they have been arranged in the body of this document into eight **thematic clusters**. The elements of such clusters typically interact strongly among themselves, and so are best treated in a coordinated fashion. There are also connections between clusters, so one element may have relevance in several themes, although for conciseness it is described only in one. The thematic clusters are deliberately not aligned with traditional disciplinary boundaries.

Thematic clusters (blue text) and research elements

Rainfall Variability Distribution Processes Land surface feedbacks Rainfall in GCMs	**Land Cover** Degradation Fragmentation Fires Biodiversity loss Water resources Wetlands	**Livelihoods** Fisheries Pastoralism Crop farming Vulnerable people and places	**Cities** Flooding Sea level rise Pollution Water resources Infrastructure
Diseases & Pests Environmental and emergent Advanced bioclimatic modelling	**Africa and the Earth System** Carbon cycle Dust aerosols Water cycle Ocean-land interaction Palaeoclimate Biogeochemistry Regional climate modelling	**Integrated Development** Energy Transportation Air quality Scenarios Governance	**Marine** Ecosystems and coral reefs Biodiversity and food resources Large-scale circulations

To further organize and prioritize the research topics in this African Global Change Research Strategy, we applied the following seven principles:

1. Favour a limited number of multi-year coordinated research programmes over a large number of short-term, independent projects;
2. Promote inter-disciplinarity, multi-institutional and regional research;
3. Develop science-policy-practice interfaces;
4. Build lasting human and institutional capacity;
5. Ensure that the products of scientific research are credible, salient and legitimate;
6. Contribute to the global research agenda from an African perspective;
7. Recognise and develop indigenous knowledge and capacity.

The resulting themes represent the intersection of the information needed to support development of favourable research opportunities, and the research capabilities desired in Africa. The objective is to develop the capacity, within Africa, to anticipate and adapt to global change and to adopt a development path that is locally and globally sustainable.

It is taken as given that only research that meets widely-accepted quality standards is useful in this quest, and that the mechanisms by which a coordinated research effort is implemented must be transparent, accountable and efficient. Each of these eight *thematic clusters* (and their associated *research elements*) are described in the science plan, with more detailed information (including examples of specific research questions and issues) presented as supplementary material in the Annex.

Finally, the science plan proposes a structure and mechanism by which these themes and elements can be approached, and gives an estimate of the level of support needed to make AfricanNESS into a functional research network for Africa.

Footnotes

1. Siegenthaler, et al., 2005; Spahni, et al., 2005
2. Foley, et al., 2005
3. Galloway et al., 2004
4. Charlson et al., 1992; Pope III & Dockery, 2006

This science plan has its primary origins in two efforts to describe the global environmental change issues most relevant for Africa. One was through the AfricanNESS initiative that started with a scoping workshop in September 2005 in Nairobi, Kenya that attracted more than 70 participants from across Africa and beyond. The first AfricanNESS science plan was drafted after a second workshop in Pretoria, RSA in June 2006, with the input from many of the participants from the original workshop. It was further refined during and after a meeting in Nairobi, Kenya in December 2006. The second effort was coordinated and published by the International Council for Science (ICSU) Regional Office for Africa. In drawing up the ICSU science plan, the authors took into consideration the ICSU Strategic plan 2006-2011, the AU/NEPAD Africa's Science and Technology Consolidated Plan of Action, the UN Millennium Development Goals for Africa, and reports from interdisciplinary bodies and joint initiatives. The ICSU ROA convened its 2nd Regional Consultative Forum for Africa in Boksburg, South Africa, on 25-27 September 2006, to provide a platform for this science plan (and others developed by ICSU) to be critically evaluated by the broader scientific community. Both science plans were circulated through several media to the international community at large for comments and input. The processes by which both were developed were transparent and participatory in nature.

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Acronyms and Abbreviations

AB	Advisory Board (AfricanNESS)
ACCESS	African Collaborative Centre for Earth System Science
AEO	Africa Environment Outlook
AfDB	African Development Bank
AfricanNESS	African Network of Earth System Sciences
AIACC	Assessments of Impacts and Adaptations to Climate Change
AIDS	Acquired Immune Deficiency Syndrome
AMMA	African Monsoon Multidisciplinary Analysis
APN	Asia-Pacific Network for Global Change Research
ARGO	Array for Real-time Geostophic Oceanography
AU	African Union
CEDEAO	Communaute Economique des Etats de l'Afrique de l'Ouest
CGIAR	Consultative Group on International Agriculture Research
CLICOM	Climate Computing Project (World Climate Data Monitoring Programme)
CLIPS	Climate Information and Prediction Services
CLIVAR	Study on Climate Variability and Predictability (WCRP project)
COSMAR	NEPAD Coastal and Marine Programme
CSAO	Club du Sahel et de I'Afrique de I'Ouest
CSD	Commission on Sustainable Development (UN)
CST	Committee on Science and Technology (UNCCD
DARE	Data Rescue
DECAFE	Dynamique et Chimie Atmosphérique en Forêt Equatoriale (Dynamic and Atmospheric Chemistry in the Equatorial Forest)
DFID	Department For International Development (UK)
DIVERSITAS	International programme on biodiversity science
DPSIR	Driver-Pressure-State-Impact-Response
ENSO	El Niño – Southern Oscillation
ESSP	Earth System Science Partnership
EXPRESSO	Experiment for Regional Sources and Sinks of Oxidants
FAO	Food and Agriculture Organisation (UN)
GAP	Good Agricultural Practices
GCOS	Global Climate Observing System
GCM	Global Climate Model

GCSS	GEWEX Cloud System Study
GCTE	Global Change and Terrestrial Ecosystem project
GEC	Global Environmental Change
GECAFS	Global Environmental Change and Food Systems
GECHH	Global Environmental Change and Human Health
GECR	Global Environmental Change Research
GEF	Global Environmental Facility
GEO	Global Environment Outlook
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse Gas
GIS	Geographical Information System
GISP	Greenland Ice Sheet Project
GIWA	Global International Waters Assessment
GLOCHAMORE	Global Change and Mountain Regions
GLOWA	Global Change in Hydrological Cycle
GLP	Global Land Project
GMO	Genetically Modified Organisms
GOFC/GOLD	Global Observation for Forest and Land Cover Dynamics
GOOS	Global Ocean Observing System
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities
GWP	Global Water Partnership
GWS	Global Water Systems
GWSP	Global Water Systems Project
HELP	Hydrology for the Environment and Policy
HIV	Human Immunodeficiency Virus
IAI	Inter-American Institute for Global Change Research
ICSU	International Council for Science
ICSU-ROA	ICSU Regional Office for Africa
IDEAL	International Decade for the East African Lakes
IDS	Institute of Development Studies (UK)
IEA	International Energy Agency
IFPR	International Food Policy Institute
IGAC	International Global Atmospheric Chemistry Project (IGBP)
IGAD	Inter-Governmental Authority on Development
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme
IIASA	International Institute for Applied Systems Analysis
IIED	International Institute for Environment and Development (UK)

iLEAPS	Integrated Land Ecosystem-Atmospheric Processes Study
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute
ISPRE	International Science Panel on Renewable Energy (ICSU)
IUCN	World Conservation Union
IUGS	International Union of Geological Sciences
IUPAP	International Union on Pure and Applied Physics (ICSU)
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LME	Large Marine Ecosystem
LOICZ	Land-Ocean Interactions in the Coastal Zone
LUCC	Land-Use and Land-Cover Change
MA or MEA	Millennium Ecosystem Assessment
MDGs	Millennium Development Goals of United Nations
NAO	North Atlantic Oscillation
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organisation
NSF	National Science Foundation (USA) (already an entry for US NSF)
PAGES	Past Global Changes (IGBP project)
PIRATA	Pilot Research moored Array in the Atlantic
PRCM	Regional Programme for the Protection of Coastal and Marine Resources
PV	Photovoltaic
RAMSAR	The Ramsar Convention on Wetlands
ReNED	Research Network for Environment and Development
ROA	Regional Office for Africa (ICSU)
ROSA	Regional Office for Southern Africa (IUCN - The World Conservation Union)
SA NRF	South African National Research Foundation
SAFARI	Southern African Regional Science Initiative
SCOPE	Scientific Committee on Problems of the Environment
SIWI	Swedish International Water Institute
SSC	Scientific Steering Committee (AfricanNESS)
SST	Sea Surface Temperature
SRES	Special Report on Emissions Scenarios (IPCC)
START	SysTem for Analysis, Research and Training
TOGA	Tropical Oceans and Global Atmosphere
UGEC	Urbanization and Global Environmental Change (IHDP project)
UN	United Nations

UNCB	United Nations Convention on Biodiversity
UNCC	United Nations Conference Centre
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
US NSF	United States National Science Foundation
UNSO	United Nations Sudano-Sahalian Office
VACS	Variability of the African Climate System
WCRP	World Climate Research Programme
WHYCOS	World Hydrological Cycle Observing System
WS	Water System
WWF	World Wildlife Fund

1 Introduction

The UN Millennium Development Goals are an inspiring and formidable challenge for society: within the next decade we must aim to eradicate extreme poverty and hunger; achieve universal primary education; promote gender equality and empower women; reduce child mortality; improve maternal health; combat deadly diseases; ensure environmental sustainability; and construct a global partnership for development. At the same time, society is faced with other challenges such as global climate change, air pollution, decreases in global biodiversity, food resources and how all of these issues tie into global security.

Some have argued that it is not feasible to address all of these issues at once, and that we should simply use a sort of cost-benefit analysis to choose one on which to concentrate. This view may be appealing, but it is fundamentally misguided. It would be a tragedy if, for instance, we were able to completely eradicate HIV/AIDS only to discover that by ignoring global environmental change issues, malaria had become even more widespread or freshwater resources even scarcer. We do not have the luxury of solving these problems one at a time; they need to be tackled together. Understanding how the natural Earth System works, and how we humans influence (and are influenced by) it is at the very heart of addressing these issues, and achieving the Millennium Development Goals.

We now know that human activities now match (and often exceed) the natural forces that regulate the Earth System. Recent ice core data show that current levels of carbon dioxide and methane are well outside the range of natural variability over the last 800,000 years (Siegenthaler, et al., 2005; Spahni, et al., 2005). Roughly half of the world's ice-free land surface has been altered by human actions (Foley, et al., 2005). Humans now fix more nitrogen than nature does (Galloway et al., 2004). Particles emitted by human activities alter the energy balance of the planet, as well as have adverse effects on human health (Charlson, et al., 1992; Pope III and Dockery, 2006). These may seem to be unrelated issues; however, over the last decades, we have gained a deeper understanding of the degree to which all of these separate issues are linked. The Earth System is a very complex system with myriad feedbacks, and it has and presumably can still exhibit rapid, global-scale responses to changes in environmental conditions.

We adopt the definition of "**Global Environmental Change**" (GEC) as referring to the set of biophysical transformations of land, oceans and atmosphere, driven by an interwoven system of socio-economic and natural processes. Concurrent with the modern phenomenon of "globalisation" (the growing and accelerated interconnectedness of the world) and, to some extent, as a consequence – humans have begun to induce these various large-scale changes in Earth's life-support systems. This reflects the now huge collective environmental impact of humankind, as a function of population size, economic activity, prevailing technologies and consumption patterns.

Human-induced changes to the structure, composition or function of large natural biogeophysical and ecological systems entail changes in the complex array of forcings and feedbacks that characterise the internal dynamics of the Earth System (Steffen, et al., 2003). These planetary-scale environmental changes are of great significance because they are diminishing the capacity of the Earth's natural environment to supply and replenish resources, and to absorb and recycle the waste products from human activities. Global environmental change cannot be understood in terms of a simple cause/effect paradigm and cannot be considered in isolation of the other coincidental changes. These effects interact with each other and with local- and regional-scale changes in ways that are difficult to describe and predict. These cross-scale and transdisciplinary aspects of the issues are real challenges for GEC research.

Another challenge for the global change research community is to establish meaningful dialogues between scientists and users, and to offer accessible and informative resources to stakeholders – particularly those concerned with sustainable development. We are frequently expected to answer questions on the effects of global change on regional- and even local scales: stakeholders seek strategies to deal with future environmental change. This is particularly important for the developing world, since the capacity to adapt to local or regional changes driven by global factors is often limited.

The need to understand how the natural world works has not diminished, but in fact underpins the answers to questions of sustainable development. We still must concentrate on first-class science involving the interactions and feedbacks between biological, chemical and physical processes and human systems. However, scientists, resource managers and policy makers require a common understanding in order for their interactions to be mutually beneficial.

At the local, regional and global scales, sustainable development in general and adaptation in particular represent perhaps the most pressing challenges that humanity faces (Adger, et al., 2006; Adger, et al., 2003). This science plan lays focus on the crucial role of science and scientific knowledge for global environmental research in Africa. Science is herein defined in its broadest terms, encompassing the natural and social sciences. The assumption is that it is this full contribution and integration of knowledge from across this spectrum of disciplines which will result in a true science - society interface for sustainable adaptation to global environmental change. The approach of the science plan keeps in mind the pillars of sustainable development: environment, society and economy.

With the rich cultural, geographical, economic and environmental diversity that characterises Africa, this science plan recognises the need for fundamental partnership between science and society.

1.1 PURPOSE AND ORIGIN OF DOCUMENT

The overall purpose of this document is to describe the areas of global environmental change research that are of particular importance and interest for Africa, to describe the basic research needed to support cogent decisions about adaptation and mitigation, and to provide reasonable options for the support structure needed to facilitate and implement the research.

This science plan has its primary origins in two efforts to describe the global environmental change issues most relevant for Africa. One was through the AfricanNESS initiative that started with a scoping workshop in September 2005 in Nairobi, Kenya that attracted more than 70 participants from across Africa and beyond. The first AfricanNESS science plan was drafted after a second workshop in Pretoria, RSA in June 2006, with the input from many of the participants from the original workshop. It was further refined during and after a meeting in Nairobi, Kenya in December 2006. The second effort was coordinated by the International Council for Science (ICSU) Regional Office for Africa. In drawing up the ICSU science plan, the authors took into consideration the ICSU Strategic plan 2006-2011, the AU/NEPAD Africa's Science and Technology Consolidated Plan of Action, the UN Millennium Development Goals for Africa, and reports from interdisciplinary bodies and joint initiatives. The ICSU ROA convened its 2nd Regional Consultative Forum for Africa in Boksburg, South Africa, on 25-27 September 2006, to provide a platform for this science plan (and others developed by ICSU) to be critically evaluated by the broader scientific community. Both science plans were circulated through several media to the international community at large for comments and input. The processes by which both were developed were transparent and participatory in nature.

While each of the plans had its own special character, there was sufficient commonality for the scientific community to realize that a single science plan expressing the needs for global environmental change research in Africa would be desirable. After consultation among the international scientific community, a small writing group (the editors of this document) was appointed to merge the two plans into a single document. The aims for this writing group were to produce a single science plan accurately reflecting the scientific themes, priorities and approaches of the original plans, to make sure that the merged document retained the participatory nature of the original processes, and produce a document that can serve to galvanize enthusiasm and support for implementing the research.

1.2 AFRICA AND GLOBAL ENVIRONMENTAL CHANGE

A consequence of the interconnectedness of the coupled human-environmental earth system is that no region is independent of the rest of the world. In the case of Africa, processes at work in the region (e.g., desertification, biomass burning) can have global consequences, and process occurring in other regions can have influences in Africa (e.g., the possibility that particulate emissions from other continents affect rainfall patterns in sub-Saharan Africa). This interconnectedness manifests itself as well in the fact that global environmental research requires the involvement of African scientists, and global environmental change research in Africa needs the input of scientists from outside the region; we are all interdependent.

Africa is characterised by its diversity of peoples and natural environments. The continent and its adjacent islands occupy a total land area of 30.4 million km^2, slightly more than 20% of the world's landmass. It had a population of over 880 million in 2005, with a growth rate of 2-4%, twice the global mean. As a result, Africa's population is projected to double in 22 years, even with AIDS reversing decades of gains in life expectancy. The growing population will exacerbate existing problems of food security and the provision of safe water, education and health services. It adds ecological stresses to the glaring economic strains evident in Africa. The key challenges facing Africa, arguably to a greater degree than other regions of the world, include:

- **Poverty:** Africa was the only major developing region showing a decline in income per capita over the period 1980–2000 (Sachs, et al., 2004). Two-thirds of the least developed countries are in Africa.
- **Disease:** Africa's health conditions are the worst on the planet (Sachs, et al., 2004). It has the highest under-5 mortality rate (140 per 1000) and life expectancy at birth is only about 54 years. A large portion of the population experiences diseases such as malaria, HIV/AIDS, cholera and tuberculosis, largely under control elsewhere in the world.
- **Hunger:** Forty percent of the population in sub-Saharan Africa is undernourished (Benson, 2004). Most of the countries currently facing food emergencies are in Africa. Hunger, poverty, disease and vulnerability to environmental change are all closely linked.
- **Desertification:** Dry lands cover 43% of the continent, and a third of the population lives in them (World Water Forum, 2000). Droughts and floods seem to have increased in frequency and severity over the past 30 years. West Africa is the source of nearly half of the mineral aerosols entering the atmosphere globally (Andreae, 1995; Duce, 1995).
- **Deforestation:** in Africa amounted to 5.2 million ha/y (0.78 % of the forested area per year) for the period 1990-2000.

Two recent high-level reports (the IPCC 4th Assessment Report and the Stern Review) have stressed that developing countries are particularly vulnerable to predicted future climate changes – which will bring them higher costs and few benefits. The second African Environment Outlook (AEO-2) (UNEP, 2006) also reports on growth within the environment, society and economy and the role of GEC in attaining development goals. Low incomes and vulnerability to both systemic changes (e.g. desertification) and increasing extreme events make adaptation to climate and environmental change particularly difficult. Because of these vulnerabilities, global environmental change is likely to further increase poverty and reduce the ability of households to invest in a better future (Low, 2005; Boko et al., 2007).

Contemporary Africa is demonstrably vulnerable to both droughts and floods, with negative impacts on food production, human health, water resources, and degradation in dry lands and coastal zones. Africa's vulnerability is likely to increase in future, because the future is likely to be hotter, and large areas are projected to become drier and even more rainfall-variable than at present. In general, the adaptive capacity of local, national and regional institutions in Africa is relatively low due to limited economic, human, infrastructural, and information resources and governance and various types of conflicts that exacerbate the situation. Africa is particularly vulnerable to changes with a negative impact on food production, human health, water resources, and natural-resource-based livelihoods. These needs have informed our selection of focal issues and research themes, described in detail later in the document.

A recent report on global environmental change (GEC) research activities and capacity in Africa (Scholes, et al., 2006a) noted that there were active GEC researchers in virtually every country in Africa, but over half of the approximately 740 known African researchers in this field were in only five countries: Cote d'Ivoire, Ghana, Kenya, Nigeria and South Africa. The African researchers represent around 2 to 5% of the global research effort in GEC research, but their publications constitute only 0.5 to 1% of the papers in leading international GEC research journals. The GEC researchers in Africa are organised into multiple overlapping networks, and include several existing acknowledged centres of excellence. There is an equally large research community that work on development-related issues that are highly relevant to GEC research, but is currently somewhat disconnected from it.

Despite the substantial body of research, on the one hand, that exists on GEC in Africa, it remains inadequate to address the serious challenges facing the continent. On the other hand, Africans have a rich history of adaptation to challenging environments, and the continent offers unique opportunities for global environmental change research. The multiple causality of environmental change offers opportunities to examine multiple approaches to environmental change knowledge construction (e.g. Airhihenbuwa, 1995; Carruthers, 2005; Oomen, 2005; Gibbons, et al., 1994) and methods of analysis (e.g. Freire and Faundez, 1989), particularly since Africa is so culturally diverse. This is a comparative advantage for African global chance scientists. It further provides scope for north-south and south-south scientific exchanges.

The emphasis of global environmental change research in Africa is shifting from an impact-led approach (i.e. describing the physical hazards associated with change, with an emphasis on predictions and assessments) to a vulnerability-led approach, focussed on understanding the socio-economic, institutional, cultural and biophysical factors that increase or decrease vulnerability, and is likely to continue to shift into active strategies to avoid or adapt to change. Such shifts enable a wide range of research options, including research on adaptation (e.g. Adger, et al., 2006; Brooks, 2005a) and links between environmental change and development (IIED, 2006).

These new emphases and connections place Africa at the leading edge in terms of the *possibility* to pursue global environmental change research that is relevant to the needs of today and tomorrow. This science plan attempts to present a vision for how some of these possibilities could be realized.

2 Conceptual Framework

Four top-level issues are the focus of concern with respect to global environmental change and its impacts in Africa:

- **Food and nutritional security,** including crops, wild-gathered resources, livestock resources and fisheries;
- **Water resources,** particularly in the water-limited subhumid, semi-arid and arid regions;
- **Health,** especially in relation to the biodiversity-linked, environmentally-mediated and vector-borne diseases that are responsible for the high disease burden in Africa; and
- **Ecosystem integrity,** on which the persistence of biodiversity and the delivery of ecosystem services depends.

These focal issues find expression, for instance, in the Millennium Development Goals.

These four focal issues are directly and indirectly influenced by a number of interconnected drivers of change, the 'Global Environmental Change Syndrome', including **land cover change** resulting largely from agriculture, forest clearing and infrastructure development; **atmospheric composition change** as a result of human-induced emissions of greenhouse gases, aerosols and nitrogen- and sulphur-containing trace gases; the **climate change** that they together cause; **biodiversity change** resulting from over-harvesting, loss of habitat and pollution; the interconnected economic and political factors involved in **globalisation;** the **demographic** changes in the size, composition, and distribution of populations; including the tendency towards **urbanisation;** and the changes in resource consumption and waste production that accompany **increasing wealth** and **novel technologies.**

Between the 'focal issues' and the 'global drivers of change' are a series of causal links, processes and feedback loops (Figure 1). Since it is these interconnections that determine the specific outcome of Global Environmental Change in Africa, the research programme outlined in this document focuses on this connecting layer – we will call these **research thematic clusters**. These clusters prioritise those issues that are most critically important for human wellbeing in Africa; that lend themselves to adaptive actions; or that are of global importance, but best-studied in Africa.

Successfully addressing these links in an African context will require international collaboration. Three of the focal issues are closely aligned with the themes of three of the joint projects of the Earth System Science Partnership [1]: health, food and water systems. The fourth focal issue – ecosystems – has considerable emphasis particularly in DIVERSITAS and IGBP. There is also close correspondence between the eight research thematic clusters and a number of projects within the four partner Programmes of the ESSP. Some specific examples of how the research proposed here can be aided by activities of the ESSP and its partner Programmes will be given in the description of each of the research thematic clusters, as well as in the Implementation section. Exploiting the expertise and international infrastructure of the ESSP to aid global environmental change research in Africa provides enormous mutual benefit: African scientists have access to leading scientists and facilities outside the continent, and can place African issues in a global context; researchers from outside Africa can have access to leading scientists and facilities on the continent, and can collaborate on learning more about how global changes will play out in a regional African context and feed back again to the global scale.

The researchable topics in such a wide-ranging area are unavoidably many and interconnected. To achieve a degree of focus and clarity, they have been arranged in the body of this document into eight **research thematic clusters**. The elements of such clusters typically interact strongly among themselves, and so are best treated in a coordinated fashion. There are also connections between clusters, so one element may have relevance in several themes, although for conciseness it is described only in one. The thematic clusters are deliberately not aligned with traditional disciplinary boundaries.

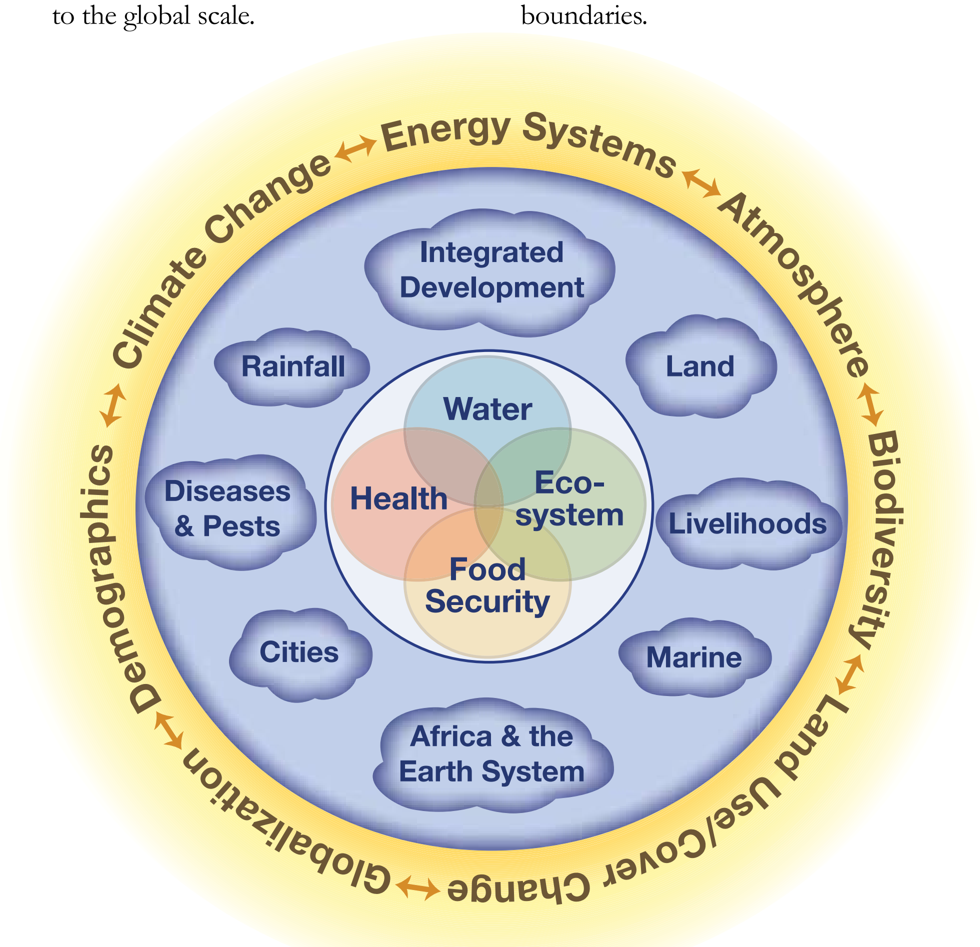


Figure 1. Conceptual framework for strategic GECR in Africa.

To further organise and prioritise the research topics in this African Global Change Research Strategy, we applied the following seven principles:

1. **Favour a limited number of multi-year coordinated research programmes over a large number of short-term, independent projects**
   Only by taking a programmatic rather than project-based approach can the synergies resulting from coordination be realised. The complexity of the task can be reduced by focussing on a limited number of large, integrated efforts at a time.
2. **Promote inter-disciplinarity, multi-institutional and regional research**
   Environmental change, in Africa and elsewhere, has multiple causality and is the result of the coupling of human and natural systems. It can only be unravelled and understood by an interdisciplinary approach. Successful inter-disciplinary research requires competence within the base disciplines. The Earth Systems Science approach is inherently inter-disciplinary, but has its roots in a strong physical and biological research tradition that still dominates the forms and nature of scientific enquiry. While the deterministic approaches of the biophysical sciences are clearly valid and relevant, they are often insufficient by themselves. Various epistemological approaches informed from the

Footnote

1. The ESSP is a partnership of DIVERSITAS, an international programme of biodiversity science; the International Geosphere-Biosphere Programme (IGBP); the International Human Dimensions Programme on Global Environmental Change (IHDP); and the World Climate Research Programme (WCRP).

social, political, health, cultural and economic sciences provide additional avenues for the GECR community to consider (e.g. Airhihenbuwa, 1995).

3. **Recognise and develop indigenous knowledge and capacity**
   Even more challenging than the integration between human and biophysical sciences described in point 2 above is linking the 'Western/Northern' knowledge systems to African indigenous knowledge systems in a way that enriches both communities and impoverishes neither. In this way the GECR effort in Africa may not only broaden its reach in the region, but also add new insights globally.
4. **Develop science-policy interfaces**
   While there is clearly a need and a critical role for ongoing fundamental science-led research, the realities of the African continent especially require a very pragmatic, user-focussed approach to real-world problem solving and priority setting. A well-functioning set of science-practice-policy interfaces is therefore essential to ensure that what is known is swiftly negotiated, debated, and efficiently applied (e.g. Guston, 2001). It must also serve to ensure that knowledge gaps identified by the user community are effectively researched. Institutions need to turn from being knowledge consumers into knowledge creators, and to structure themselves in order to transfer knowledge to where it is needed, in a form in which it can be used. Such interactions between science and society are better described as spiderwebs rather than uni-directional pipelines or even bi-directional bridges. The diversity of power relations between actors is a key issue (e.g. Miller, 2001); a range of 'brokers' and institutional designs that can both *convey and receive* information between producer and user groups are suggested (e.g. Jasanoff, 1987; Cash, 2001; Guston, 2001; Miller, 2001; Cash and Moser, 2000; Vogel, et al., 2006, under review GEC). Existing modes of science-policy interactions, such as assessment processes like the IPCC and MEA provide some useful models.
5. **Ensure that the products of scientific research are credible, salient and legitimate**
   (Cash, 2001). This means that in addition to greatly improving the dissemination of results *after* the research is done, the research agenda, where relevant and appropriate, needs to be negotiated *with users at the outset* – including recognition of relevant, diverse knowledge systems. It is not a trivial effort to balance the needs of relevance and rigour in such initiatives, and much thought, reflection and research is required on this very activity alone.
6. **Build lasting human and institutional capacity**
   Capacity building includes not only training and developing the next generation of scientists, but also ensuring that the institutional capacity is enhanced in Africa. This requires a multi-faceted, coordinated and deliberate effort, including creating institutions for advanced study and training ('centres of excellence'); supportive Africa-based networks ('communities of practice') in areas such as modelling; engagement of non-African experts in specialised training interventions in Africa; improving the retention of skills in Africa; creating incentives for temporary or permanent repatriation or participation of African experts currently abroad; encouraging regional mobility of experts and mutually beneficial north-south and south-south cooperation; and developing receptive capacity in users of research and the research communicators ('extension workers') who link to them.
7. **Contributing to the global research agenda from an African perspective**
   The topics selected should take note of global initiatives and priorities, such as those in the ICSU Earth System Science Partnership (ESSP) and work programmes of its partners (WCRP, IHDP, IGBP and DIVERSITAS), and exploit African comparative advantages within them, in order to draw as much global research effort into the African sphere as possible.

The resulting themes represent the intersection of the information needed to support development, favourable research opportunities, and the research capabilities desired in Africa. The objective is to develop the capacity, within Africa, to anticipate and adapt to global change and to adopt a development path that is locally and globally sustainable.

It is taken as given that only research that meets widely-accepted quality standards is useful in this quest, and that the mechanisms by which a coordinated research effort is implemented must be transparent, accountable and efficient.

3 The Research Thematic Clusters

All of the individual research thematic clusters are highly connected – there are no hermetic seals between them. As an example, rainfall, desertification and land degradation are clearly linked – but they are described in different research thematic clusters. These linkages will exist regardless of how the themes are structured or titled. The motivation behind this particular choice was to best provide a limited number of foci for the links between the drivers of global environmental change and the top-level impact issues in Africa.

In this section we describe eight research thematic clusters that connect the focal issues for Africa and the global drivers of environmental change. These identify the issues that are most important for human wellbeing in Africa, that lend themselves to adaptive actions, or that are of global importance but best studied in Africa. Within each cluster are a number of specific topics for research. Keeping in mind the goal of favouring "a limited number of multi-year coordinated research programmes", at the end of each section we will provide a single example of a research program or project appropriate for the research thematic cluster.

It is very important to note that these are *examples* of possible projects, and not specific recommendations.

The idea of providing one example per section is to show the kind of projects and programmes that may emerge once the network infrastructure described in this strategy document is put into place, and is able to facilitate and coordinate research activities in Africa. A more detailed description of the themes and associated scientific questions can be found in the Annexes.

3.1 RAINFALL

The area of Africa in which most people live is dry. Therefore the most crucial climate issue for African decision-makers at all levels, from the household to the African Union, is rainfall, and in particular, its variability at all time scales. Climate variability refers to fluctuations in climate or deviation from the long-term meteorological average over a certain period of time, e.g. a specific month, season or year. Variability is a normal part of Africa's climate. Periods of drought and flood, warmth and cold have occurred interchangeably in the past (Ropelewski and Halpert, 1987; Ogallo, 1988; Nicholson and Grist, 2001; Tyson, *et al.*, 2002). Floods, droughts and other weather extremes are very common in several African countries and they have harsh negative effects on agriculture, livestock, wildlife, tourism, health, water resources, hydroelectric power generation and many other socio-economic sectors that are the core of the basic livelihood survival of the society.

Unfortunately, rainfall is also the variable associated with the greatest uncertainty in climate models and their projections. For many regions in Africa, there remains disagreement about the direction of future rainfall trends, including both their magnitude and variability (Solomon, et al., 2007). Even at the scale of seasonal (6 month) forecasts, which are critical for food and water security in the semi-arid regions of Africa, wide uncertainty persists (Barnston, et al., 1996). The scientific capacity in climate research across Africa is extremely low. Capacity building and retention within the educational sector and governmental organisations is one of the foremost requirements for delivery of the key scientific goal of this theme. Rainfall and desertification are intimately linked, so that the research described in this section will have direct impacts and relevance for section 3.2.1 on dry lands, desertification and land degradation, and on the UN Convention to Combat Desertification (UNCCD).

3.1.1 Climate Observation Systems

The maintenance and development of climate observing systems, including observations of the terrestrial atmosphere and surrounding ocean basins is necessary. Data are essential to the monitoring of climate and the calibration and evaluation of models. The Climate Observing System in Africa is currently the worst in the world and is deteriorating. Ways of securing climate observing and integrating climate information into development are underway (e.g. GAP analysis and AU efforts) but will require close attention over the next few decades. Rainfall measurements, quality assurance and archiving of data, analysis and modelling, evaluation and linkage to hydrological information are inadequate across many parts of the continent. Attention must be given to sustaining and expanding precipitation and hydrological monitoring networks and use of new sources of data (radar, remote sensing) so that a reliable and accessible database is created for enabling analysis of hydrology and water resources, and for well-informed resource management decisions. In this regard, sharing rainfall and hydrological information between different national agencies must be promoted. The GCOS strategy for improved climate observation systems in Africa, supported by DFID, is an important initiative in this regard (IRI, 2006). The UN Economic Commission for Africa Climate for Development in Africa programme (ClimDev: http://www.uneca.org/eca_programmes/sdd/events/climate/summary.htm) aims at mitigating the vagaries of climate variability and climate change – including improving access to climate information and observations. The Group on Earth Observations (GEO) also aims at improving observational capacity and access to data for Africa.

3.1.2 Cloud and Rain-generating Processes

Most rainfall in the water-limited areas of Africa is in the form of high-intensity convective storms. Prediction of such events on a case-by-case basis is inherently difficult, because of their complex dynamics and relatively small scale (individual storm cells are only a few kilometres wide, and last a few hours), but is also an understudied problem relative to the amount of work that has gone into climate processes in temperate regions, simply because of the global distribution of meteorological researchers. The key objective of such research is to provide an accurate statistical picture of the size and intensities of rainfall events. The need is for probabilistic rainfall projections which are more detailed in terms of both their spatial resolution (20 km) and their within-season pattern (for instance, the probabilities of spells of no rain during critical crop periods, and the likelihood of flood-creating rainfall events).

3.1.3 Land-ocean Teleconnections

It is well established that the pattern of rainfall in many parts of Africa is correlated with patterns of sea surface temperature. The El-Nino Southern Oscillation (ENSO) is the major contributor to inter-annual variability in the African climate (Gordon, 1985). Conceptually-related phenomena, such as the Indian Ocean Dipole and the North Atlantic Oscillation (NAO), require further investigation with respect to their effects on African rainfall variability. Africa offers good conditions for conducting such research. The AMMA campaign (2005-2007) will go some way in addressing these issues in West Africa, but needs to be built on in terms of coverage (east and southern Africa), content (convective storm processes, land surface feedbacks), implications and African participation.

The causal relationships between ocean conditions and climate consequences in distant regions are poorly established, and therefore hard to predict for periods longer than a few months. Dramatic improvements in seasonal rainfall forecasting resulted from the installation of the TOGA moored array in the Pacific. We expect similar improvements to follow from the Pilot Research moored Array in the Tropical Atlantic (PIRATA), and anticipate similar gains if a moored array were established in the tropical Indian Ocean.

A key medium term output of this element is the development of prediction schemes for periods of weeks to years (under the broad umbrella of seasonal prediction) and their adoption in early warning systems. Such schemes are likely to be both empirical and model based.

3.1.4 Land Surface-Atmosphere Hydrological Cycle Coupling

There is tantalising evidence that rainfall patterns at a regional scale in Africa are also partly linked to land surface conditions, through mechanisms such as the changes in surface albedo that result from reduction in vegetation cover, and processes that generate cloud condensation nuclei, which in the African context are dominated by mineral dust, emissions from biomass burning and organic particles from vegetation. These mechanisms provide an important link between this theme and the land theme, and also to the Earth Systems theme.

3.1.5 GCM Improvement and Downscaling

Whilst the global scientific community leads the way with climate model development, crucial components of this effort fall to African climate scientists. These include the evaluation of regional climate model performance, recognition of model deficiencies over Africa and surrounding oceans, improvements in the spatial and temporal resolution of model outputs through dynamical and empirical downscaling and recognition and improvements in the simulation of key components of the circulation. Direct impacts of climate change are more severe at local and regional levels and therefore it is important to downscale the global climate scenarios into regional and local climate change scenarios. Various downscaling techniques are currently available for vulnerability and impact assessment studies. The availability of past climate records and the use of computer models are the major tools available in the detection and attribution of climate change.

3.1.6 Adaptation to Rainfall Variability

Another dimension of climate research in Africa is into historical climate – societal interactions and adaptations. Improved adaptation to inter- and intra-seasonal variability in rainfall is thought to be a useful analogue for enhanced capacity to respond to decadal climate change. Impacts of climate variability on natural resources result in challenging survival problems for rural population very dependant on natural system equilibrium for their daily livelihoods. Adaptation strategies that reduce various vulnerability issues are mainly responses to shocks that can be slow change or rapid and extreme events. This theme can also explore the lessons in adaptation that can be learned from traditional African strategies for coping with climate variability. Research in this area is also of relevance for the topic of dry lands, desertification and land degradation (3.2.1).

RAINFALL - Example Program:
Vulnerability to and Building Adaptive Capacity for Rainfall Variability

A program on this topic could begin by mapping the areas and activities in Africa vulnerable to variable rainfall, and to potential changes in rainfall variability. For these areas, the program could go on to:

1. Determine to what extent regional rainfall patterns are related to regional land surface conditions, and what fraction of the variability is due to global influences. This can be approached with a combination of local field experiments, process modelling and regional downscaling of global climate models;
2. Determine the human and natural drivers of land use change in the region that control the land surface characteristics;
3. Examine the extent to which regional human activities such as vegetation burning affect cloud- and rain-generating processes, and the extent to which other factors (e.g., land-ocean teleconnections) determine cloudiness and precipitation in the regions;
4. Use this process understanding to develop an enhanced capability for analyzing possible adaptation strategies, and providing projections of the consequences of different adaptation approaches.

3.2 LAND

Land processes are characterized by a great complexity associated with the multiple elements in play and various relations between these elements. Land resources are the most important basis of African communities' survival. Over the years, following various human and natural shocks, land resources have been seriously damaged with serious environmental and socio-economic consequences. This degradation process has international connections both from its origin (globalization, multinationals, GEC) and in terms of its impacts (climate change, poverty issues). Improvement of land resource management in Africa is becoming a central concern of the international community and is acknowledged by several UN Framework conventions (UNCB, UNCCD, UNCC) and trans-national initiatives that aim at preserving important sectors of the world environment. Some mainstream aspects of land issues in Africa include drylands and desertification, deforestation, vegetation burning, surface water and ground water.

3.2.1 Dry Lands, Desertification, Land Degradation

Nearly half of the African continent (43%) is covered by dry lands. These areas are very vulnerable to recurrent drought and continuous land degradation process that limits the survival capabilities of the 30% of the African population living there. Dry lands are almost by definition vulnerable to variability in rainfall (see section 3.1). One of the foremost issues in dry lands is desertification. The most frequently used definitions are those of the United Nations Convention to Combat Desertification (http://www.unccd.int/): Desertification is defined as 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'. Land degradation is the 'reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation and biodiversity'.

As a consequence of these processes there are various impacts of land degradation on biophysical processes (increased atmospheric carbon dioxide concentrations or enhanced erosion of soils), and social forces, such as globalization of markets. These generate different responses such as land use options and land cover changes. Land degradation is a central concern of several international initiatives such as FAO, UNDP, GOFC/GOLD, the IGBP-Global Land Project, and the ESSP GECAFS project, and underpins various research challenges to come up with suitable sustainable mitigation alternatives.

3.2.2 Deforestation

Deforestation is the processes of forest cover loss associated mostly with human activities such as slash and burn agriculture, wood extraction, overgrazing and non-sustainable pastoral livelihoods. Figures of deforestation from FAO show that Africa is one of the continents where the regression of vegetation cover is the most active. From 1990 to 2000 the deforestation rate in the continent was estimated about 5.2 millions ha/year or 0.78 % of the forested area per year (FAO, 2006). Vegetation degradation leads to landscape fragmentation with impacts on biodiversity (selective logging, habitats degradation), reduction in carbon fixing capacities of the ecosystems and positive contributions to the carbon emissions through biomass decomposition. In addition vegetation degradation disturbs the biogeochemical cycles of carbon, nitrogen, phosphorus etc., and lead to more active wind and hydrological erosion processes. Crop production is subsequently affected by deforestation via soil properties modification over time.

3.2.3 Vegetation Burning

Vegetation burning has been clearly recognized as a serious challenge for natural resources management. Africa has been flagged for some time as an endemic zone for bushfires. Several characteristics lead to this situation. First, several African vegetation covers are fire-prone ecosystems (savanna, miombo) with a continuous grass layer that dries at the onset of the dry season resulting in large areas subjected to rapid and drastic spread of fire. Second, the use of fire in daily human activities is fully imbedded in local livelihoods because of the lack of advanced technologies that are out of reach for low income people. Third, the social and cultural meaning of fire in African societies underpins strong links between fire and various aspects of social life (beliefs, perceptions).

Impacts of burning in ecosystem components are numerous but not extensively understood. Some of the most apparent impacts of fires are on fodder resources, water resources (causes by changes in runoff, water quality and erosion), plant biodiversity (species composition, successions, and change in vegetation structure), wildlife (habitat fragmentation, composition), soil properties (soil fertility, chemical and physical properties of soils) and carbon stocks in vegetation and soils. Biomass burning is a significant source of transboundary air pollution.

3.2.4 Water Resources and Wetlands

Water bodies are known in Africa for their central role in the overall development strategies at local and regional scales. These water bodies are mostly rivers and lakes hosting a high biodiversity (serving as refuges for several animal and plant species in gallery forests or mangrove systems) and large quantities of water resources. The six biodiversity hotspots (out of 25 in the world) listed in Africa are located almost exclusively in aquatic and wetlands systems. These resources are nevertheless continuously deteriorated through land-based human activities such as domestic sewage and industrial waste water, toxic disposal from mining, and the effects of agricultural runoff containing sediments, nutrients and pesticides. The impacts accumulate down the drainage basin, and have serious consequences for wetlands and coastal zones, where they are compounded by maritime activities such as bilge pumping and the physical degradation of coastal habitats. These changes have consequences for freshwater availability for domestic, agricultural and industrial use, food and employment security, and loss of human life and property. The ecology of the aquatic systems is undergoing rapid and drastic changes with agricultural drainage, unsustainable exploitation, industrial effluents and agricultural chemicals that alter water quality, introduction of alien species such as the Nile Perch Lates niloticus and the water hyacinth Eichhornia crassipes that threaten ecosystem function.

In the coastal areas there are several wetlands ecosystems such as mangroves, lakes, and lagoons. The importance of these ecosystems is connected with the services associated with tourist activities, fish reproduction, bird concentration, recharge of groundwater, carbon sequestration etc. These coastal wetlands are rich and diversified sanctuaries for biodiversity, providing habitats for plants and animal species in the watershed, helping to absorb and slow floodwaters when rivers overflow or tsunamis occur.

Efforts supported by initiatives such as GIWA, GWSP, IUCN, WWF, Wetlands International, the World Water and Global Water Partnership RAMSAR initiative and UNESCO have resulted in a rapid increase in the knowledge of the management of aquatic systems, whereby all relevant aspects are approached in an integrated manner.

3.2.5 Ground Water and Aquifers

Ground water is an important source for water supply in all of Africa but in particular in arid and semi-arid areas. Unlike surface water, ground water is not easily accessible and its quality and accessibility varies significantly over space. The configuration of the ground waters shows a transboundary dimension with aquifers covering large areas. These resources present different water table characteristics. Some of them are superficial and can be easily refilled generally during the rainy season. Others are located in sedimentary basins or deep in the ground and become fossil fresh water. The reserves of fresh water stored in these deep water tables are considerable: of the order of several trillion m^3. They would be able to therefore in theory to cover the needs of present and future needs of Africa (CDEAO, 2006). But they are in variable depths and can reach sometimes 1000 - 2000 meters. The superficial water table is accessible but subjected to pollution or over extraction processes.

LAND - Example Program:
Assessing local and global influences on desertification and dry land ecosystems in Africa

In its report on the Conference of the Parties on its eighth session (ICCD/COP(8)/16/Add.1) the UN Convention to Combat Desertification described six operational objectives related to science, technology and knowledge. These operational objectives were to support the strategic objectives of improving the living conditions of affected populations and to improve the condition of affected ecosystems in drylands. A program coordinated by the AfricanNESS network could support these objectives through a series of actions:

1. In collaboration with the Global Earth Observation System of Systems (GEOSS), establish an open, accessible database of remote sensing data for land use and land cover in African dryland areas;
2. Facilitated through GEOSS harmonize national monitoring and documentation of biophysical and socioeconomic data and trends in affected areas, and make this data openly and freely available;
3. Focusing on the areas most vulnerable to desertification, land degradation and drought, use a combination of global and regional models to assess the relative importance of local/regional (e.g., land use change, biomass burning, local pollution sources) and global (e.g., ENSO/NAO, transcontinental transport of pollutants) processes on clouds, precipitation and the hydrological cycle;
4. Plan and carry out a series of focussed field experiments in the vulnerable areas to verify or refute model predictions about the relative importance of local and global processes on the regional hydrological cycle.

3.3 LIVELIHOODS

A livelihood consists of the assets (natural, physical, human, financial, social, political), activities, and the access to these (mediated by institutions, organisations and social relations) that are required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or combine its assets and capabilities whilst not undermining the natural resources loss (Chambers and Conway 1992). With the limited continent-wide knowledge on how GEC will impact on livelihoods, there is need to intensify analysis for understanding of the livelihood and food security impacts of GEC. Reducing the vulnerability of Africa to global change requires building the resilience of Africa's social and ecological systems, particularly through achieving food security in the region. Food security is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active healthy life (FAO, 1996).

Integrating GEC research in livelihoods and food systems must be done at the household and community levels, where vulnerability is usually more clearly expressed and at the subregional and regional levels, so that the interaction of policy and livelihoods' vulnerability can be addressed and finally, at the continental level, to understand how findings can be scaled up and outwards for policy and wider use. Greater engagements with the large research, implementation and policy communities actively working on agriculture (for example, the Consultative Group on International Agricultural Research – CGIAR), fisheries and food systems will enhance the GEC research agenda.

Cutting across the four thematic elements described in this section is the need for integrated research and understanding of vulnerability. Vulnerability has emerged as a cross-cutting theme in research on the human dimensions of global environmental yet many studies single it out from other GEC stressors (O'Brien, *et al*, 2004). In Africa the archetypes of vulnerability include risks people and ecosystems are exposed to under the various livelihood activities. No systematic methodology exists to operationalise the understanding of vulnerability in the context of multiple stressors such as those induced by GEC. There is need to develop local, national and regional vulnerability profiles of peoples and ecosystems. There is also an increasing need to develop indicators of both vulnerability and adaptive capacity both to determine the robustness of response strategies over time and to understand better the underlying processes (Adger and Vincent, 2005).

3.3.1 Crop Agriculture

Global environmental change is altering the physical and socioeconomic conditions that underpin cropping systems while globalization is transforming the production and storage of food, the movement and trade of food, access to and consumption of food, and the quality and safety of food. Understanding how these affect agricultural production, livelihoods, and the viability of rural, agricultural economies is crucial to GEC research in Africa. How these processes interact to create dynamic conditions that influence the vulnerability of ecosystems and communities is also a principal information gap. GEC affects cropping systems through the loss of productive farmland, depletion of traditional seed stocks, loss of biodiversity (agrobiodiversity), and changing climate conditions, including increasing frequency of extreme climatic events such as droughts and floods. Other globalization-related issues that need coordinated research agendas and critical appraisal of social and environmental costs and consequences include liberalization of trade in agriculture products, domestic subsidies, the role of multinational corporations and supermarkets in food production and distribution, shifts toward urban and industrial land uses, impetus for biofuel and agricultural energy economies/systems and the growing influence of consumer movements in matters such as use of GMO technologies.

3.3.2 Pastoralism

GEC regulates access to water and pasture that determine livelihood outcomes for pastoralists in many marginal areas of Africa including the Sahel, Sahara and marginal lands in Southern Africa. Intensification of GEC impacts pushes pastoralists into more marginal regions and leads to a breakdown in the networks connecting herders and farmers, further contributing to conflict between these groups. Pastoral livelihoods, ecosystems and communities became more vulnerable to drought with the intensification of this cycle. It is necessary to have a clear understanding of past and existing adaptations and innovations to these effects through vulnerability mapping, global and regional modeling and future simulations of impacts on rangelands and food security in the pastoral sector. Studies on the viability of pastoralism as an alternative livelihood where GEC effects have excluded other forms of more sedentary livelihoods are also crucial.

3.3.3 Fisheries

Research and data on African fisheries are inherently scarce and imprecise, resulting in high levels of uncertainty in resource predictions. A number of global environmental changes are expected to negatively impact fisheries development and management in the continent further introducing more uncertainty into the future of fisheries as a livelihood strategy for households, communities and nations. Studies on policies, legislation and management regimes and species diversity would expand the information databases needed adapt to and mitigate GEC effects. Fisheries prediction/performance models, vulnerability assessments and adaptation planning are possible research agendas. Other topics include the dynamics of the ecological (nutrient) and economic comparative advantages of different forms of riparian land use in relation to marine and terrestrial water bodies, and the impacts of GEC targeted physical interventions and government policies on exploitation of fisheries resources and related livelihoods.

3.3.4 Forest Based Livelihoods

The distribution of forests in Africa reflects the soils and climate of the continent. There are already indications that these forests (woodland/shrubland) areas are presently heavily impacted by a range of human activities ranging from livestock grazing to clearing for cultivation, wood fuel and infrastructure/settlements. GEC will exacerbate these impacts by putting pressure on livelihood needs for exploitation of forest and non-forest products. It is thus critical to understand the current and future impact of GEC on these forests-based livelihoods as well as adaptation mechanisms and any resultant feedback loops.

LIVELIHOODS - Example Program:
Food security in Africa

Policy interventions to improve food security in the region, such as the MDGs, need to take global environmental change into account. Africa's food insecurity arises from a combination of factors such as poor governance, weak science-policy links, inadequate agricultural infrastructure, a rapidly growing, young population, widespread poverty, war and conflicts, land degradation, and a heavy disease burden. Unfavourable soils and climate also contribute significantly in some instances. Emerging from the substantial research on food security are a number of 'larger', 'over-arching' themes that could be addressed (e.g. see GECAFS, 2005) with a focussed program concentrating on:

1. Determining how global environmental change exacerbates food insecurity in Africa;
2. Developing examples of technical and policy options to adapt food systems in Africa to cope with global environmental change? (e.g. what is the role, if any, of a possible 'Green Revolution' for food security in Africa? What are the design and technological implications of a 'Green Revolution' for Africa?);
3. Examining the trade-offs for African agriculture with regard to land put under agriculture for 'energy' (e.g. biofuels) versus land for food production;
4. Determining how the various adaptation options feed back on existing environmental and socio-economic conditions. Here adaptations refer to both the large-scale, global adaptations that may be needed to ensure sustainable food security for Africa (e.g. detailed investigation of trade regimes), as well as more local-scale adaptation options that are currently being practised but that may be insufficient given future environmental changes;
5. Determining the potential of fisheries, livestock production and cropping systems diversification options in reducing the risks associated with GEC and in increasing the communities' adaptive capacity.

Some of these questions are currently being explored by the GECAFS project in southern Africa. It is important to extend the investigations to other regions in Africa.

3.4 CITIES

The total urban population in Africa increased from about 20% to almost 35% between 1975 and 2000 and is expected to rise to more than 50% before 2025. Africa is characterized by a rapid development of urban areas with a rapid natural growth and a significant migration flux from rural areas. Urban poverty is already widespread in many African countries. For example, projections indicate that the relative number of urban poor will increase to about 50% of the total number of poor people in Mozambique by 2025. Similar trends are expected in many other African countries such as Benin, Kenya, Tanzania, Senegal, Zambia, etc. (ReNED, 2006). As more and more people move to urban areas for various complex reasons, poverty and environmental problems will follow. Many poor people in urban areas in developing countries are caught in the poverty-environment nexus. The livelihood, health and vulnerability of urban poor people are closely linked to urban environmental issues.

The Earth Summit in 2002 in Johannesburg had a strong emphasis on several of these problems, including a promotion of public-private partnerships as a mechanism to overcome them. However, the progress has not met the expectations. In spite of numerous initiatives and allocation of vast funds over the last 10-20 years, major challenges remain. The development process has in most cases lead to large increases in the percentage of the population living in urban areas, and the pressure on the urban areas has increased dramatically.

3.4.1 Urbanization

This rapid urbanization goes along with environmental consequences such as the generation of solid refuse and waste water. Water table pollution becomes therefore a major issue in parallel with an increasing demand of fresh water for urban citizens. Over-extraction of fresh water resources, unsustainability of water extraction and distribution equipment and water resources pollution are exacerbated by the urban situation. The urban environment spans several issues such as air pollution (outdated industry facilities, poor transportation systems), waste management and human health, industrial and household pollution, irregular settlements and flooding, etc. Moreover, the new GEC context with sea level rise and occurrence of extreme events (heavy rains) can be damageable of most coastal megacities such as e.g., Lagos, Conakry, Nouakchott, Dakar. The institutional dimensions and governance issues for urban areas are linked to the kinds of environmental stressors indicated above, and mediate the ability and possibility to respond to these stressors. These are key issues for the IHDP Urbanization and Global Environmental Change (UGEC) project (Sánchez-Rodriguez, et al., 2005). Urban air pollution is a central element of the IGBP International Global Atmospheric Chemistry project's task on megacities (IGAC, 2006), and is linked to the topics of atmospheric pollution (3.6.3) and air quality (3.7.2).

CITIES - Example Program:
Assessing how global environmental change influences urban air quality and human health

It is projected that by the end of this decade, more than half of the world's population will live in cities. In this respect, the development of urban areas are key to many of the challenges confronting the coupled human-environment system. Pollutant emissions from megacities can have effects ranging from local and regional (e.g., human health, visibility, effects on crops and physical infrastructure) to global scales (e.g., ozone formation, cloud and precipitation processes); in the reverse direction, global changes can influence the conditions within which urban areas develop. A program on GEC and urban development could start by choosing a small number of African megacities with different biophysical, socioeconomic and cultural conditions. With these cities as a focus, the program could:

1. Examine how lifestyle and consumption patterns within the urban areas contribute to GEC (e.g., local/regional fresh water supplies, emissions of pollutants);
2. Characterize the nature, amounts and spatial and temporal changes of aerosols, oxidants and their precursors;
3. Validate emissions inventories of these species;
4. Examine how changes in biophysical processes affect human health in urban areas;
5. Use regional climate predictions to assess how future changes in variables such as temperature, precipitation, sea level rise (including extremes) will feed back on the emissions of pollutants, human health and patterns of migration and consumption.

3.5 DISEASES AND PESTS

This thematic area covers

- environmentally-linked infectious diseases of humans and livestock whose prevalence is likely to increase as a result of global change;
- emergent diseases resulting from increased interaction between people and previously undisturbed ecosystems;
- invasive plants ('weeds') and pest animals whose spread and dominance results from the destabilisation of biotic communities due to climate change, altered disturbance regimes and the long-distance dispersal opportunities offered by global trade;
- the reorganisation of key ecosystems and biotic communities that will result from global environmental change.

In terms of human health, climate change has the potential to cause outbreaks of malaria in non-endemic malaria areas, butterflies infected with parasites, disease stricken corals and trees overgrown with fungus in many parts of tropical and non-tropical regions of the world. The top four causes of death in Africa are infectious diseases that made the transition from diseases of wildlife to diseases of humans (HIV/AIDS); or have vectors that are sensitive to climate change (malaria, diarrhoea); or are themselves sensitive to changes in climate and living conditions (lower respiratory infections). Much of the disease burden is due to parasites such as schistosomiasis, onchocerciasis, trypanosomiasis and lieshmaniasis. The World Health Organization estimates that in 2002 about 3.3 million people died globally from climate sensitive diseases transmitted through water and via vectors such as mosquitoes, pathogenic algae and bacteria. 29% of these deaths were from the Africa region (McMichael, et al., 2003). The goal of substantially reducing the mortality rate in Africa, the highest in the world, cannot be achieved unless the dynamics of these diseases are well understood. Scientific evidence is being rapidly acquired, indicating that disease pathogens would be able to

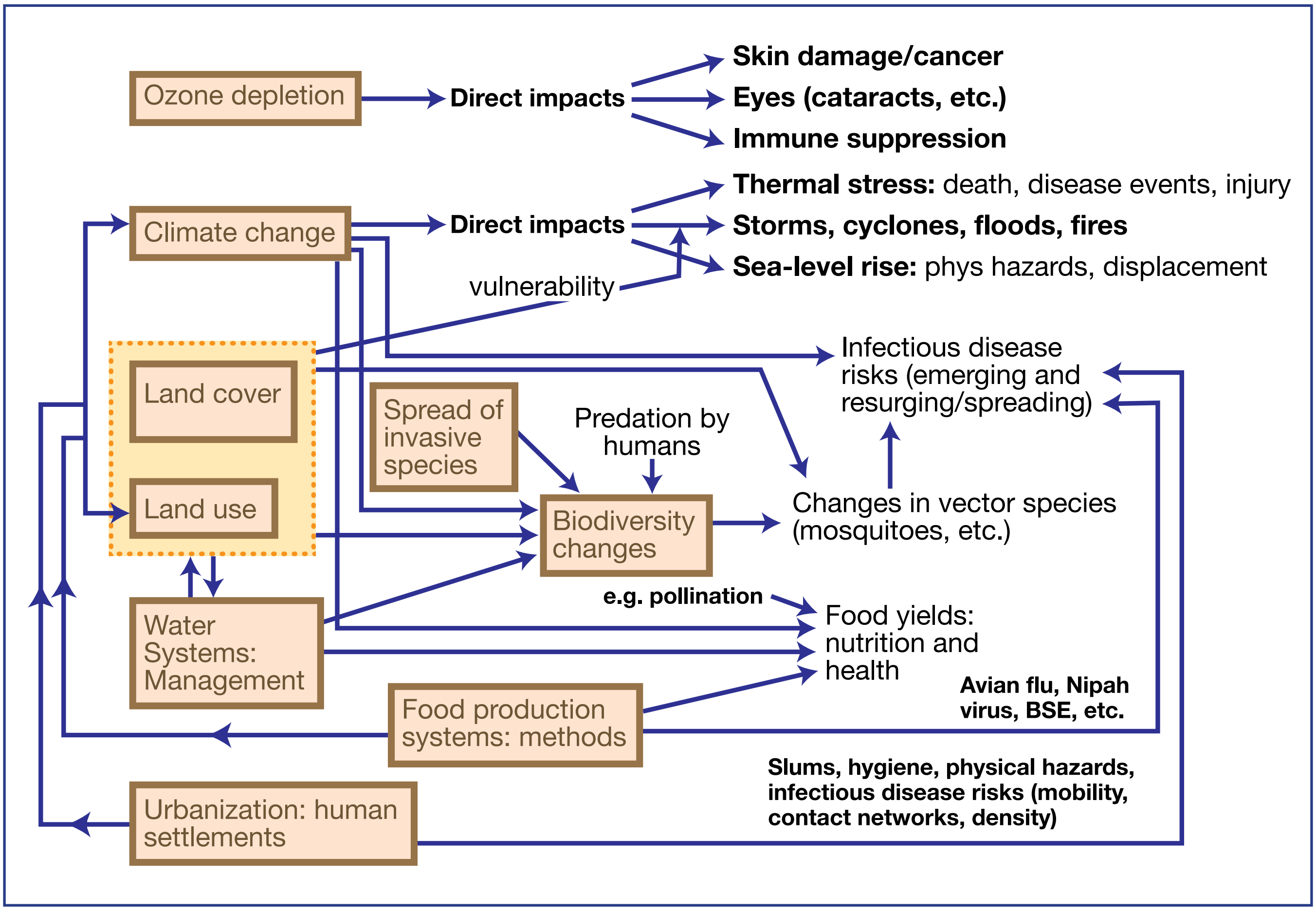


Figure 2. The main biogeophysical pathways by which global environmental changes can affect human health (Confalonieri and McMichael, 2006)

spread over areas where their survival rates were inhibited previously by prevailing climate. Climate change and variability might also produce stress to plants and animals, making them more susceptible to infection. A quarter of African food production is lost to pests, weeds and diseases of crops, contributing to food insecurity and malnutrition, itself a major cause of mortality, but also a predisposing factor to disease.

There are a host of pathways through which GEC can affect human health (Figure 2) including ozone depletion, climate change, land use, land cover, water systems, food production systems and urbanization (GECHH, 2006). The elements of GEC may cause direct and indirect human health impacts and vulnerability to health problems.

The invasion by alien organisms of land, freshwater and coastal ecosystems has lead to loss of biodiversity and declines in their capacity to deliver services such as water and fisheries.

3.5.1 Advanced Bioclimatic Modelling

Niche envelope modelling tools have helped to identify likely problem areas, but are currently unable to reveal the magnitude of the impact or its likely trajectory in time and space (Heikkinen, et al., 2006). The next generation of niche envelope models must include demographic processes, dispersal mechanisms, limits based on organism physiology, and interspecies interactions. These tools have application not only in this theme, but also in the land theme, livelihood theme and elsewhere.

3.5.2 Prognostic Modelling of Disease, Pest and Weed Spread

It is far more effective to prevent disease outbreaks than to try to contain them once they have occurred, and the same applies to veterinary diseases, crop diseases, agricultural pests and weeds. In order to do so, it is necessary to have the ability to predict which situations are likely lead to disease, pest or weed problems, and this in turn requires an understanding of the causal pathway that leads to the emergence of the problem. A combination of epidemiological techniques, with ecological and sociological insights offers a way to gain this understanding. There are strong connections between this element and the DIVERSITAS bioHealth project, as well as with the crop agriculture activities described in section 3.3.1.

DISEASES AND PESTS - Example Program: GEC and infectious diseases

Population health is a ‘bottom-line’ indicator of the impacts of GEC on human societies. Health outcomes are affected, directly or indirectly, by changes in water and food supplies, the integrity of terrestrial and coastal ecosystems, biodiversity, the microbial environment and climate. Therefore, in principle, trends in population health should provide critical information about society’s success in attaining sustainable development – since sustainable development is, in the final analysis, primarily about maximizing and maintaining positive human experiences: wellbeing, health and survival. The potential population health impacts of GEC extend into future decades, and are likely to increase if environmental conditions deteriorate further. This is nowhere more germane than in Africa. A program on GEC and infectious diseases could concentrate on:

1. Studying the net mortality impact of a shift in the annual distribution of temperature and extreme weather events;
2. Undertaking systematic studies of recent trends in incidence, seasonality and geographical distribution in selected infectious diseases (and, where appropriate, their vectors) in relation to associated climatic trends;
3. Study the many potential drivers (e.g., conversion of natural lands into agricultural ones, climate change, biodiversity loss) on factors such as the abundance and distribution of vectors, their ability to transmit disease, the requirements for the pathogen, infection rate;
4. Study the health consequences of climate change on socioeconomic disruptions resulting from resource conflicts and large-scale population migrations.

3.6 AFRICA AND THE EARTH SYSTEM

The Earth System provides a variety of essential, free services for humans, for example, purification of water and air, recycling of nutrients, and prevention of soil erosion. Human activities can affect these services at local and regional scales, for example, acid rain, smog, toxic chemicals, and deforestation. Our planet functions as a self-contained, finite system, with key substances moved between and transformed in the components of the Earth system – atmosphere, oceans, and land.

Africa provides a rich record of environmental and climatic dynamics. Africa is unique in that it is the only continent that, almost symmetrically, straddles the equator, and hence experiences both northern and southern hemispheric climatic influences. This coupled with the influence of the oceans that surround it, results in an intriguing record that offers the possibility of understanding the links in climate between the high latitudes and the tropics, and inter-hemispheric teleconnections.

The continent is known for being the cradle of human origins and evolution. This phenomenon is closely linked to the evolution of African Rift System that has been impacted by active volcano-tectonic palaeo-climatic history. It has also been one of the continents where ancient civilizations prospered and collapsed. The full range of climatic and environmental changes having affected such human events has not yet been fully understood. For example, recent preliminary results from the deep lake drilling project in Malawi have indicated a major dry interval at 75,000 years ago probably inducing human migration out of Africa (Scholz, et al., 2007).

The Mediterranean and the Red Seas have been sites of migration out of Africa probably due to climate and environmental reasons. For example between 200,000-100,000 years ago, *H. Sapiens*, our own species, made its first appearance in Africa and subsequently spread to Asia and Europe. Archives such as lake sediments and archaeological evidence indicate that a green Sahara was established between 10,000 and 5000 years ago sustaining a range of wild animals, lakes and ground water reservoirs. Also, cattle were domesticated and pastoralism emerged before these spread to East Africa. It is necessary to clearly understand the main drivers of such past migrations.

Africa is widely held to be particularly vulnerable to climate change due to a combination of naturally high levels of climate variability, high reliance on climate sensitive activities such as rainfed cultivation and limited economic and institutional capacity to cope with and adapt to climate fluctuations. High exposure and low adaptive capacity is experienced on an individual through national level so that the ability to anticipate, respond, and recover effectively from climate related shocks is limited. Africa is also the least well covered by studies on global environmental change. For these reasons, the overarching goal of this thematic activity is to enhance the understanding of regional peculiarities of the continent in relation to Earth System processes, including palaeoclimate, land-ocean interactions, atmospheric pollution, carbon cycle, water cycle, ocean circulation and regional climate modelling.

3.6.1 Palaeoclimate

Palaeoclimatic records can provide insight into regions with ecological and hydrological systems sensitive to climate change and others that served as refuges during critical climatic conditions providing criteria for prioritizing actions and for conservation (Brooks, 2006). Such regions need to be identified and mapped throughout the continent.

Palaeoclimatic records can also provide data that will serve to test the ability of climate and Earth system models to simulate African regional climate, moreover, to improve the predictive capability of such models. African palaeoclimate data will have a crucial role to play, in particular through the role of continental climate conditions in the tropical and sub-tropical regions which might provide evidence for the contribution of atmospheric processes associated with rapid climatic variability (Brasseur, et al., 2003; Vidal and Arz, 2004) and to understand mechanisms responsible for the transfer of climate signals (Brooks, et al., 2005a).

Palaeoclimatic records in the African continent can also be linked to climate forcing mechanisms such as orbital forcing, solar forcing and volcanic forcing. The African continental data have also the potential to be correlated with oceanic and cryospheric processes such as those affecting the thermohaline circulation and to give information on how such processes can impact future regional climates in Africa under the future human-induced greenhouse world.

Extension of the relatively short (ca. 100yr) instrumental records in Africa with palaeodata also provides a long-term context for observed regional and local changes. The data can be a basis for hypothesis testing, e.g. on the regional scale variability of the hydrological cycle or on the nature of ocean-land linkages.

3.6.2 Land-Ocean Interaction

With a 25,600-km long coastline, the African continent benefits from a number of quite diverse coastal and marine ecosystems, the main ones being mangroves and coral reefs (including cold coral reefs). It is recognized that 40% of the Africa's population depends on these coastal and marine ecosystems and resources for their livelihoods. Major economic activities like fisheries and tourism depend on these resources. However, the continuous coastal concentration together with the development of major coastal urban centres increase the pressures on these ecosystems, many of them being now threatened. These anthropogenic pressures are superimposed on natural changes that affect the ecosystems and their functioning. The main sources of ecosystems degradation include pollution, overexploitation of resources, degradation of habitats, coastal erosion, siltation, and salinisation. In some parts of the coastal zone, like for example along the Mediterranean coast, industrialization is a major source of degradation of the ecosystems.

The expected sea level rise due to climate change, together with other changes in climate parameters, will exacerbate these trends and could seriously threaten many coastal and marine ecosystems. This could have important socio-economic impacts (losses in revenues and infrastructure). It is thus of prime importance that the impacts of global change on the marine and coastal ecosystems as well as human systems be assessed and appropriate adaptation measures be identified. This must be based on achieved and ongoing projects and programmes addressing these questions in the continent and elsewhere as articulated by Barange and Harris (2003).

This research agenda in this sub-theme will couple and have linkages with other initiatives including the IGBP-IHDP LOICZ project, different initiatives to protect coastal and marine ecosystems (IUCN, WWF, Wetlands International), sub-regional programmes (PRCM in West Africa), LME projects for the Canary, Guinea and Benguela currents, fisheries commissions, IOC projects, UNEP/Regional Seas and GPA, COSMAR.

3.6.3 Atmospheric Pollution

Observations and models show that the tropospheric concentrations of most reactive chemical species are increasing in time and space over all of Africa. A series of research programmes (SAFARI 92, EXPRESSO, DECAFE, SAFARI 2000) have greatly advanced our understanding of this phenomenon. The potential for elevated concentrations of ozone is particularly high in many areas of Africa because of the combination of solar radiation and high emission of precursors, such as nitrogen oxides and volatile organic compounds, from both human and natural sources. Studies in Africa have shown that current-day ambient air pollution concentrations are capable of inflicting significant damage to human health, crops, local vegetation, and materials. Severe visibility reduction, increased respiratory diseases and chest congestion complaints are widely reported. Nitrogen compounds, ozone and particulate matter are the main hazards regionally, with sulphur compounds becoming important in locations of smelting, power generation, high vehicle density and oil refineries. Therefore this sub-theme will focus on the study of a variety of atmospheric processes coupled with modelling in order to understand the effect of exchange of reactive carbon and nitrogen compounds on atmospheric composition and climate feedback mechanisms. This topic has connections to the IGBP IGAC project, and to activities described in the Air quality section 3.7.2.

3.6.4 Carbon Cycle

The carbon cycle and the green house gases budget are highly linked to the climate change including global warming. They are drivers of and affected by the climate change at the same time. It is important to understand the influence of GHG emissions on the Earth System and how the climate change affects the primary productivity and other ecosystems processes. To this end it is essential to establish a monitoring network of carbon stocks and fluxes and GHG sources and sinks, and to develop new models for up-scaling the observations from point to the regional and global level and to relate field data to the remote sensed ones. A better understanding of carbon exchanges between different carbon pools will be way forward to develop mechanisms for subsequent carbon sequestration as one of the mitigation options included in the 1997 Kyoto Protocol.

3.6.5 Water Cycle

In the context of the Earth System, the water cycle includes runoff, geomorphology, sediment processes, evaporation, moisture transport, and precipitation. The water cycle encompasses not only hydrological processes over and under the land surfaces of the earth, but also in its oceans, coastal zones, and atmosphere. There are a number of internal and external drivers and feedbacks within the system, which govern the functioning of the system. They act at different space and time scales and are impacted differently by global environmental change. Therefore, there is a need to focus research on up-scaling and down-scaling of the processes (fluxes, circulations, etc). Human activities are significantly and rapidly changing the entire African water system. Research into issues of management and governance of water resources – and the institutions needed to support these issues – is also needed for a truly systemic approach to the water cycle (GWSP, 2005). The causes and manifestations of these changes need to be factored in for an Africa-wide research agenda in order to counteract the current and future threats to public health, ecosystems integrity, economic progress and biodiversity loss cause by GEC. To effectively address the African water system, including water cycle, it is important to take global view of the water system, and focus attention on the linkages and feedbacks in the system and at the same time taking account of the many social science and natural science aspects of the water resources. This topic has clear links to the ESSP Global Water System Project.

3.6.6 Ocean Circulation

Africa is located between the two major oceans: Atlantic and Indian. The African continental data therefore will have the potential to be correlated with oceanic processes affecting near transfer across latitudes and to give information on how such processes can impact future regional climates in Africa, such as global warming. Observational records of the recent years have shown exceptional rainfall events over the Sahel and Eastern Africa, associated with factors such as ENSO that generated catastrophic floods and droughts (Nicholson, 1997). Today the vulnerability of societies to climate change and particularly that of Africa is rapidly increasing. Understanding ocean circulation is therefore necessary to better predict the possible future trends in the dynamic earth system and to generate robust predictive models that can be used for analyses and formulation of long-term sustainable development options in Africa.

3.6.7 Regional Climate Modelling

Climate models, especially the more complex and realistic ones known as General Circulation Models (GCMs) are the main tools available for developing projections of climate change into the future. These models are computer simulations of the climate that incorporate the basic physics and dynamics of the climate system and that take into account the interactions between the different components of the climate system i.e., the atmosphere, oceans, land, ice and biosphere. To understand climate change, scientists must understand the detailed nature of the extremely complex climate system and their interactions, which is possible through physical climate modelling. There exists a variety of increasingly complex GCMs available today that are capable of determining the horizontal (geographical) and vertical (atmospheric and oceanic) distributions of a group of climatic quantities such as temperature, wind, water vapour, clouds and precipitation in the atmosphere; soil moisture, soil temperature and evaporation on the land; and temperature, currents, salinity and sea ice in the ocean. Direct impacts of climate change are more severe at local and regional levels and therefore it is important to downscale the global climate scenarios into regional and local climate change scenarios. Various downscaling techniques are currently available for vulnerability and impact assessment studies. The availability of past climate records and the use of computer models are the major tools available in the detection and attribution of climate change. Adequate climatological records for use in climate change detection, attribution and modelling is still a major challenge in Africa.

AFRICA AND THE EARTH SYSTEM - Example Program:
Rainfall, droughts and water management

The global water system is the global suite of water-related human, physical, biological and biogeochemical components and their interactions (GWSP, 2005). Since the areas where most of the African population live are dry, access to fresh water is of paramount importance. Water issues are intrinsically cross-scale and cross-sector in nature. Global environmental changes can influence rainfall, surface hydrology, and ecosystem behaviour, while local and regional processes can determine access to and the quality of water resources. All of these factors impact on the livelihoods, health and wellbeing of a large fraction of the African population. A program on rainfall, droughts and water management could contain the following elements and activities:

1. Create regional maps of current water stress (the ratio between annual withdrawals and availability) as well as water stress maps for a number of future projections;
2. Use regional climate model projections to assess changes in vegetation, wetland distribution, soil erosion and sedimentation, salt water intrusion into coastal groundwater, and accelerated salinization through evaporation;
3. Using these projections, assess how water management instruments (dams, diversions, channelization) affect nutrient, particulate and carbon retention, streamflow variability and extremes, loss/gain of spatial connectivity of watersheds;
4. Classify and compare water governance systems in Africa, and analyze the effects and impacts of the different types of governance on regional water resources;
5. Analyze the relationship between governance structure and projected water stress, and prepare maps of future vulnerability to changes in regional water resources.

3.7 INTEGRATED DEVELOPMENT

Global environmental change research naturally entails links to development. This is nowhere more apparent than in Africa, where most of the world's least developed countries are concentrated, and where the hard-won gains are threatened by an unpredictable future. The GEC research community and the development research and implementation communities have not in the past communicated well, partly because of issues of scale. Development efforts are often place-based, and focussed on the next ten years, while GEC research is by definition global to regional, and multi-decadal. What GEC research can provide to development planners and practitioners is the large-scale context within which development must occur. It can provide information about the changing boundary conditions for local and regional efforts, and the capacity to integrate across issues, disciplines and sectors. The economic evidence from Europe, North America and Asia and elsewhere is clear: building a viable science and technology sector is itself a necessary and effective development intervention, and one that so far has not been achieved in Africa. More specifically, African scientists need to be able to bring their achievements to the daily decision making process and social development pathways.

While development is an extremely broad endeavour, there are aspects that are particularly relevant for GEC research. These aspects allow us to focus on a relatively small number of issues. The broad sectors that simultaneously most affect both the environment and development (not only in Africa, but all around the world) are energy supply, water supply, transportation systems and agriculture (including forestry).

Economic development in most parts of the world is led by agriculture and the use of natural resources, and there are few reasons to expect a different pattern in Africa. Agriculture and forestry are the main drivers of land degradation, landscape fragmentation, biodiversity water use and pollution, loss, and the main source of greenhouse gas emissions from Africa. Many of the issues related to agriculture and forestry are addressed in the research themes on Land and on Livelihoods. Many of the development issues related to water are captured in the themes on rainfall, land, livelihoods and cities.

Energy use and development state are empirically highly correlated. Energy issues are intricately linked with other issues, and can provide a fundamental input to satisfying needs such as health, education, sanitation, job creation, income growth, while at the same time promoting productivity, economic growth and achievement of Millennium Development Goals through economic stability and governance. While energy issues are clearly relevant to global environmental change research in Africa, they are sufficiently comprehensive to warrant a separate approach. The ICSU Regional Office for Africa has coordinated the development of a science plan for energy for sustainable development in Africa (Davidson, et al., 2007) that describes concrete projects aimed at developing sustainable energy systems for sub-Saharan Africa.

Within the Integrated Development research theme, we will concentrate on four main topics: transportation systems, air quality, scenario development and governance research.

3.7.1 Transportation Systems

The ability to move people and goods can be viewed as an essential human need. Efficient transportation systems facilitate economic development, distribution of food and other essential resources, and enable the existence of cities and urban development. But the transportation sector accounts for a significant fraction of global emissions for a number of pollutants, and the establishment of transport networks is closely linked to global change phenomena such as deforestation, land cover change and ecosystem fragmentation. In 2004, transport was responsible for 23% of world energy-related greenhouse gas emissions with about three quarters coming from road vehicles. Over the past decade, transport's greenhouse gas emissions have increased at a faster rate than any other energy-using sector (IPCC, 2007). This research element will explore the relationship between transportation systems and global change, particularly concentrating on issues that cut across the various research themes such as livelihoods, cities, pests and diseases and Africa in the Earth system.

3.7.2 Air Quality

Air quality is a multi-scale issue that, like transportation, both links and transcends several research themes. For example, it links to cities and land through the roles that megacities and biomass burning play as sources of transboundary air pollution, and to rainfall through the role of gaseous and particulate air pollutants in acidification and altering cloud formation and precipitation development. In all of these areas, the understanding gained from process studies in the mid-latitudes

or other regions may not be directly transferable to tropical conditions. As well, the available data in Africa are not sufficient to permit a reliable quantification of hazards for use in cost-efficient strategies for reducing pollutants and for assessment of their impacts in terms of economic costs. This research element will assess current knowledge of pollution impacts on people, crops and natural systems, and is linked with the atmospheric pollution topic of section 3.6.3.

3.7.3 Scenario Development

Scenarios for socioeconomic development, and their consequence on the global climate system, have been at the heart of the first four IPCC assessment reports. While these scenarios include regional-scale processes, the focus has been on the overall global socioeconomic development and how it affects the emissions of important greenhouse gases and aerosols. This research element will concentrate on scenario development particularly from an African perspective, particularly linking the research themes of Land (3.2), Livelihoods (3.3) and Cities (3.4). The aim is to derive African-based scenarios from which analyses of the potential risks, vulnerabilities and opportunities of different development pathways can be performed (e.g., Africa Environment Outlook 2, UNEP, 2006a). It could involve the development of integrated models for Africa, explicitly linking the demographic and economic growth to energy and transport systems, agriculture, water and other natural resources.

3.7.4 Governance Research

Many of the key GEC issues emerge at a transboundary scale – climate change, shared river basins and the depletion of marine fisheries are examples. Throughout the world, there is little experience with effective governance and institutional structures at a supra-national scale and with a longevity comparable to the kinds of time scales associated with climate change. While there are examples of global-scale institutions (e.g., framework conventions on climate, biological diversity, the ozone layer, wetlands) the majority of governance structures function on a national or sub-national level (IHDP Report no. 16, Young, et al., 2005). This is a particular concern for Africa, since the number of countries and the diversity in institutional capacity between African nations is large. Regional conflicts within Africa, often associated with different kinds of environmental stressors, exacerbate the difficulty of establishing functioning regional- and continental-scale resource governance structures. Examples of GEC areas which require the presence of transnational governance structures include above- and below-ground watersheds that extend across several national boundaries; the access to and distribution of water resources between watershed basins; transboundary air pollution; access to and use of marine resources. The effects of in regions are often worsened by the inability to transport water from areas in which there is a surplus to those lacking sources from rainfall or runoff. This research element will explore the institutional dimensions of global environmental change with an African perspective, concentrating on the areas of Rainfall (3.1), Land (3.2), Livelihoods (3.3) and Oceans (3.8).

INTEGRATED DEVELOPMENT - Example Program:
Harmonized Scenario Development for Africa

There are multiple approaches in use for scenario development to explore future changes in the Earth system. For example, the IPCC's Special Report on Emissions Scenarios (SRES) describes a series of greenhouse gas emission scenario storylines ("narratives") making a range of assumptions about future energy use, land use and other human activities which are then implemented in integrated assessment models. This results in a strong quantitative approach that allows calculation of greenhouse gas and aerosol concentrations and climate change. The Millennium Ecosystems Assessment has used a different, more qualitative scenario approach. Their scenarios were developed for evaluating different approaches to managing ecosystem services, based on narratives. These narratives proved essential in translating global drivers towards regional and local drivers in a consistent way. In addition, current impacts and vulnerability assessments are based on a multitude of different socio-economic and environmental (including climatic) baselines combined with different scenario approaches. Often, these assessments do not use the full range of SRES or MA scenarios.

A program on this topic could contain the following elements and activities:

1. Mapping out areas in Africa that are most vulnerable to e.g., climate change, loss of biodiversity, environmental pollution, and increases in diseases or pests;
2. With these areas as a focus, convene a group of researchers from a wide range of disciplines (both social and natural sciences) that encompasses climate and biodiversity science and impacts and adaptation communities to develop guidelines for a consistent, harmonized set of scenarios (narratives) for development in Africa;
3. Using these guidelines, develop a suite of scenarios that can be used in both global and regional models to calculate future human-environmental changes;
4. From these results, assess the impact of different possible adaptation schemes on the regions of interest;
5. Assess what governance structures will be needed to effectively deal with the regional impacts.

3.8 MARINE

The ocean covers over 70% of the Earth's surface and plays a central role in global climate by means of its great capacity to store and transport heat and materials but also to store or liberate carbon and other elements through biogeochemical cycles. The Atlantic Ocean and the Indian Ocean in particular are two systems that influence African weather and global climate. The focus of this research theme is the relations between climate change, variability and ocean characteristics and their impacts on fisheries, large scale circulation process and important marine elements such as coral reefs and marine biodiversity.

The equator-to-pole transfer of energy, in the form of the global oceanic thermohaline circulation, is the 'slow engine' of the global climate system and ultimately influences or controls the regional distribution of terrestrial and marine air temperatures and precipitation. Our understanding of its complex three-dimensional dynamics and the impact of its variability on the global and regional climate systems remain rudimentary. The oceanic region south of Africa is a critical crossroads for the inter-ocean communication of heat and freshwater, where exchanges of water, salt, heat, biota and anthropogenic tracers occur between the subtropical Indian and South Atlantic gyres.

The importance of the oceans in the overall climate system can be appreciated through the way the ocean, atmosphere and land influence and interact with each other. Without properly recognizing these interactions, it is impossible to understand the mechanisms of climate change. These interactions occur on a multitude of time and spatial scales. For instance, phenomena such as the El Niño/Southern Oscillation (ENSO) has important regional and global effects, in an inter-annual and decadal time scales. The ENSO causes unusual weather patterns throughout the world and influences on our lives in terms of impacts on e.g., the fishing industry, agriculture, rainfall patterns, and temperature variations. The impact of ENSO in Africa has not yet been assessed extensively and it is important to consider the importance of the prediction of such phenomenon to improve adaptive capacity and the prevention of potential negative impacts of this phenomenon.

This research theme will focus on four elements of the marine system of particular importance to Africa, all of which are linked by marine biodiversity: marine ecosystems and coral reefs, marine biodiversity and food resources, large-scale oceanic circulation, and marine biotic community reorganisation. It should be noted that these three elements are closely linked, and will have areas of significant overlap.

3.8.1 Marine Ecosystems and Coral Reefs

The ocean contains 60 times more CO^2 than does the atmosphere, and absorbs between 30% and 50% of CO^2 emitted by human activities (Prentice, et al., 2001). The carbon dioxide that dissolves in the oceans lowers the pH of surface waters. If the pH decreases below a critical point, the marine organisms that use dissolved CO^2 to produce a certain form of solid carbonate (aragonite) shell would no longer be able to do so. Coral reefs – and their associated biodiversity and complex food webs – are particularly sensitive to changes in both temperature and pH. Marine organisms are a very important part of the "marine carbon pump" that removes CO^2 from the atmosphere. Recent estimates show that under the "business as usual" scenario we could reach this point as soon as 2050, with potentially large changes in marine ecosystems (Orr, et al., 2005). Thus, oceans play a significant interactive role in the carbon cycle and the any alterations of the processes that influence the way the CO^2 is accumulated in the ocean can generate impacts on marine biodiversity, biomass, and ecosystems.

3.8.2 Marine Biodiversity and Food Resources

The cross-boundary nature of all ecosystems is important, but especially so in the fluid context of marine ecosystems. The approach to marine biodiversity studies has been through the notion of Large Marine Ecosystems (LMEs), aimed at establishing the information and knowledge base required to manage their resources most efficiently. LMEs are defined using criteria such as bathymetry, hydrography, productivity and trophodynamics, and are aimed at distinct socio-economic benefits such as enhanced quality of environmental governance and management. The strategy with respect to marine biodiversity would be to elaborate a 'mega LME' stretching the entire length of sub-Saharan Africa (thus integrating the Guinea Current, Benguela Current and Agulhas and Somali Current LMEs). Three linked international projects to be carried out between Cape Agulhas and the Horn of Africa from 2006 to 2012, funded by the Global Environmental Facility (GEF), are addressing the latter LME.

3.8.3 Large-scale Circulations

Sustained observations coupling atmosphere, oceans and land processes around sub-Saharan Africa will provide the only means to monitor the variability within this region. Direct linkages with current LME studies in operation along the sub-Saharan African coastline will lead to a better understanding of how the background circulation influences the nature of coastal habitats, their biodiversity and productivity. The ultimate aims of an LME study are to derive methods to reduce coastal pollution, to restore damaged habitats and to recover depleted fish stocks, develop an ecosystem approach to global assessment and management of coastal waters as well as a better understanding of the background circulation. A co-ordinated regional framework is needed for sub-Saharan Africa to facilitate the securing and sharing of knowledge, data and information for the marine environment and its influence on global change, climate variability and ecosystem management.

3.8.4 Marine Biotic Community Reorganisation

Africa straddles the equator. Therefore the eastern and western coastlines of Africa both show poleward biogeographical gradients, from tropical to temperate communities. The issues with respect to the impacts of climate change on the integrity and migration of these communities are in some respects similar to those for terrestrial communities (which is why this element is grouped in this theme), but also have some unique features, for instance, the linear nature of coastlines and the vectored dispersion processes driven by ocean currents.

A particular concern relates to the biodiversity-rich and fisheries resource-rich coral reef communities. The temperature sensitivity of the two types of organism that make up coral – the polyp and the alga – differs, and the mutualism fails for quite small increases in sea temperature. An additional stress is imposed by the acidification of seawater due to rising atmospheric carbon dioxide, the pressures of fishing and tourism, and invasion by alien species. There have already been major episodes of coral bleaching in East Africa that threaten the sustainability of livelihoods dependent on this resource. Mangrove and seagrass communities represent other examples of critical marine ecosystems under threat.

MARINE - Example Program:
Ocean acidification and marine ecosystems

Roughly one quarter of the CO_2 emitted into the atmosphere ends up in the oceans. As a consequence, the pH of surface ocean water is changing rapidly. Changes in ocean pH and temperature can effect marine ecosystems throughout the food chain – particularly species such as corals, macroalgae and pteropod molluscs.

1) Undertake chemical and biological monitoring at a variety of oceanographic settings using standardized protocols;
2) Undertake mesoscale CO_2/pH perturbation experiments in a number of locations around Africa at the community to ecosystem level;
3) Identify the sub-lethal effects on marine organisms of chronic exposure to elevated CO_2;
4) Investigate the impacts of multiple stressors (e.g., temperature, CO_2) on food webs, biodiversity and species distributions;
4) Prepare scenarios for long-term impacts and adaptation strategies for timescales of decades to centuries.

Implementation Strategy

4.1 MECHANISMS

GEC research in Africa will be supported and coordinated through a multiplicity of mechanisms rather than one monolithic mechanism. This reflects both the current reality, and a desired state: the presence of several mechanisms helps to ensure robustness, dampens the fluctuations associated with single-source control, and helps to allay fears of national or disciplinary biases. Two of those mechanisms already exist; a third has periodically been used to great success; and the fourth needs to be created.

The first mechanism is **national programmes**. This is currently the main source of support for the hundreds of African scientists who spend all or a part of the time on GEC or related research, and will continue to be a major source. It is important that it remain so in order that the research agenda is firmly rooted in national needs, and so that a strong sense of ownership of, and responsibility for, the research products is developed. International partners also need to recognise that although their contributions are important in absolute dollar terms and in terms of the technology they bring, the bulk of the human effort is national, and therefore an equal role in research design and governance, even at the international level, is earned rather than awarded as an act of charity. National research funding and coordination mechanisms must be encouraged to align their programmes with this African strategy by strength of argument rather than coercion: it makes good sense to pool the scarce research resources around well-designed programmes designed to address shared problems.

The second mechanism is **bilateral and multi-lateral international initiatives**. These include nation-to-nation scientific cooperation agreements, development aid organisations, collaborative research funding opportunities such as the EU framework programmes, and the limited set of truly international funders such as the GEF or UN-based initiatives. The G8 countries have pledged to increase their support to Africa, and in particular in relation to climate change, so this mechanism could potentially be a growing source of support. The drawback is that with the exception of the bilateral agreements, African countries have little say in the structure and direction of the opportunities. Hopefully, this unified statement of African GECR priorities will help to influence those opportunities.

The third mechanism is the **focussed research campaign**. These typically have very specific objectives, a finite lifetime (about 5 years) and a defined geographical scope, usually regional. They are funded from a combination of the above two mechanisms (and in future, potentially also through the fourth mechanism, described below), but typically have their own governance, largely drawn from the participating researchers. They are often incubated under the wing of one of the international research programmes. They have proved to be an exceptionally efficient and effective way of bringing cutting-edge research to Africa, and leaving a strong legacy of skills, equipment and networks. Good examples are the SAFARI 2000 campaign around vegetation fires, the IDEAL project on the palaeo-climatology of African lakes, and the AMMA campaign on land-ocean-atmosphere links in West Africa. They work best when African and international partners have parity, and when the problem is well-defined, of international interest, and best studied in Africa. National governments can promote this mechanism by making it easier to do research in Africa: facilitating customs and immigration controls, removing restrictive practices around granting research permission, and making national facilities and cofunding available. Highly-coordinated research effort is a natural consequence of this mechanism. The objective should be to have several such campaigns at various stages of development in Africa at any given time.

The fourth mechanism – an **African funding mechanism in GEC research** – does not currently exist, and its absence is a major factor limiting the development of GEC research on the continent. The initiation of such mechanisms in Latin America (the IAI) and Asia (APN) were key mechanisms for promoting GEC research in those regions. The mechanism needs to be founded on a transparent, accountable and efficient system of awarding small, medium-sized and large grants, on a competitive, peer-reviewed basis. Most would be in response to directed calls for proposals, but some could be standing facilities (such as for scholarships or travel grants) or unsolicited proposals (such as for emerging campaigns). The institutional basis for such a mechanism, currently absent, is discussed below, under institutions.

4.2 INSTITUTIONS

The word 'institutions' is used here in the sense of ways of organising things, rather than necessarily physical locations. Many researchers, research groups and other actors are already engaged in global environmental change science in Africa. Their efforts, although substantial, are inadequate for the task at hand. Significantly greater financial support, and along with it, greater coordination and focus, is required. The institutional design needed to effectively realise the vision of a self-sustaining and sufficient GECR system in Africa has the following necessary components:

- **A 'Web' of research partners.** There is an established tradition of networks of GEC research in Africa, many (but not all) linked to the members of the ESSP, and several existing centres of excellence. The competence is patchy and thinly spread, but the anointment of a single 'centre of excellence' for African GEC research would be counterproductive, and inappropriate for such a diverse field. An alternative is a distributed 'web' (a 'network of networks') of researchers with a core 'secretariat' and 'nodes' of excellence with delegated coordination responsibilities in particular regions or domains.
- **A 'Hub' for administration and coordination.** An appropriate administrative and secretariat 'hub' would be responsible for the following functions: maintaining a database of African GEC research (a Wiki-type approach may get around the perennial problem of out-datedness of such databases); calling periodic African GEC research conferences and workshops; coordinating review and strategy-setting processes; and catalysing the formulation of projects in identified areas. *It is proposed that this function be satisfied by the creation of an African GEC research secretariat, to be known as* ***AfricanNESS,*** *recognised by both the ICSU family and the African Union as the coordinating body for GEC research in Africa.* It should be associated and co-located with the funding mechanism described below.
- **'Pipelines' for the targeted and efficient delivery of funding support.** African GEC research is chronically underfunded: for most African GEC researchers there are no dedicated national sources of support, and the international sources are unattainable because they have high entry barriers, such as communication difficulties, accounting requirements, complex and daunting proposal processes. Yet there are African and international funding bodies that have expressed a desire to support GEC research in Africa, if they could find a satisfactory institutional mechanism. What is needed is a way to convert large blocks of 'wholesale' funding into 'retail' opportunities in an efficient and transparent way. From the donor side this means accountability in the evaluation and the allocation processes, focussed investment in good-quality science, and high efficiency (i.e. low leakage and overheads) in the system. The needs from the researcher point of view are for a quick turn-around system with a range in funding opportunities (from small grants to support individual graduate research, through moderate funding for post-docs, to large sustained funding for centres of excellence), with review processes with clear rules and a level of effort commensurate with the size of the funding.
- **'Spaces' for science-policy-practice interaction.** One of the outcomes of the AfricanNESS meeting in 2005, was a call for the establishment of various forums where contributions from science and inputs from policy and society could be gathered. These 'safe spaces' could provide a very critical vehicle for ensuring that GEC science is mindful of, and useful to, society at large – aiding cross-sector communication and the development of decision making tools. One successful model for such interactions is the assessment process, as exemplified by the IPCC or the MA, but performed at the scale of Africa (or regions in Africa), on limited topics. Such synthesis activities produce not only useful scientific outputs but also enable GAP analysis to be undertaken. It is suggested that ICSU-ROA take a lead in the science-policy-practice interface, by convening *ad hoc* assessment panels, along the lines of SCOPE panels, to address important policy-relevant Global Change issues in Africa not already covered by IPCC or similar global assessments. ICSU-ROA, together with other partners, could also play a role in generating 'spaces' of engagement on themes of interest both to scientists and society at large.

AfricanNESS – The Institution

It is proposed that a new institution be established with the mission of promoting global change research in Africa. It is proposed that it be associated with the African Development Bank, in order to give it an appropriate international legal status, and a ready-made system for the accountable handling of funds. There is a danger of creating an over-complex governance and guidance mechanism for global change research in Africa, and thus dissipating the effort of the relatively small cadre of leading African researchers in duplicative efforts without clear lines of authority. It should accordingly initially be a simple structure consisting of Advisory Board (AB; consisting of political and donor stakeholders), a Scientific Steering Committee (SSC) and an Administrative Secretariat, legally established as an independent non-governmental organisation (NGO), or hosted by an international organisation operating in Africa and with common interest in global change science and capacity development. The host institution should provide enabling environment and incentives such as office space, support personnel and communication facilities. The key administrative personnel and scientists should be appointed by the Administrative Board on the advice of the Scientific Steering Committee.

The Advisory Board, Scientific Steering Committee members should represent geographical regions and scientific disciplines and should serve for a fixed period of time before rotating off to be replaced by new members. The rotation should be staggered to maintain continuity and institutional memory. Similarly, the Chief Administrators should also be appointed for a specific period of time. But appointments can be renewed once or twice depending on exceptional performance.

The Advisory Board's responsibilities should include, among other duties, fundraising for research and management activities. The Scientific Steering Committee to be responsible for review and planning of research activities. The Administrative Personnel to be responsible for the day to day running of the secretariat.

4.3 PARTNERSHIPS

Global Environmental Change is a research area involving a large number of players, which interact in very complex networks. The African GEC research network described here will therefore need to reach out to other research interests, programmes, organisations and initiatives within and outside the continent. AfricanNESS will pursue its research themes in collaboration with the organisations in the research, observation, assessment and development sectors, supported by a variety of funding sources, and aiming to provide information and results useful for stakeholders. It is important, both for the success of AfricanNESS and to avoid overtaxing the scarce African GEC research capacity, to have some degree of coordination in this constellation, but at the same time to avoid the burdens of over-connectedness.

4.4 CAPACITY BUILDING

Capacity building is a central concern in developing countries, where limited financial resources and an absence or short history of universal education systems are key constraints. There is wide and growing acceptance internationally of the need to build capacity for adaptation to global change, particularly in the more vulnerable parts of the world. Although climate change is a global environmental issue, neither the industrial causes of the problem nor the tools of its analysis are native to sub-Saharan Africa. As a result, Africa is faced with the necessity of dealing with a complex economic, scientific and social issue, having neither the scientific background, the necessary tradition of public awareness and mobilisation, nor the availability of financial resources and implementation structures to do so.

The six crucial challenges to building scientific capacity are to:

1. build and strengthen human capital;
2. provide research infrastructure, adequate remuneration and incentives for researchers to retain capacity;
3. communicate more effectively between science and society;
4. develop the culture of strong links between science and policy;
5. trengthen the links between education, research, and between researchers in different parts of the African region, in order to establish critical mass; and
6. develop clear national strategies for building capacity.

Capacity building in this context also means providing the skills and frameworks for project identification, formulation and implementation, making the maximum use of existing skills and resources.

The following limitations will need to be targeted if scientific and technical capacity is to be built and sustained:

- The scarcity of researchers, research infrastructure and research funding. Science and mathematics education is a critical aspect. This requires, in particular, strengthening research capabilities in academic institutions. It is important to link these tertiary institutions to modern research to promote and sustain national innovation.
- Institutional capacity - enabling local, regional and national authorities and civil society to respond to disasters, to adapt to global change and to plan and adopt mitigation measures. This includes strengthening the capacity of national focal point personnel e.g. in negotiating skills, and the development of new and appropriate technologies (renewable energies, flood control measures, etc.)
- Systematic observation – involvement of all sectors of society in recording information on climate and natural resources (e.g. rainfall, fish landings, soil quality, crop yields and vegetation cover).
- Vulnerability and adaptation assessment – the use of community-based techniques to measure and record information and assess vulnerability to global change, and the training of researchers to better assess the risks faced due to these changes.
- Integration of adaptation responses into national development strategies - building capacity to respond to climate change events. This includes reducing the risk of climate impacts on infrastructure investments ('climate proofing'), enhanced disaster preparedness, use of traditional knowledge and new technologies, and coordinated regional response.
- Enabling environments for technology transfer – introduction of appropriate technologies to aid adaptation (flood control systems, emergency shelters etc.) and mitigation (energy efficiency, reforestation etc.) and the strengthening capacity to adopt and maintain new technologies.
- Education and raising public awareness – increasing awareness of the causes and effects

of global change and possible responses from primary schools to universities, and in civil society through NGOs and community groups.

The main obstacles encountered in capacity building can be summarised as follows:

- Lack of an integrated or cross-sectored approach. Global change issues need to be addressed throughout the public and private sectors in order to achieve a consolidated approach.
- Lack of high-level political commitment, which leads to financial instability as predictable resourcing is not provided for in central budgetary processes.
- Communication difficulties between the agencies, institutions, government departments, NGOs or community groups involved in the capacity building activity. For instance, technical data can be difficult to obtain. In addition, further difficulties may be encountered in securing cross border and inter-regional cooperation.
- Complex institutional policies including overly bureaucratic systems and difficulties in identifying key advisors for training opportunities.
- Lack of awareness. As long as global environmental change remains low on a country's list of development priorities it is difficult to make significant progress. This is also reflected in awareness raising activities in civil society, where environmental change is rarely given significant importance.
- Difficulties in targeting the most appropriate candidate for training activities and difficulties in reaching people outside capital cities and across the range of government ministries and departments.
- Failure by donors to adequately integrate global change into development cooperation policies and programmes.

Capacity building must involve both institutional and human resource development. Institutional capacity building must involve decision-makers at the highest level in order to ensure support after the initial programme is completed.

Capacity needs to be built in the 'receiving environment' as well. Without well-functioning institutional, policy and legal frameworks, efforts to build research capacity are unlikely to have broader policy level outcomes. Capacity building activities in the public sector should be an integral part of overall public sector reform processes. In the interests of sustainability, it is important that responses to risks to the environment be mainstreamed within nationally-owned strategies such as poverty reduction strategies and into existing projects and programmes relating to the range of government ministries. Specific capacity building projects are more successful when they establish policy links to other ministries such as agriculture, water, energy and finance.

Capacity building activities must be country- and demand-driven in order to assure the level of support needed to make their outcomes sustainable. In local and regional programmes it is essential to have appropriate regional and national authorities and institutions on board. Both donors and host countries must adopt a long-term approach to capacity development and this requires financial sustainability, ultimately supported by national policies and budgets that reflect national policy priorities. Without the financial resources, spare parts and know-how necessary to maintain equipment and new technologies, the outcomes of programmes are limited to short-term impacts.

Absence of political stability or the existence of security problems affects the ability to build a critical mass of highly trained individuals, who (by definition) have skills in demand elsewhere. The loss of trained staff to take up more attractive offers outside Africa, or within Africa but outside the research domain or the public sector, results in a brain drain and compromises future capacity development. Recruiting talent into science is a concern: attracting, developing, and retaining talent in science and technology must be a priority of the scientific community.

There is a widening gap between advancing scientific knowledge and technology and society's ability to capture and use them. Better communication of science to the public will help transcend the diversity of experiences and enable constructive dialogue about the risks and benefits of scientific discoveries and new technologies.

The Global Change SysTem for Analysis, Research, and Training (START), through its Pan-African Start Secretariat, has played a leading role in GEC research capacity development in Africa, and must continue to do so.

4.5 TIMELINES

We will stratify the development of AfricanNESS into three time horizons: The short-term (0-2 years), the middle distance (5 years) and the long-term (10 years). Each time horizon will have its own specific objectives, outputs, and success criteria. These are summarized in Table 1. The major success criteria will vary along the time trajectory. The short-term criteria will be ones assessing how inputs are developed and used – how efficiently and well the network is built up. The mid-term criteria will measure how well the network is starting to produce output such as papers, workshops, campaigns and students. The long-term criteria will measure the impact of the network in terms of assessments, policy products and functioning infrastructure.

Success criteria for the network as a whole are described in section 4.7. These success criteria will evolve as AfricanNESS matures, and the success criteria appropriate for the different stages of AfricanNESS' development will vary depending on the objectives for each stage network development. Care will be taken to provide annual assessments of the progress of the network with respect to achieving the objectives outlined here.

TIME HORIZON	Objectives	Example Activities
Short term	• Establish network • Spin up projects and activities	• Write and submit proposals for support • Establish Secretariat • Develop web site • Establish contact and resource network and database • Plan and host planning meetings for projects and activities; develop science plans for activities • Help facilitate initial project activities
Middle term	• Support network operations • Produce identifiable products	• Facilitate or host field campaigns, model intercomparisons • Plan and host workshops, training activities • Help network scientists publish research results • Produce public- and policy-relevant products
Long term	• Synthesize network output • Produce policy products	• Produce synthesis of network products and activities • Plan for second phase of network

Table 1. Time horizons for AfricanNESS

4.6 BUDGETS

As outlined in section 4.2, we propose that a new coordination secretariat be established to coordinate and support the work described in this science plan. The work plan presented here refers to the activities of this secretariat, and is based on estimates for similar facilities carried out by the ESSP. The budget figures are intended to be approximate; the actual costs will depend on the amount and nature of the in-kind support offered by the host institution.

4.6.1 Two Year Work Plan

The AfricanNESS secretariat work plan consists of (i) supporting the Scientific Steering Committee (SSC) and Advisory Board (AB) in implementing their activities, (ii) support initiatives to further promote the AfricanNESS mission.

Some examples of the kinds of activities of the AfricanNESS Secretariat will be:

- Supporting the SSC and AB and their meetings;
- Assisting the SSC with fund raising;
- Producing an annual report of activities in the network;
- Promoting closer relationships between AfricanNESS and the client community through publications (including a website, brochures, newsletter);
- Coordinating the development of a long-term business plan for AfricanNESS.
- Administering funds for AfricanNESS activities;
- Participating in relevant meetings of the international GEC programs and their projects to report on AfricanNESS and to seek feedback, as well as seeking suggestions for new key activities;
- Carry out detailed planning for these activities and support their execution as required for successful implementation.

4.6.2 Example Budget

The following budget estimates assume a small office with adequate facilities and maintenance, ample telecommunication facilities and the possibility to outsource some tasks (e.g., travel preparation, financial administration). It comprises a full time coordinator and a science officer plus a part time administrative assistant.

A small but efficient and effective office that promotes cohesion and development among the ESSP-partners will require 370 k€ (Year 1) to almost 400 k€ (Year 2).

4.7 SUCCESS CRITERIA

With any effort of this scope and complexity, it is crucial to be able to assess whether we are fulfilling our objectives in an efficient and effective manner. Accountability – both scientific and economic – is a basic building block of a successful enterprise.

AfricanNESS is envisioned as a science network, and scientific output, building lasting connections and capacity building are our primary products. We have the additional aim that we communicate this scientific knowledge in a way that is understandable and usable to stakeholders and the general public. We will use the following criteria to judge the degree of success for AfricanNESS:

4.7.1 Scientific Output

- Number of papers in refereed scientific journals arising from research facilitated by AfricanNESS
- Number of books, reports and other publications from AfricanNESS-related research

4.7.2 Achievement of Goals

- Major field campaigns and model activities organized under AfricanNESS and its activities
- Number of new interdisciplinary and multi-institutional collaborations within Africa started through AfricanNESS
- Identification and documentation of adaptive capacities of local communities
- Number of science-policy dialogues and operational results of the dialogues
- Number of collaborations with international organisations facilitated through AfricanNESS

4.7.3 Reporting

- Publication of an annual report for AfricanNESS activities
- Progress reports and presentations to funding agencies
- Proper and transparent accounting of funds
- Number of publications directed at the stakeholder community

Expenses (in Euros)				
Item	**Year 1**	**Year 2**	**Total**	**Notes***
Office and equipment	8,000	8,160	16,160	1, 2
Staff	230,000	234,600	464,600	3
International travel	22,500	22,950	45,450	4
C offsetting travel	3,500	4,200	7,700	5
Finance management	3,000	3,100	6,100	6
Other outsourcing	5,000	5,100	10,100	7
Publication	10,000	10,200	20,200	8
AB	12,000	12,240	24,240	9
SSC, AB meetings	36,000	36,720	72,720	10
New activities	30,000	45,000	75,000	11
Unforeseen	10,700	11,500	22,200	12
Total	370,700	393,770	764,470	

*** Notes.**

1. Rent of space and office facilities; renting teleconference facilities.
2. A 2% inflation correction is applied to all line items
3. Staff (2 full time, one part time), total cost, incl 2% annual raise
4. Travel plus lodging, at 15 trips per year @ 1.5 k€ in average.
5. Cost to offset CO_2 from travel (coordinator, SSC members, AB members (estimated at 5% of travel cost).
6. Cost of support for financial transactions and auditing.
7. Outsourcing of other specialized activities to specialized offices and consultants, of publications, website, posters, databases, etc.
8. Publications: printing, dissemination, display.
9. SSC meetings (conference facilities for full and executive meetings; travel of ICSU-members @ 1.5 k€ per trip).
10. SSC, AB meetings: 12 SSC, 12 AB members @1.5 k€ each
11. New activities. The lower value in Year 1 reflects that the entire procedure needs to start up.
12. At a low 3% of the listed expenses.

References

Adger W.N., J. Paavola, S. Huq and M.J. Mace, 2006: *Fairness in Adaptation to Climate Change,* The MIT Press, Cambridge Massachusetts, London, England.

Adger, A.W. and K. Vincent, 2005. Uncertainty in adaptive capacity. *C. R. Geoscience* 337 (2005) 399–410. Adger and Vincent, 2005.

Adger, W.N., S. Huq, K. Brown, G. Conway and M. Hulme, 2003: Adaptation to climatic change in the developing world. *Progress in Development Studies*, 3, 179-195.

African Development Bank (ADB), 2007. Selected Statistics on African Countries 2007, Volume XXVI

Airhihenbuwa, C.O., 1995: *Health and Culture Beyond the Western Paradigm,* Sage Publications, International Educational and Professional Publisher, Thousand Oaks, London and New Delhi.

Alverson KD, Bradley RS and Pedersen TF (Ed.s) (2003) Paleoclimate, Global Change and the Future. Springer-Verlag, Berlin, Heidelberg. 220pp.

Andreae, M.O., 1995: Climatic effects of changing atmospheric aerosol levels, *World Survey of Climatology 16,* Future climates of the world (A Henderson Sellers ed) Elsevier Amsterdam 341-392.

Barange, M. and R. Harris, 2003: *Marine ecosystems and global change*. IGBP, Stockholm, IGBP Science no.5, 32 pp.

Barnston, A. G., W. Thiao, and V. Kumar, 1996: Long-Lead Forecasts of Seasonal Precipitation in Africa Using CCA. Weather and Forecasting, 11, 506-520.

Battarbee, R. W., Gasse, F., and Stickley, C. E., (eds) 2004. Past climate variability through Europe and Africa. Developments in palaeoenvironmental research, Volume 6. Springer, Dordrecht, The Netherlands.

Bengtsson, J., P. Angelstam, T. Elmqvist, U. Emanuelsson, C. Folke, M. Ihse, F. Moberg, M. Nystrom, 2003: Reserves, resilience and dynamic landscapes. *Ambio*, 32(6), 389-396.

Benson, T., 2004: *Africa's Food and Nutritional Security Situation: Where We Are and How Did We Get Here,* International Food Policy Research Institute 2020. Discussion Paper 37.

Berkes, F. and D. Jolly, 2002: Adapting to climate change: Social-ecological resilience in a Canadian Western Arctic community. *Conservation Ecology*, 5(2): art. no. 18.

Biggs, R., E. Bohensky, P. Desanker, C. Fabricius, T. Lynam, A.A. Misselhorn, C. Musvoto, M. Mutale, B. Reyers, R.J. Scholes, S. Shikongo and A.S. Van Jaarsveld, 2004: *Nature supporting people. The Southern African Millenium Ecosystem Assessment. Integrated Report.* Council for Scientific and Industrial Research, Pretoria, South Africa, 58 pp.

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda, 2007: Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds., Cambridge University Press, 433-467.

Brasseur G.P., R.G. Prinn and A.A.P. Pszenny (Ed.s), 2003: Atmospheric Chemistry in a Changing World: An Integration and Synthesis of a Decade of Tropospheric Chemistry Research. Springer-Verlag, Berlin, Heidelberg. 300pp.

Brooks, N., Di Lernia, S., Drake, N., Chiapello, I., Legrand, M., Moulin, C., and Prospero, J. 2005a. The environment-society nexus in the Sahara from prehistoric times to the present day. The Journal of North African Studies 304, 253-292.

Brooks, N., 2005b: Cultural heritage and conflict: the threatened archaeology of Western Sahara, *The Journal of North African Studies* 3-4 413-439.

Brooks, N., 2006: Cultural responses to aridity in the Middle Holocene and increased social complexity, *Quaternary International, vol. 151 (July 2006).*

Camoroff, J., 1997: The discourse of rights in colonial South Africa: Subjectivity, Sovereignty, Modernity, in Sarat and Kearns *Identities Politics and Rights*. The Amherst Series in Law Jurisprudence and Social Thought, Ann Arbor: University of Michigan Press.

Canadell J, Pataki D and Pitelka L (Ed.s) (2006) Terrestrial Ecosystems in a Changing World. Springer-Verlag, Berlin, Heidelberg. *In press.*

Carruthers, J., 2005: Africa's environmental history, *IHDP Update* 02/2005 www.ihdp.org/updatehistory05/references.htm.

Cash, D. and S. Moser, 2000: Linking global and local scales: Designing dynamic assessment and management processes, *Global Environmental Change* 10 2 109-120.

Cash, D., 2001: In order to aid in diffusing useful and practical information: agricultural extensions and boundary organisations, *Science Technology and Human Values Special Issue: Boundary Organisations in Environmental Policy and Science* 26 4 431-453 .

CEDEAO-CSAO/OCD. 2006. Atlas de l'intégration Africaine en Afrique de l'Ouest. Les bassins fluviaux transfrontaliers. 20 p.

Chambers, R. 1989. "Vulnerability, coping and policy." IDS Bulletin Vol 20, pp. 1-7

Chambers, R., and G. Conway. 1992. *Sustainable rural livelihoods: practical concepts for the 21st century.* IDS Discussion Paper 296, Institute of Development Studies, Brighton, Sussex, UK

Charlson, R. J., S. E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, J. E. Hansen, and D. J. Hofmann, 1992: Climate Forcing by Anthropogenic Aerosols. Science, 255, 423-430.

Clark B.M. (2006) Climate change: a looming challenge for fisheries management in Southern Africa. *Marine Policy*, 30(1): 84-95.

Confalonieri, U. and A. McMichael, Eds., 2006: Global Environmental Change and Human Health: Science Plan and Implementation Strategy, ESSP Report #4, Earth System Science Partnership, Paris, France, 86 pp.

Corvalan, C., S. Helas and A. McMichael, 2005: *Ecosystems and Human well-being, Health Synthesis. A Report of the Millennium Ecosystem Assessment*, World Health Organization, Geneva.

Cousins, B., 2001: *Land reforms at the crossroads: Who will benefit?,* Programme for Land and Agrarian Studies: University of the Western Cape, February 2001.

Crossland CJ, Kremer HH, Lindeboom HJ, Marshall Crossland JI, and Le Tissier MDA (Ed.s) (2005) Coastal Fluxes in the Anthropocene. Springer-Verlag, Berlin, Heidelberg. 231pp. Kabat P, Claussen M, Dirmeyer PA, Gash JHC, Bravo de Guenni L, Meybeck M, Pielke Sr RA, Vörösmarty CJ, Hutjes RWA and Lütkemeier S (Ed.s) (2004) Vegetation, Water, Humans and the Climate: A New Perspective on An Interactive System. Springer-Verlag, Berlin, Heidelberg. 566 pp.

Davidson, O. and M. Conteh, 2006: "Energy and the Millennium Development Goals in Africa", Paper for Forum of Energy Ministers of Africa for CSD-14, Kampala, Uganda, April 2006.

Davidson, O., M. Chenene, E. Kituyi, J. Nkomo, C. Turner, and B. Sebitosi, 2007: Sustainable Energy in sub-Saharan Africa, ICSU Regional Office for Africa Science Plan, 22 pp.

De Ronde, C., Trollope, W.SW., Parr, C.L., Geldenhuys, C.J. 2004. Fire effetcs on flora and fauna. In Wildland Fire Management handbook for sub-sahara Africa. Goldammer, J.G. and de Ronde, C. edts. Pp 60-87.

DFID, 2004: *Climate Change and Poverty, Making Development Resilient to Climate Change*. Development for International Development. Gov. UK.

DIVERSITAS (2002). Diversitas Science Plan. Diversitas, Paris, Report n°1, 40 pp.

Dixon R.K., Smith J. and Guill S. (2003) Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. *Mitigat. Adapt. Strat. Glob. Change*, 8(2): 93-113.

Duce, R., 1995: *Sources, distributions and fluxes of mineral aerosols and their relationship to climate*, Proc Workshop on Aerosol Forcing of Climate (Charlson and Heintzenberg eds) Berlin 43-72.

FAO, 1996: Sixth World Food Survey, Rome

FAO, 2006: Global Forest Resources Assessment 2005, 320 pp.

Fasham M (Ed.) (2003) Ocean Biogeochemistry: The Role of the Ocean Carbon Cycle in Global Change. Springer-Verlag, Berlin, Heidelberg. 297pp.

Fischer G, Shah M and van Velthuizen H (2002): *Climate Change and Agriculture Vulnerability*, International Institute for Applied Systems Analysis, Austria.

Fischer G, M. Shah, N. Tubiello and H. van Velthuizen (2005): Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080, *Phil. Trans. R. Soc*. 360 2067-2083.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. N. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder, 2005: Global Consequences of Land Use. Science, 309, 570-574.

Folke, C., S. Carpenter, et al. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. Scientific background paper prepared for the Environmental Advisory Council to the Swedish Government. ICSU Series for Sustainable Development, No. 3.: Available at: http://www.resalliance.org/reports/resilience_and_sustainable_development.pdf

Food and Agriculture Organisation of the United Nations (FAO) (1995): Irrigation in Africa in figures - L'irrigation en Afrique en chiffres. Water Reports / Rapports sur l'eau. Food and Agriculture Organization of the United Nations, Rome. ISSN 1020-1203. Available online: http://www.fao.org/docrep/v826b/v8260b00.htm

Food and Agriculture Organisation of the United Nations (FAO) (2006): Georeferenced database on African dams (8 September 2006). AQUASTAT, Land and Water Development Division. Available online at: http://www.fao.org/ag/agl/aglw//aquastat/damsafrica

Freire, P. and A. Faundez,1989: *Learning to Question,* New York Continuum.

Galloway, J. N., F. J. Dentener, D. G. Capone, E. W. Boyer, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. C. Cleveland, P. A. Green, E. A. Holland, D. M. Karl, A. F. Michaels, J. H. Porter, A. R. Twownsend, and C. J. Vörösmarty, 2004: Nitrogen cycles: past, present, and future. Biogeochemistry, 70, 153-226.

Gasse, F. 2000. Hydrological changes in the African tropics since the Last Glacial Maximum. Quaternary Science Reviews. 19: 189-211

GECAFS, 2006. GECAFS Southern Africa Science Plan and Implementation Strategy. GECAFS Report No 3. 38pp. Oxford. GECAFS, 2006

GECHH, 2006: *Global Environmental Change and Human Health: Science Plan and Implementation Strategy*. ESSP Report No. 4. Editors: C. Ulisses and T. McMichael.

GEOTRACES Planning Group, 2006. *GEOTRACES Science Plan*. Baltimore, Maryland: Scientific Committee on Oceanic Research.

Gibbons M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott and M. Trow, 1994: *The New Production of Knowledge, the Dynamics of Science and Research in Contemporary Societies*, SAGE publications, London.

Githeko, A. K., J. M. Ayisi, P. K. Odada, F. K. Atieli, B. A. Ndenga, I. J. Githure and G. Yan (2006) 'Topography and maleria transmission heterogeneity in the western Kenya highlands: Prospects for focal vector control', Malaria Journal, vol 5, p107

GLP, 2004: IGBP Report 53 / IHDP Report 19, Global Land Project *GLP Science and Implementation Strategy,* IGBP Secretariat Stockholm Sweden.

GWSP, 2005: The Global Water System Project: Science Framework and Implementation Activities. GWSP Report No. 1, ESSP Report No. 3, Earth System Science Partnership. Available online at: http://www.gwsp.org/downloads/GWSP_Report_No_1_Internetversion.pdf

GLOCHAMORE, 2006: Global Change and Mountain Regions: Research Strategy. ADAG Copy AG, Switzerland.

Goldammer, J.G. and C. de Ronde, (Eds), 2004. Wildland Fire Management Handbook for Sub-Sahara Africa. Preface. Global Fire Monitoring Center (GFMC), 432 p.

Gordon, N.D., 1985. The Southern Oscillation: a New Zealand perspective. *J. Roy. Soc. N.Z.*, **15**, 137-155.

Guston, D., 2001: Boundary organisations in environmental policy and science: an introduction, *Science Technology and Human Values Special Issue: Boundary Organisations in Environmental Policy and Science* 26 4 399-408.

GWSP, 2005: The Global Water System Project: Science Framework and Implementation Activities. Earth System Science Partnership

Heikkinen, R. K., M. Luoto, M. B. Araújo, R. Virkkala, W. Thuiller, and M. T. Sykes, 2006: Methods and uncertainties in bioclimatic envelope modeling under climate change. Progress in Physical Geography, 30, 751-777.

Hewawasam I. (2002) *Managing the marine and coastal environment of sub-Saharan Africa. Strategic directions for sustainable development.* World Bank, Washington, 57 pp.

Hulme, M. (ed) 1996. Climate Change and Southern Africa: an exploration of some potential impacts and implications for the SADC region. Climate Research Unit, University of East Anglia/WWF International, Switzerland

IDS Bulletin, 2005: New Directions for African Agriculture IDS Bulletin Volume 36 2 June 2005.

IEA, 2005: "World Energy Outlook", International Energy Agency, Paris, France.

IGAC, 2006: Science Plan and Implementation Strategy. Report No. 56, IGBP Secretariat, Stockholm. 44 pp.

IGBP, 2006: Science Plan and Implementation Strategy. IGBP Report No. 55. IGBP Secretariat, Stockholm. 76pp.

IIED, 2006: (S. Huq, H. Reid and L.A. Murray): Climate Change and Development Links GateKeeper Series 123.

iLEAPS, 2005: Science Plan and Implementation Strategy. IGBP Report 54, IGBP Secretariat, Stockholm. 52 pp.

Ingram J. S. I. & Brklacich, M. (2002). Global Environmental Change and Food Systems (GECAFS) A new, interdisciplinary research project. *Die Erde,* 113, 427-435.

INTERNATIONAL CLIVAR PROJECT OFFICE (2006): Report of the 4th Meeting of the CLIVAR Variability of the African Climate System (VACS) Panel. September. International CLIVAR Project Office, CLIVAR Publication Series No. 108. (not peer reviewed).

IPCC, 2001a: *Climate Change 2001 - Impacts Adaptation and Vulnerability*, Cambridge University Press, Cambridge.

IPCC, 2007: Africa. Chapter in the working group 2 volume of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva.

IRI, 2006: A GAP analysis of the implementation of the Global Climate Observing System programme in Africa. International Research Institute, Columbia University, New York.

Jasanoff, S.S., 1987: Contested boundaries in policy relevant science, Social studies of Science, 17 195-230

Karakezi, S., 2006: "African Energy Sector: Priority Issues", A Background Paper for the 27 Forum of Energy Ministers in Africa for CSD-14, April 2006.

Kasperson R E and Dow K (2005) (with others). Vulnerable Peoples and Places, Chapter 6 in Ecosystems and Human Well-being: Current State and Trends. Millennium Ecosystem Assessment, on-line at http://www.millenniumassessment.org

Lambin E and Geist H (Ed.s) (2005) Land Use and Land Cover Change: Local Processes, Global Impacts. Springer-Verlag, Berlin, Heidelberg.

Lambin, E. F., H. J. Geist, and E. Lepers. 2003. Dynamics of Land-use and Land-Cover Change in Tropical Regions. Annual Review of Environment and Resources 28:205-241.

Leach M & Mearns R (1996): *The Lie of the Land: challenging received wisdom on the African environment*, the International African Institute, Villiers Publications, London

Leach, M., R. Mearns and I. Scoones, 1997: *Environmental entitlements: a framework for understanding the institutional dynamics of Environmental Change,* IDS Discussion Paper 259, Institute of Development Studies, Sussex UK.

Leemans, R. and R. Costanza, 2005: Integrated history and future of people on earth (IHOPE) IHDP Update 02/2005 www.ihdp.org/updatehistory05/references.

Low, P. S., Ed., 2005: Climate Change and Africa. Cambridge University Press, 369 pp.

Mbow, C., Nielsen, T.T., Rasmussen, K. 2000. Savanna Fires in East-Central Senegal: Distribution Patterns, Resource Management and Perceptions. Human Ecology; 28:4, pp 561-583.

McMichael, A.J., D.H. Campbell-Lendrum, C. F. Corvalan, K.L. Ebi, A. Githeko, J.D. Scheraga, A. Woodward, 2003: *Climate Change and Human Health-Risks and Responses*, World Health Organization, Geneva.

McNeill, J., 2005: Modern Global Environmental History a turbulent and dramatic scenario *IHDP Update* 02/2005 www.ihdp.org/updatehistory05/references.htm.

MEA, 2003: Millennium Ecosystem Assessment, Ecosystems and human well-being. Island Press, Washington, D.C.

MEA, 2005: Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Current State and Trends, Volume I-IV, Island Press, Washington.

Melillo, J. M., C. B. Field, and B. Moldan. 2003. Interactions of the Major Biogeochemical Cycles: Global Change and Human Impacts. Island Press, Washington, D. C., USA. 320 pp

Merrill HM (2006): "Developing power: international equity, economics and electricity", IEEE Power & Energy, volume 4, number 2, March/April 2006 p85.

Miller, C., 2001: Hybrid management: Boundary organisations Science Policy and Environmental Governance in the Climate Regimes, *Science Technology and Human Values Special Issue: Boundary Organisations in Environmental Policy and Science* 26 4 478-500.

Mooney, H., Ed. 2003. Ecosystems and Human Well-Being: A Framework for Assessment. Washington, D. C., Island Press.

Muyale-Manenji, F., 1998: *The Effects of Globalization on Culture in Africa in the Eyes of an African Woman*, ECHOES, World Council of Churches, pp. 1-4, www.wcc-coe.org.

Naiman, R. J., A-H. Pieur-Richard, A. Arthington, D. Dudgeon, M. O. Gessner, Z. Kawabata, D. Knowler, J. O'Keefe, C. Loque, D. Soto, M. Stiassny, C. Sullivan. 2006. Freshwater Biodiversity: Challenges for freshwater biodiversity research. DIVERSITAS Report No. 5. 48 pages

Nicholson, S. E., 1997: An analysis of the ENSO signal in the tropical Atlantic and western Indian oceans. International Journal of Climatology, 17, 345-375.

Nicholson, S. E. and J. P. Grist, 2001: A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales. International Journal of Climatology, 21, 1733-1757.

Niederberger AA (2005): Science for climate change policy-making: applying theory to practice to enhance effectiveness, *Science and Public Policy* 32 1 2-16.

Nielsen T.T., Rasmussen K., Mbow **C.,** Touré A. 2003. The fire regime of Senegal and its determinants. *Danish Journal of Geography*, 103 (1), pp 43-53.

Nilsson, C., C.A. Reidy, M. Dynesius and C. Revenga, 2005: Fragmentation and flow regulation of the world's large river systems. Science 308: 405-408.

North, D.C., 1991: Institutions, institutional change and economic performance, Cambridge Univ. Press, Cambridge.

O'Brien, K., R. Leichenko, U. Kelkar, H. Venema, G. Aandahl, H. Tomkins, A. Javed, S. Bhadwal, S. Barg, L. Nygaard, and J. West, 2004: Mapping vulnerability to multiple stressors: climate change and globilization in India. Global Environmental Change, 14, 303-313.

Obura D.O. (2001) Differential bleaching and mortality of eastern African corals. In: Richmond M.D. and Francis J. (Eds.), *Marine science development in Tanzania and Eastern Africa*. Institute of Marine Science/Western Indian Ocean Marine Science Association, Zanzibar, 301-317.

OECD, 1999. OECD Environmental Data Compendium, Paris, Organization for Economic Cooperation and Development

Ogallo, L. A., 1988: Climatological Aspects of Drought. *UNESCO, IGADD Workshop, Kampala*.

Oomen, B., 2005: *Chiefs in South Africa Law Power and Culture in the Post-Apartheid Era,* James Currey, Oxford.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, G.-K. Plattner, K. B. Rodgers, C. L. Sabine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437, 681-686.

Patz, J.A., 2002: *A human disease indicator for the effects of recent global climate change*, Proc. National Academy of Science. USA, 99, No. 20, 12506-12508.

Pope III, C. A. and D. W. Dockery, 2006: Health Effects of Fine Particulate Air Pollution: Lines that Connect. J. Air & Waste Manage. Assoc., 56, 709-742.

Prentice, I. C., G. D. Farquhar, M. J. R. Fasham, M. L. Goulden, M. Heimann, V. J. Jaramillo, H. S. Kheshgi, C. Le Quere, R. J. Scholes, D. W. R. Wallace, D. Archer, M. R. Ashmore, O. Aumont, D. Baker, M. Battle, M. Bender, L. P. Bopp, P. Bosquet, K. Caldeira, P. Ciais, P. M. Cox, W. Cramer, F. Dentener, I. G. Enting, C. B. Field, P. Friedlingstein, E. A. Holland, R. A. Houghton, J. I. House, A. Ishida, A. K. Jain, I. A. Janssens, F. Joos, T. Kaminski, C. D. Keeling, R. F. Keeling, D. W. Kicklighter, K. E. Khohfeld, W. Knorr, R. Law, T. Lenton, K. Lindsay, E. Maier-Reimer, A. C. Manning, R. J. Matear, A. D. McGuire, J. M. Melillo, R. Meyer, M. Mund, J. C. Orr, S. Piper, K. Plattner, P. J. Rayner, S. Stich, R. Slater, S. Taguchi, P. P. Tans, H. Q. Tian, M. F. Weirig, T. Whorf, and A. Yool, 2001: The Carbon Cycle and Atmospheric Carbon Dioxide. IPCC 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, Eds., Cambridge University Press, 881.

ReNED, 2006. Urban Environmental Management in Developing Countries – Environmental Health, Planning and Capacity Development. Proceedings and Conclusions of the ReNED Conference. Copenhagen, Denmark, 23 August 2006, 28p.

Ropelewski, C. F. and M. S. Halpert, 1987: Global and Regional Scale Precipitation Patterns Associated with the El Niño/ Southern Oscillation. Monthly Weather Review, 115, 1606-1626.

Sachs J.D., J.W. Mcarthur, G. Schmidt-Traub; M. Kruk, C. Bahadur, M. Faye and G. McCord, 2004: Ending Africa's Poverty Trap, *Brookings Papers on Economic Activity* 1 *117-240*.

Southern African Sub Global Assessment (SAfMA) 2005. Ecosystem Services in Southern Africa: A Regional Assessment Edited by R.J. Scholes and R. Biggs. SafMA, Midrand

Sánchez-Rodriguez, R., K. C. Seto, D. Simon, W. D. Solecki, F. Kraas, and G. Laumann, 2005: Science Plan: Urbanization and Global Environmental Change. IHDP Report No. 15, IHDP Secretariat, 61 pp.

Schellnhuber, H. J. and V. Wenzel, Eds. 1998. Earth System Analysis: Integrating Science for Sustainability. Berlin, Springer-Verlag.

Scholes, R.J. and R. Biggs, 2004: A biodiversity intactness index, *Nature*.434, 45-49.

Scholes, R.J., W. Kuper and R. Biggs, 2006a: Chapter 7: Biodiversity, In **Africa** *Environment Outlook 2 – Our Environment, Our Wealth (AEO-2)*, UNEP, Nairobi, 226-261.

Scholes R.J., D. Olago and L. Sigha-Nkamdjou, 2006b: Global Change and the New Partnership for African Development. NEPAD, Pretoria. 73 pp

Scholz, C. A., T. C. Johnson, A. S. Cohen, J. W. King, J. A. Peck, J. T. Overpeck, M. R. Talbot, E. T. Brown, L. Kalindekafe, P. Y. O. Amoako, R. P. Lyons, T. M. Shanahan, I. S. Castañeda, C. W. Heil, S. L. Forman, L. R. McHargue, K. R. Beuning, J. Gomez, and J. M. Pierson, 2007: East African megadrooughts between 135 and 75 thousand years ago and bearing on early-modern human origins. Proc. Nat. Acad. Sci, 104, 16416-16421.

Sebitosi AB & Pillay P (2005): "Energy Services in Sub-Saharan Africa: How conducive is the environment?", Energy Policy Elsevier vol 33/16 pp 2044-2051, November 2005.

Siegenthaler, U., T. F. Stocker, E. Monnin, D. Lüthi, J. Schwander, B. Stauffer, D. Raynaud, J.-M. Barnola, H. Fischer, V. Masson-Delmotte, and J. Jouzel, 2005: Stable Carbon Cycle-Climate Relationship During the Late Pleistocene. Science, 310, 1313-1317.

Sitch, S., Smith, B., Prentice, I. C., and others. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biology 9(2):161-185.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., (2007): IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 996 pp. pp.

Spahni, R., J. Chappellaz, T. F. Stocker, L. Loulergue, G. Hausammann, K. Kawamura, J. Flückiger, J. Schwander, D. Raynaud, V. Masson-Delmotte, and J. Jouzel, 2005: Atmospheric Methane and Nitrous Oxide of the Late Pleistocene from Antarctic Ice Cores. Science, 310, 1317-1321.

Steffen, W., A. Sanderson, P. Tyson, J Jäger, P. Matson, B. Moore III, F. Oldfield, K. Richardson, H-J Schellnhuber, B. L. Turner II and R. Wasson, 2004: Global Change and the Earth System: A Planet Under Pressure. Springer-Verlag, Berlin Heidelberg. 336pp.

Stern N (2007) The Stern Review on the Economics of Climate Change, Cambridge University Press, Cambridge, UK.

Tyson, P., R. Fuchs, C. Fu, L. Lebel, A.P. Mitra, E. Odada, J. Perry, W. Steffen and H. Virji (Eds.), 2002: Global-Regional Linkages in the Earth System. Springer-Verlag, Berlin, Heidelberg. 198pp.

UNDP, 2004: Human Development Report 2004 Cultural Liberty in Today's Diverse World.

UNDP/UNSO, 1997: Aridity zones and dryland populations: an assessment of population levels in the World's drylands, UNSO/UNDP, New York.

UNECA, 2006: "Report on Energy for Sustainable Development in Africa", prepared for CSD`-14.

UNEP, 2003: Action plan of the environment initiative of the New Partnership for Africas' Development (NEPAD), page 43.

UNEP, (2006). *Second Africa Environment Outlook: Our Wealth Our Future.* UNEP, London: Earthscan.

UNEP, 2006a: *Africa Environment Outlook 2: Our Environment, Our Wealth.* UNEP, Nairobi, 542 pp.

UNEP, 2006b: *Marine and Coastal Ecosystems and Human Well-Being. A synthesis based on the findings of the Millenium Ecosystems Assessment.* UNEP, Nairobi, 76 pp.

UNEP, 2006c: Challenges to International Waters – Regional Assessments in a Global Perspective. UNEP/GCSS. IX/INF/9. United Nations Environment Programme, Nairobi, Kenya. ISBN 91-89584-47-3.

Vidal, L. and H. W. Arz, 2004: Oceanic climate variability at millenial time scales: modes of climate connections. Past Climate Variability through Europe and Africa, R. W. Battarbee, F. Gasse, and C. E. Stickley, Eds., Kluwer, 31-40.

Vogel, C., S.C. Moser, R.E. Kasperson, and G.D. Dabelko (2007). Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. Global Environmental Change 17: 349

Von Maltitz, Scholes, R.J. (2006): AIACC working paper no. 24, Vulnerability of Southern African Fauna and Flora to Climate Change.

Walker, B., W. Steffen, J. Canadell and J. Ingram, 1999: The Terrestrial Biosphere and Global Change: Implications for Natural and Managed Ecosystems. Cambridge University Press, Cambridge, UK. 439pp.

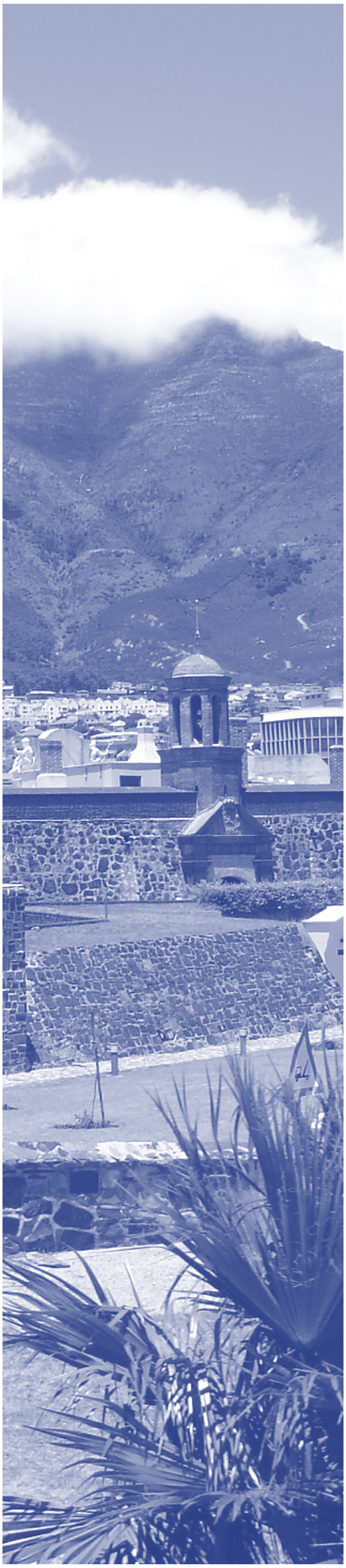
WEC (2005): "Regional Energy Integration in Africa", A report of the World Energy Council, June 2005 (ISBN 0-946121-20-6).

WHO (2006): "Fuel for Life: Household Energy and Health", World Health Organisation, Geneva, Switzerland.

World Bank (2005): "World Development Report", Washington DC, USA.

World Water Forum, 2000: The Africa Water Vision for 2025, Equitable and sustainable use of water for socioeconomic development, WWF The Hague 30 pp.

Young, O. R., A. Agrawal, L. A. King, P. H. Sand, A. Underdal, and M. Wasson, 2005: Science Plan Institutional Dimensions of Global Environmental Change, IHDP Report No. 16, 162 pp.



Annexes

As mentioned in the introduction, this science plan is a merged product of two original science plans. The purpose of the supplemental material in the annexes is twofold; to provide more detail about specific scientific issues and the approaches needed to address them than is included in the body of the science plan, and to make sure that important material from each of the original science plans is reflected here. In particular, the annexes include examples of specific research questions and projects. These are far too many to be pursued simultaneously, and the rationale for prioritising among them is given above.

Annex A Supplementary Material

RAINFALL

The most crucial climate issue for African decision-makers at all levels, from the household to the African Union, is rainfall. Unfortunately it is also the variable associated with the greatest uncertainty in climate projections. For many regions in Africa, there remains disagreement about the direction of future rainfall trends, including both their magnitude and variability. Even at the scale of seasonal rainfall forecasts, which are critical for food and water security in the semi-arid regions of Africa, wide uncertainty persists. Since improved adaptation to inter-seasonal variability in rainfall is thought to be a useful analogue for enhanced capacity to respond to decadal climate change, the need to increase the confidence in the medium-term forecasts is an important and practical objective on the route to longer-term reductions in vulnerability.

Most rainfall in the affected areas of Africa is in the form of high-intensity convective storms. Prediction of such events on a case-by-case basis is inherently difficult, because of their complex dynamics and relatively small scale (individual storm cells are only a few kilometres wide, and last a few hours), but is also an understudied problem relative to the amount of work that has gone into climate processes in temperate regions, simply because of the global distribution of meteorological researchers. The key objective of such research is to provide an accurate statistical picture of the size and intensities of rainfall events. The need is for probabilistic rainfall projections which are more detailed in terms of both their spatial resolution (20 km) and their within-season pattern (for instance, the probabilities of spells of no rain during critical crop periods, and the likelihood of flood-creating rainfall events).

It is well established that the pattern of rainfall in many parts of Africa is correlated with patterns of sea surface temperature. The causal relationships are poorly established, and therefore hard to predict for periods longer than a few months. Dramatic improvements in seasonal rainfall forecasting resulted from the installation of the TOGA moored array in the Pacific. Will similar improvements follow from the Pilot Research moored Array in the Tropical Atlantic (PIRATA), and what would be gained from a moored array in the Tropical Indian Ocean?

There is tantalising evidence that rainfall patterns at a regional scale are also partly linked to land surface conditions, through mechanisms such as the changes in surface albedo that result from reduction in vegetation cover. Rainfall is also influenced, in complex ways, by aerosols that form cloud condensation nuclei, which in the African context are dominated by mineral dust, emissions from biomass burning and organic particles. These mechanisms provide an important link between this project area and the land degradation/biodiversity area: if these feedback and feed-forward mechanisms are significant, they have important consequences for land use policy.

Given the multiple feedbacks that are present, it is unlikely that the coupled land-atmosphere-ocean-human system will change smoothly in response to the global change drivers applied to it. It is more likely to change as a series of shifts in state, each with an associated variability regime. Examination of the historical record from this perspective will be instructive. The Pleistocene variations provide a useful model, well-studied in Africa due to their relevance for human evolution. Abundant proxy records, in the form of lake and coastal sediments, speleothems and tree rings, are available in Africa for this purpose. The ACCESS project aims to make the paleoclimatology of Africa and the Southern Ocean one of its key pillars.

There is thus an urgent need for integrated land surface – ocean temperature – atmospheric circulation – tropical rainfall climatological research in Africa, and Africa offers good conditions for conducting such research. The WCRP/IGBP AMMA campaign (2005-2007) will go some way to addressing these issues in West Africa, but needs to be built on, in terms of coverage (east and southern Africa), content (convective storm processes, land surface feedbacks), implications and African participation.

Another dimension of climate research in Africa is into historical climate – societal interactions and adaptations. We consider it likely that the coupled atmosphere-ocean-land-human system will not exhibit smooth change, but could show more-or-less abrupt and persistent shifts into new states or regimes (including new patterns of variability).

Rainfall measurements, quality assurance and archiving of data, analysis and modelling, evaluation and linkage to hydrological information are inadequate across many parts of the continent. Attention must be given to sustaining and expanding precipitation and hydrological monitoring networks and use of new sources of data (radar, remote sensing) so that a reliable database is created for enabling analysis of hydrology and water resources, and for well-informed resource management decisions. In this regard, sharing rainfall and hydrological information between different national agencies must be promoted. The GCOS strategy for improved climate observation systems in Africa, supported by DFID, is an important initiative in this regard (IRI, 2006).

RAINFALL

	Key Research Questions	Output	Activities
1	What is climate variability and change and what are the mechanisms controlling the variability and change in Africa?	Climate scenarios for vulnerability and impact assessments.	Promotion of research by African scientists through organisation like CLIVAR-VACS, CLIPS, START
2	What are the available tools for climate change modelling?	Climate prediction, early warning and coping mechanisms.	Climate change modelling and scenario development Evaluations and improvements of model simulations for the African region
3	What are the potential impacts of climate variability and change in Africa and what are the coping/adaptation mechanisms?	Understanding of Impacts of climate variability and change in Africa as well as adaptation mechanism.	Links with projects on regional climate outlooks Joint activities with other potential funding partners and make data accessible to the wider climate community; promote development of African climate databases and foster access thereto for research purposes in cooperation with projects such as CLICOM, DARE

RAINFALL (cont)			
	Key Research Questions	**Output**	**Activities**
4	What is the nature of long term high amplitude African monsoonal variability (beyond the Late Quaternary) and tele-connections between the northern and southern African Tropics?	Impact of strong climate change on large African lakes and ecosystems that could have lead to major shifts in past human adaptation strategies	Obtain high resolution long records of at least the last glacial/inter-glacial cycle from large lakes and marginal oceans in and around Africa (Malawi, Bosumyui, Tana, Indian and Atlantic Oceans) Working group on monsoon variability in new PAGES Focus 3
5 6	What are the driving forces and impacts of abrupt and extreme events, such as mega-droughts and palaeo-floods on the environment and human adaptation? What changes occurred in Africa during global to regional-scale abrupt climate anomalies and what was the nature of signal transfer to Africa?	Human-environment interactions and responses to rapid, abrupt and century scale climate changes Better understanding of changes caused by climate anomalies	Obtain very high resolution records of climate and environmental changes from medium and small lake sediment records spanning the last glacial period Obtain similar records for the last 2000 years from the following data archives: lake sediments, documentary, river flows, palaeo-soisl, stalagmites and tree rings
7 8 9 10	How did climate parameters (temperature, precipitation, pressure) change over the last two millennia (including the Little Ice Age and Medieval Warm Period)? What are the characteristics of rainfall and hydrological patterns of the last 1000 years at decadal and annual scale resolution (such as ENSO variability)? What is the response of African climate to hydrographic changes in the Indian and Atlantic Oceans? What was the range of climate extremes in the past and what trends can be deduced for the future?	Better understanding of mechanisms underlying rainfall and hydrological variability and periodicity Extension of the short (ca 100 yrs instrumental records) Better information on decadal scale rainfall and hydrological variability for environmental management and planning	Obtain records from tree rings, stalagmites, corals, documents, river flows Validate the data with historical, documentary and instrumental records Study processes (coupled ocean/ atmosphere/land use/ land cover) affecting the variability Disentangle human impact from climate change Regional synthesis studies on climate variations during the last 2000 years (one or two African research groups and one Mediterranean (including North Africa) MedCLIVAR group, all in new PAGES Focus 2)
11 12	What is the interaction between humans and the bio-physical systems in Africa over the last 10,000 years? What effects did land-cover and other environmental changes by man have on regional and global climate-environment and how reversible are these effects?	An integrated history of socio-ecological interactions to inform us about options for the future Better understanding of the complex reasons for the emergence, resilience, sustainability or collapse of coupled socio-ecological systems	Map the integrated record of biophysical and human system change in Africa over the last 10 thousand years, with higher temporal and spatial resolution in the last 1000 and the last 100 years.

LAND

In Africa, interactions with the land are particularly important because of their impacts on the capacity of the land to sustain livelihoods and biodiversity (including that of disease-bearing organisms). Land properties are central: there are many links between land cover changes and the other research fields outlined in the GECR strategy including those on Health and Natural Hazards. These links operate via, for instance, biogeochemical feedbacks, air quality, hydrology and climate.

Change in land cover and use in Africa typically does not occur as a sudden transformation, but rather as a continuous process of degradation. Degradation is defined here as a persistent decrease in the capacity of the land to deliver ecosystem services; degradation of dry lands is called 'desertification'. This has been a concern in Africa for decades, leading for instance to the UN Convention on Combating Desertification. The lack of progress in solving the issue is partly because the underpinning science has not received sufficient attention: there is little consensus on the causes, consequences or best remedies for degradation in general, and desertification in particular. As a result it is easy for the international community to dismiss desertification as a purely local problem, brought about by resource mismanagement.

The reality is significantly more complex. There are both local and global causes of degradation – for instance, circumstantial evidence links the sharp drop in Sahelian rainfall in the 1970s to changes in the global ocean and atmosphere circulation. There is also a case for regional-scale climate feedbacks involving surface reflectance and dust aerosols. There are regional and global consequences of land degradation, including impacts on the climate system through changes in emissions of greenhouse gases (GHGs) and aerosols and surface albedo, loss of biodiversity, and the displacement of people no longer able to sustain a livelihood in the degraded lands.

Overall, Africa had its fair share of the world's original biodiversity, but it has retained a larger fraction than many other regions (Scholes, et al., 2006a). For this reason, non-Africans travel to Africa for nature-based tourism and lobby for the protection of African forests, wildlife and coastlines. Africans have always had a direct and intimate dependence on natural resources and biodiversity, but the mechanisms which have allowed their past coexistence have broken down under the pressures of the modern era. Loss of biodiversity, at all levels from the gene to the ecosystem, has a direct and negative impact on the well-being of Africans (Scholes and Biggs, 2004). Many natural resources, including fish, firewood, timber, medicinal plants and wild foods, are increasingly scarce.

The causes of accelerating biodiversity loss vary between locations and between the major plant and animal groups. Over-harvesting has been an important historical cause of fisheries, forest and wildlife decline. At present habitat loss, fragmentation and degradation are the key threats. Climate change is projected to be the dominant driver of biodiversity loss by the middle of the 21st century (von Maltitz et al., 2006).

Biodiversity is key to African GECR for three reasons: the biodiversity of Africa at all scales is relatively intact but threatened; African peoples have a close relationship with, and high dependence on biodiversity and the ecosystem services it provides; and biodiversity is a relative strength of African researchers. Biodiversity research in Africa must include, but go far beyond, the study of wild species in protected areas. It must be people-oriented, with a focus on the sustainable use of natural resources and the persistence of viable levels of diversity at the gene, species and ecosystem levels within terrestrial, freshwater or coastal ecosystems, especially those that are inhabited and used by people.

Degradation, biodiversity loss and their effects on human well-being is a key issue on land, in freshwaters, on the coast and in the oceans. On the land, it is not only concentrated in tropical rainforests or biodiversity hotspots, but also in the dry lands and mountain lands. Freshwater biodiversity in Africa, as on other continents, is often the first to be transformed by human activities, through over-fishing, water abstraction, sedimentation, pollution and the invasion of alien species. Marine and estuarine biodiversity, which underpins economically and nutritionally-important fisheries, is a critical concern around the African coast. It is threatened by the direct and indirect effects of fishing, coastal pollution and climate change (particularly with respect to coral bleaching).

The cross-boundary nature of all ecosystems is important, but especially so in the fluid context of marine ecosystems. The approach to marine biodiversity studies has been through the notion of Large Marine Ecosystems (LMEs), aimed at establishing the information and knowledge base required to manage their resources most efficiently. LMEs are defined using criteria such as bathymetry, hydrography, productivity and trophodynamics, and are aimed at distinct socio-economic benefits such as enhanced quality of environmental governance and management. The GECR strategy with respect to marine biodiversity should be to elaborate a 'mega LME' stretching the entire length of sub-Saharan Africa (thus integrating the Guinea Current, Benguela Current and Agulhas and Somali Current LMEs). Three linked international projects to be carried out between Cape Agulhas and the Horn of Africa from 2006 to 2012, funded by the Global Environmental Facility (GEF), are addressing the latter LME.

The land degradation and biodiversity loss activities that GECR strategy could undertake include:

- Improvement of observation systems in line with GEOSS objectives: maps and inventories of endemic and endangered species and ecosystems and determination of the causes and indicators of biodiversity loss.
- Implementation and elaboration of the ESSP Global Land Project in Africa, specifically focussing on the following questions:
  - How do changes in land use and cover impact on local, regional and global climate processes, such as convective storm generation, dust delivery to the oceans and surface albedo?
  - How do land-governance and decision-making processes act to facilitate or frustrate development, alter ecosystem service delivery and affect human environmental security? Here themes on environmental governance and links to gendered themes on land use and management could be explored (e.g. Cousins, 2001; Muyale-Manenji, 1998; see also work by those working at Rutgers University, www.anthro.rutgers.edu; www.msu.edu/~gendervr/core-faculty.htm).
  - How do changes in land use and cover change alter the epidemiology of diseases such as malaria? (e.g. Githeko, 2006).
  - To what extent can local knowledge, institutions and culture better inform our understanding of land cover process and their impacts on people? (e.g. Camaroff, 1997; Cousins, 2001; Oomen, 2005) and what lessons can be shared across tropical developing regions, such as Mexico and Brazil? Linked to such an approach would also be historical environmental change (e.g. Brooks, 2006; Brooks, 2005b). Here expanding GECR networks to those actively working in the social sciences, holds further exciting opportunities.
- Future options for land-use and livelihoods, taking into account the interacting effects of climate change, population growth, urbanisation, globalisation, and neo-liberalisation, amongst other factors (e.g. IDS Bulletin, 2005; www.ids.ac.uk; www.nepad.org; Safma, 2005; MEA, 2005). An important possible linkage is also to the GECAFS project of the ESSP. An integrated model for the Africa region (bringing together economics, environment, technology and demographics) is an important goal. Key themes requiring more research activity include:
  - The institutional dimensions of land use change, both those associated with the State and those framed by local settings, and cultures of governance and economic planning (e.g. Leach, et al., 1997; Oomen, 2005).
  - The importance of detailed, local and regional assessments that provide insights into the interlocking drivers and stresses shaping land use and change and inform changes detected at larger scales of observation.
  - The urban-rural trends that are emerging and what this may mean for competing land-use options.
- Environmental history. Africa has a strong tradition of social history research. Engagement of the humanities has the potential to bring in researchers engaged in African GEC problems, previously outside the GECR community. Environmental history enables the exploration of the spatial and temporal dynamics of land use and land cover change, and their interactions. This perspective has recently highlighted themes of biodiversity conservation, eco-justice, colonial agricultural policy, and landscape heritage. This body of scholarship has begun to contest certain assumptions about environmental change processes, such as the processes underpinning desertification, degradation and deforestation. It will provide a basis for fruitful interaction with environmental history researchers elsewhere (e.g. McNeill, 2005; Leemans and Costanza, 2005)

who are trying to construct analogues of past change that may help us steer our way through future environmental changes.

- Establishing the links between biodiversity, ecosystem function, ecosystem services and human well-being.
- Projections of patterns and trends in ecosystem distribution in the near and long term.
- Development of strategies for conservation and sustainable use of biodiversity-based natural resources in Africa and its surrounding oceans.

Development of sustainable alternative livelihood options that will enable the rural communities to use for their subsistence, thereby reducing the pressure on the existing biodiversity.

Water Resources and Their Governance

Africa is the driest continent, after Australia, but unlike Australia, it supports over 800 million people, many of whom live in dry lands. Water-imposed constraints on human development, including absolute shortage, declining water quality and water-borne diseases are already a reality in Africa, and will intensify in the future. Deteriorating water quality is becoming a dominant factor in determining water availability, in particular for human consumption. Quality and quantity interact, because as the quantity declines, the contaminants become more concentrated.

The volume of stream-flow and its split between reliable base-flow and storm-flow is influenced by changes in the climate and on the land surface, as well as by impoundments and abstraction of water for human use. A large fraction of African people depend on groundwater, which is being used unsustainably virtually everywhere. There is inadequate information regarding the recharge of groundwater, its dependence on rainfall variability and on land use.

The decline of water resource quality is due to land- and sea-based human activities such as the disposal of domestic sewage and industrial waste water, toxic leachates from mining, and the effects of agricultural runoff containing sediments, nutrients and pesticides. The impacts accumulate down the drainage basin, and have serious consequences for the coastal zone, where they are compounded by maritime activities such as bilge pumping and the physical degradation of coastal habitats. These changes have consequences for fresh water availability for domestic, agricultural and industrial use, food and employment security, and loss of human life and property.

Solutions to these multi-faceted problems require a multi-disciplinary approach, combining the physical and social sciences. In particular it needs the greater involvement of social scientists, with experience in policy analysis of problems where environmental, social, institutional, political and economic variables interact.

There is an urgent need for comprehensive assessments of the state of water resources, the significant sources of land-based pollution and the extent of ecosystem degradation in the region. While water resources management rests on global principles, the application must be adapted and adjusted to local conditions, including: the water law and governing institutions, policies of allocations and pricing, the relative importance and nature of the consumer sectors (often this relates to the national and social role of the agricultural sector), environmental issues, international water sources and the harmonisation with neighbouring countries.

The development of interactive databases, forecasting methods and economic planning models appropriate to the task of managing water resources in an efficient and sustainable manner requires the application of new techniques such as geographical information systems and decision support models to gather, assimilate, analyse and display multi-sectored information and to optimise decision-making.

Better management of water resources and water infrastructure depend very much on appropriate governance and institutional arrangements, whether it is a decision to get into contractual arrangements with operators for water and sanitation services or to set a tariff policy or to ensure better water allocation. Wise water management cannot be accomplished by technical or regulatory measures alone, but must encompass education and awareness-raising initiatives. Curricula must be more practical, teachers must be trained to deliver water education and stronger links must be fostered between schools, water companies, city managers, relevant government ministries and non-governmental organisations (NGOs).

Progress towards more sustainable water resource management will require the establishment or strengthening of research and development programmes at the national, sub-regional, regional and international levels. Such programmes must make full use of local expertise and resources and must be appropriate for the needs of the country or countries concerned. Key research issues, which should be considered as an inter-related ensemble, include:

- Protection of water resources, water quality and aquatic ecosystems.
- Assessment of groundwater recharge, pollution and threats (especially climate change) and the determination of sustainable use practices.
- The consequences of rainfall and water resource variability for food security and rural development and the impacts of climate change on this relationship.
- Treatment and safe re-use of domestic and industrial waste waters in urban and rural areas.
- Research into demand management options, including: efficient water use in agriculture, industry and mining, allocation and pricing mechanisms for all sectors.
- Identification of critical areas and opportunities for research into adaptive strategies relating to water and strengthening capacity to do such research.
- Translation of research results on irrigated agriculture and aquaculture into practical and accessible technologies and provision of the support needed for their rapid adoption at the field level.
- Strengthening of sector monitoring and information management at sub-national, national and international levels, through GCOS, WHYCOS and similar strategies.
- Integrated water resources development and management, as a framework for informed decision-making.
- Development and promotion of water harvesting and integrated water and nutrient management techniques for increasing water use efficiency and productivity.
- Improving water management and use at the watershed and community level.

IUGS has stated its willingness to support the development of a large, integrated water-resource related project in Africa, as soon as possible.

Biodiversity

Biodiversity (see text block) underpins the Earth's life-support system. Both natural and managed ecosystems deliver important ecological services such as the production of food and fibre, the capacity to store carbon and to recycle nitrogen, and the ability to mitigate effects of climate and other disturbances. Nevertheless, changes in the structure and function of ecosystems resulting from biodiversity alterations and loss can reduce the availability of vital services and affect the aesthetic, ethical and cultural values of human societies (Naiman, et al., 2006). Of serious concern is that the planet is experiencing unprecedented rates of species extinctions and shifts in ecological processes, the consequences of which could be numerous and far-reaching for human societies. Unfortunately, our ability to predict the outcome of interactions between natural processes and human activities is limited. Better understanding of the consequences of biodiversity change will require an integrative approach drawing on the strengths of both natural and social sciences. Measuring and describing biodiversity associated with genes, species and ecosystems must continue, but must be coupled with efforts that determine how humans can be motivated to conserve and to use biodiversity in sustainable ways. Without question, the most pressing challenge is to establish a scientific foundation for appropriate actions aimed at maintaining an ecologically acceptable level of biological diversity (Naiman, et al., 2006).

Three characteristics of Africa make this region of special need to assess current state and trends of biodiversity:

- Africa is a continent with several hotspots of biodiversity that are highly impacted by the current changes in human activities and practices.
- Many human African societies depend to some extent on natural biodiversity resources for their livelihoods and main income (fuel, food, medicines, etc.)
- Africa is currently experiencing high rates of change in the land and water (freshwater and sea) uses, due to industrial and developmental changes as well as climate change.

In Africa, biodiversity is quite rich with more than 50,000 known plant species, 1,500 species of birds, 4,000 fish species and 1,000 mammal species. However, it is estimated that about 2,000 animal species and 1700 plant species are actually threatened of extinction. Africa hosts 6 of the

Biodiversity

The UN Convention on Biological Diversity defines biological diversity as 'the variability among living organisms from all sources including…terrestrial, marine and aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems.'

world's 25 biodiversity hotspots. This biodiversity is actually threatened mainly by the development of urban centres, the extension of agriculture –which induce the fragmentation, degradation or loss of habitats - and by invasive species (Scholes, et al., 2006a). Moreover, studies indicate that due to climate change, species ranges will shift with potential for an increase in endangered or extinct species.

The importance of biodiversity for local communities (used for different purposes, mainly food, fibre, fuel, medicines) but also for the economy of the countries (basis for tourism or potential use for medicines and other commercial products) is still underestimated mainly because of a lack of knowledge on the existing species but also of their potential use. This sub-theme will offer research linkages to many networks, institutions and initiative in the continent and beyond such as DIVERSITAS, IUCN, WWF, Wetlands International, Convention on Biodiversity.

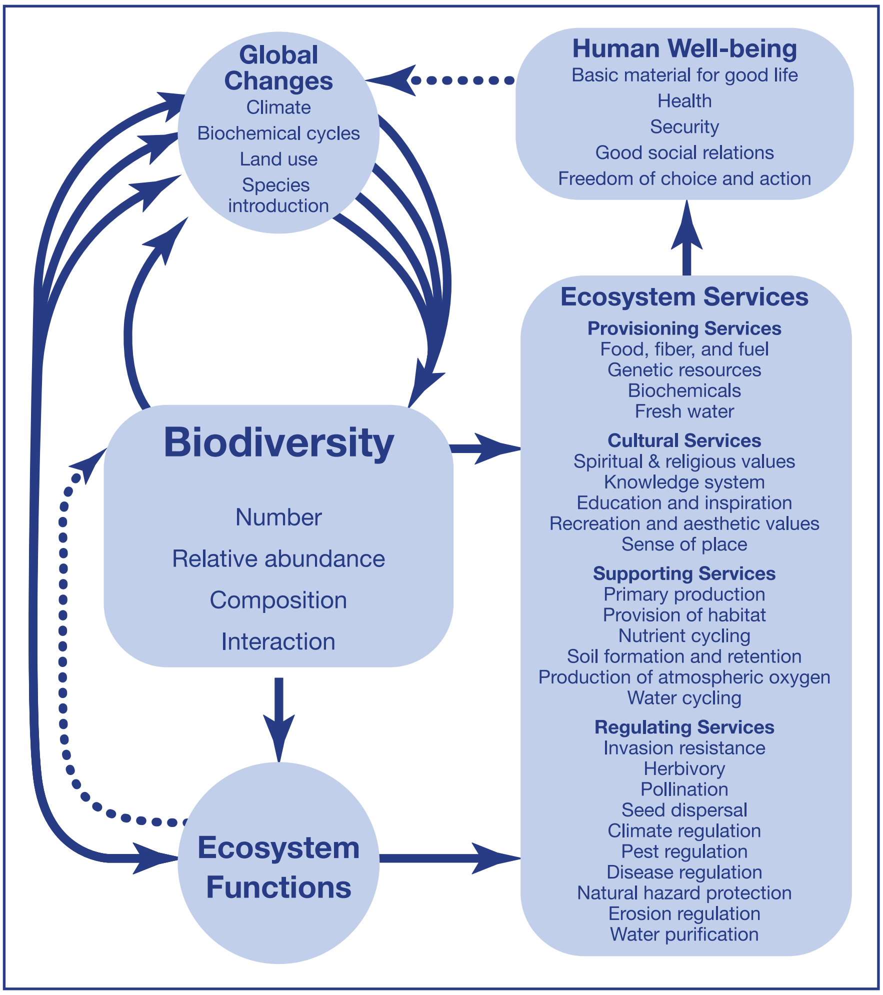
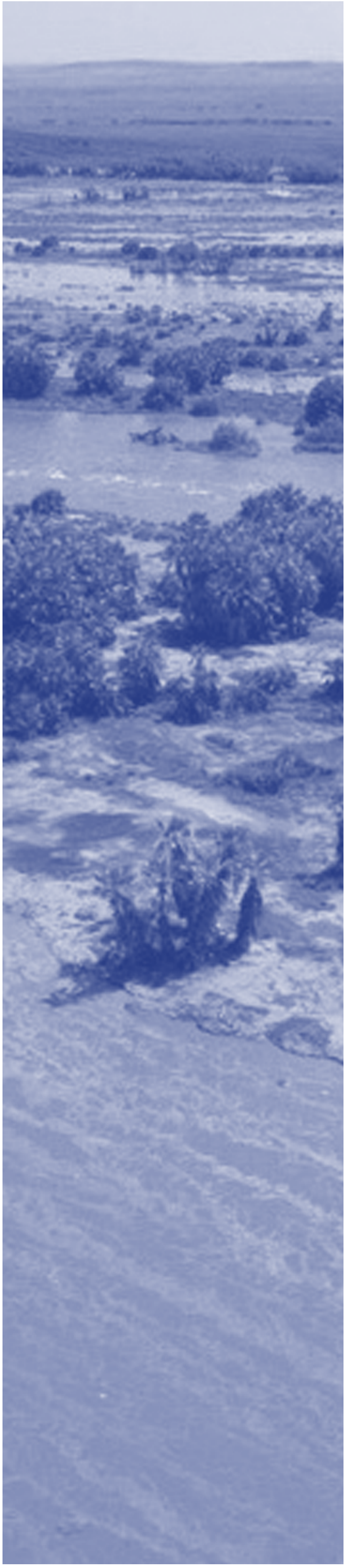


Figure 3. Biodiversity in the context of ecosystems services and human well-being. (Source: MEA, 2005; Biggs, et al, 2004)

LAND - Biodiversity			
	Key Research Questions	**Output**	**Activities**
1	What is the real status of biodiversity in Africa?	Updated lists of endemic and endangered species Status of the biodiversity in different regions, including genetic, population, community	Inventories, especially of endemic and endangered species Inventories of small-size groups (invertebrates, bacteria, etc.)
2	What are the trends/changes in biodiversity?	Identification of changes (if possible quantitative) in biodiversity Determination of key indicators of change in biodiversity Evidence of the main causes of changes in biodiversity	Assessment of changes in biodiversity in appropriate regions/ ecosystems Evaluation of the main drivers of change in biodiversity

LAND - Biodiversity (cont)			
3	What are the links between biodiversity, ecosystems and human communities/livelihoods?	Determination of food web levels, processes and functional services of biodiversity and ecosystems Identification of links between biodiversity and livelihoods or economic activities Identification of critical thresholds in the use of biodiversity resources	Establishment, for selected regions/ecosystems of the main links between biodiversity and local livelihoods Case study evaluation and comparison of key services performed by biodiversity across three or four countries in Africa Determination of the main links between biodiversity/ecosystems and major economic activities (for example between mangroves and fisheries)
4	What are the effects of global change on biodiversity?	Identification of vulnerable species/ecosystems to global change	Assessment of potential impacts of global change (especially climate change) on biodiversity
5	What is the efficiency of current protection/conservation measures?	Measure of the efficiency of existing conservation policies Identification of the main causes of inefficiency of the conservation measures and alternative options Determination of the efficiency of traditional conservation measures /policies Identification of the role of trans-boundary institutions in the management of biodiversity	Review of the current biodiversity conservation policy in Africa Identify successes and failures in protection/conservation measures and their causes Review the traditional ways to conserve biodiversity in Africa Assessment of some experiences in transboundary conservation policies
6	What adaptation measures could enhance the conservation and sustainable use of biodiversity?	Identification of a biodiversity assessment and monitoring framework for a better management of biodiversity Key conservation measures identified to face current and future global change impacts on biodiversity	Development of a biodiversity assessment and monitoring framework to facilitate the sustainable management of key biodiversity resources in Africa Evaluation of alternative measures for the conservation of biodiversity
7	How can capacity to integrate biodiversity conservation and studies be identified, developed and retained in Africa	Database of African biodiversity scientists and human resource capacity	Development of a database of African biodiversity scientists, organisations and institutes and their expertise. Development of a database on human resource capacity, as well as the review of current biodiversity policy, and identification of areas (both geographic and subject-specific) where capacity enhancement is most urgently required.



Wetlands Resources

Globally, aquatic systems are rich and diversified sanctuaries for biodiversity, providing habitat for plants and animals species in the watershed, helping to absorb and slow floodwaters when rivers overflow - this ability to control floods can alleviate property damage and loss and can even save lives. Aquatic systems also absorb excess nutrients, sediments, and other pollutants. The value of aquatic systems has been more understood in recent decades and the need for proper management approaches has been widely acknowledged. Efforts supported by initiatives such as GIWA, GWP and World Water Forum, have resulted in a rapid increase in the knowledge of the management of aquatic systems, whereby all relevant aspects are approached in an integrated manner. Good and workable approaches in integrated river basin management or integrated water resource management have become available, while successful and sustainable management of critical aquatic systems is being achieved in many countries and regions.

Close to 50% of wetland ecosystems have already been lost in the developing world (OECD, 1999) and African freshwater bodies are more degraded than terrestrial and marine habitats (UNEP, 2006). The link between wetland ecosystem functions and values, development and poverty alleviation is a challenge that has not been met in the efforts towards alleviating poverty. Africa's many aquatic systems display the characteristics of richness in diversity with regards to both the number of species present, as well as the localised endemism of species. The aquatic systems in the high rainfall, hot and humid climatic zones like the Congo Basin, contain richer species diversity than in the drier zones like in northern Africa. Africa is subject to frequent droughts and floods, whose intensity and impact are aggravated by environmental degradation (upstream deforestation, soil erosion) and ill-conceived infrastructure development. The impacts are greatest for the poor who reside on marginal lands and rely on rain-fed and floodplain agriculture, especially in the Sahel as is the case with the Inner Niger Delta in Mali, the Lake Chad Basin, the dry zones of northern Africa and southern Africa. Aquatic systems in Africa experience enormous pressure from human activities and global change leading to their degradation and loss. These pressures come from activities that include drainage for agriculture and settlement, unsustainable exploitation, industrial effluent and agricultural chemicals that alter water quality, introduction of alien species, such as the Nile Perch Lates niloticus and the Water Hyacinth Eichhornia crassipes, that threaten ecosystem function.

Rising industrial and urban pollution, the spread of invasive species, salinisation of soils and saltwater intrusion are factors that are all leading to a decrease in both the quality and quantity of ground and surface waters available to African people, especially in rural areas. African groundwater resources are currently being overexploited with drastic falls in the water tables from 0.5-5.0 meters/year in some areas. About 45-50% of the rural population in Africa lack access to quality water and to sanitation (World Water Forum, 2000).

LAND - Wetlands Resources			
	Key Research Questions	**Output**	**Activities**
1	What is the intensity and frequency of climatic and human forcing and what is their predict-ability?	Formulation and implementation of innovative projects to make the best use of aquatic systems for economic and social long term development	Develop a network of studies on multiple stress impacts among aquatic ecosystems.
2	How can local, regional and global changes be assessed in Africa in order to characterize their implications and feedbacks to local aquatic processes and functionality from an ecosystems perspective?	Characterization of local, regional and global changes in relation to local ecosystems functionality	Develop coordinated research strategies to facilitate the further development of integrated tools to deal with non-linear dynamics associated with extreme events experienced at different scales of time and space.
3	How does global change and adaptation to global change affect human impact on aquatic environments in Africa?	Pollution control at basin scale with the involvement of cities and industries	Promote integrated research efforts to assess ecosystem-scale effects of nutrients and sediments as well as toxic organic and inorganic compounds on aquatic produc-tivity, species composition, and decomposition.
4	How do impacted aquatic systems respond to removal of stressors of global change?	Protection and restoration of watersheds, including the hydro-logical regime of watercourses, soils and forests	Modelling to assess the overall net effect of multiple stressors on aquatic ecosystem functioning and resilience.
5	How does global change affect the spread of invasive species and what is the effect on ecosystem function?	Prevention, control and/or eradica-tion of invasive species	Comprehensive assessment of invasive species and their spread in Africa following the GISP method-ology
6	How can trans-boundary hot spots be identified where the risk of conflict exacerbated by global change is exceeded by the capacity of the natural, and/or social system to accommodate or adapt?	Development and implementation of trans-boundary joint initia-tives that enhance desertification control and mitigate the negative effects of droughts and global change	Comprehensive assessment and modelling to identify transboundary hot-spots

Land Use and Land Cover Change

Human transformations of ecosystems and landscapes are the largest source of change on Earth, affecting the ability of the biosphere to sustain life (Steffen et al., 2004). Intensification and diversification of land use and advances in technology have led to rapid changes in biogeochemical cycles, hydrologic processes, and landscape dynamics (Melillo, et al., 2003). Changes in land use and management affect the states, properties, and functions of ecosystems. In turn, these consequences affect human well-being and land use. The UN Convention to Combat Desertification (UNCCD) defined desertification as land degradation in arid, semi-arid and dry sub-humid environments caused by various factors including climate factors and human activities. The scientific input into the convention was limited and the Committee on Science and Technology (CST), and its Group of Experts, have not been able to make the scientific input that would be required to address desertification on the ground. In contrast, policy and advocacy institutions, using the literature on deforestation, and particularly its impact on climate and the results of long-term observation and research, have resulted in interventions being applied (both appropriately and inappropriately) in many places around the globe. Great attention has been paid to establishing communication systems; networks or other approaches to support flow of research results and information, in terms of desertification and land degradation. At the same time little if anything has improved amongst communities faced with decreasing productivity of degraded lands.

Global environmental changes are expected to affect the coupled human-environment system differently in different parts of the continent. Biophysical alterations, such as increased atmospheric carbon dioxide concentrations or enhanced erosion of soils, and social forces, such as globalization of markets, generate different responses as seen land use options and land cover changes. These, in turn, influence local land use decisions and the provision of ecosystem services. The resulting change to the environment can either promote or reduce the rate of environmental change. Links between decision-making, ecosystem services, and global environmental change define important pathways of feedback from coupled human-environment activities at the local and regional scale to and from global scales (GLP, 2004). The scientific community, in Africa and throughout the globe, has been conducting research concerning desertification control and rehabilitation, land degradation and deforestation for many decades, and in the case of deforestation, several centuries. Desertification, with the more recent inclusion of rehabilitation of degraded lands, has remained on the research agenda as a contentious issue (does it or doesn't it happen? is it caused by climate change or by human activity? is it an evitable accompaniment of development in drylands? is poverty the key driver?).

The changes in states and functioning of ecosystems and related human activities are best captured at local, national and regional scales. The theme therefore focusses its research agenda on these scales emphasizes the study of changes in the coupled human-environmental system at local to regional scales, because changes in the states and functioning of ecosystems and related human activity tend to be captured at these scales. Understanding changes in the coupled human-environmental system is enhanced when directed to the level of ecosystems and their synergy with human agents and societal structures, including the human consequences of biophysical changes. This research strategy provides a framework to better study the vulnerability and sustainability of the "coupled-system" in different parts of Africa in relation to other parts of the world.

The goal of AfricanNESS land use sub-theme, like that of the Global Land Project (GLP) (GLP, 2004) is to measure, model, and understand the coupled human-environmental system ("land system") as part of broader efforts to address GEC in relation to changes in Earth processes and subsequent human consequences and their adaptability in Africa. The sub-theme also aims to increase the understanding of the relationship between global change land use and land management in Africa by examining the drivers of desertification, land degradation and deforestation. This initiative has close links with research efforts within the individual International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme (IHDP) core projects, especially the Global Change and Terrestrial Ecosystem (GCTE) and Land Use-Cover Change (LUCC) projects, along with other projects sponsored by the Earth System Science Partnership (ESSP), including DIVERSITAS and the recent Global Land Project (GLP) from which this science plan borrows greatly (GLP 2004). The sub-theme also relates to the Global Change and Mountain Regions (GLOCHAMORE) initiative in response of the need to understand the causes and impacts of global change in mountain regions (GLOCHAMORE, 2005).

LAND - Land Use and Land Cover Change			
	Key Research Questions	**Output**	**Activities**
1	How does GEC affect regional and local land use decisions and practices in Africa?	Understanding of how globalisation impacts Africa and how policy direction can assist adaptation	Detailed case studies to understand both the forces driving market integration (exogenous factors) and endogenous response to other external factors and processes by which drivers of change from multiple scales interact
2	How does population change affect regional and local land use decisions and practices in Africa?	Greater understanding of the links between population and land use	Comparative studies of migration processes, with attention to the broad-scale changes in biogeochemical cycles and ecosystems affected
3	How do changes in land management decisions and practices affect biogeochemistry, biodiversity, biophysical properties, and disturbance regimes of terrestrial ecosystems in Africa?	A decision support mechanism that would assist create an enabling framework for wise policy interventions	Develop comparative studies of the land use effects on ecosystem dynamics across gradients of land use intensities and study ecosystem changes associated with different land use conversions
4	How do the atmospheric, biogeochemical and biophysical dimensions of global change affect ecosystem structure and function?	Improved knowledge and understanding of interaction between land and air	Develop models to evaluate ecosystem responses to multiple stressors, such as climate change, CO_2 increases, nitrogen-additions, ozone, and UV radiation Characterise the effect of interacting climate and atmospheric composition changes on vulnerable ecosystems
5	How do changes in ecosystem structure and functioning in Africa affect ecosystem services and the delivery of human well-being?	A monitoring and evaluation strategy in place, based on indicators relevant to Africa	Development of a robust conceptual framework and methodologies to assess changes in the delivery of ecosystem services
6	How do humans adapt to changes in ecosystem service provision in Africa?	Adaptation strategies (toolbox) available to African governments	Develop new institutions, mechanisms and procedures to mediate and resolve conflicts over the use and management of ecosystem services among stakeholders under GEC
7	How do the vulnerability and resilience of land systems in Africa vary due to changes in human and environment interactions?	A better appreciation of the sub-regional approaches and responses by local communities to change	Detailed case studies to address the vulnerability and resilience of the coupled land system, as well as comparative assessment of extant research
8	How do African decision makers see the results of research on desertification, land degradation and deforestation being applied and at what level?	Improved systems of informing decision makers on key issues on global change	Using social-science methodologies, ascertain perceptions and understanding of desertification, land degradation and deforestation by African decision makers

LIVELIHOODS

Resilience of Food Systems

Reducing the vulnerability of Africa to global change requires building the resilience of Africa's social and ecological systems, particularly through achieving food security in the region. Food security is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active healthy life (FAO, 1996). Food security includes both issues of *food and agricultural production* (e.g. crops, soil quality and food derived from oceans, lakes and rivers) as well as *issues of food access.*

Policy interventions to improve food security in the region, such as the MDGs, need to take global environmental change into account. Africa's food insecurity arises from a combination of factors such as poor governance, weak science-policy links, inadequate agricultural infrastructure, a rapidly growing, young population, widespread poverty, war and conflicts, poor governance, land degradation, and a heavy disease burden. Unfavourable soils and climate also contribute significantly in some instances.

Emerging from the substantial research on food security are a number of 'larger', 'over-arching' themes that could be addressed (e.g. see GECAFS, 2005). For example:

- How does Global Environmental Change exacerbate food insecurity in Africa?
- What technical and policy options can adapt food systems in Africa to cope with Global Environmental Change? (e.g. what is the role, if any, of a possible 'Green Revolution' for food security in Africa? What are the design and technological implications of a 'Green Revolution' for Africa?)
- What are the trade-offs for African agriculture with regards to land put under agriculture for 'energy' (e.g. biofuels) versus land for food production?
- How will the various adaptation options feed back on existing environmental and socio-economic conditions? Here adaptations refer to both the large-scale, global adaptations that may be needed to ensure sustainable food security for Africa (e.g. detailed investigation of trade regimes), as well as more local-scale adaptation options that are currently being practised but that may be insufficient given future environmental changes.
- What is the potential of crop and cropping systems diversification options in reducing the risks associated with GEC and in increasing the communities' adaptive capacity?

Some of these questions are currently being explored by GECAFS for southern Africa (GECAFS, 2006). It is important to extend the investigations to other regions in Africa. Integrated research needs to be carried out at three levels. First, at the household and community levels, where vulnerability is usually more clearly expressed. Second, at the sub-regional level, so that the interaction of policy and food systems' vulnerability can be addressed and finally, at the continental level, to understand how findings can be scaled up and outwards for policy and wider use. Greater engagements with the large research, implementation and policy community actively working on agriculture, fisheries and food systems will enhance the GECR agenda.

Sustainable Livelihoods

A livelihood consists of the assets (natural, physical, human, financial, social, political), activities, and the access to these (mediated by institutions, organisations and social relations) that are required for a means of living. Sustainable livelihood comprises the capabilities, assets including material and social resources and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or combine its asset and capabilities whilst not undermining the natural resources loss (Chambers and Conway, 1992). Sustainable livelihood deals with improving and sustaining the quality of life of the vast majority of the population. Ensuring and improving quality of life calls for reforms in the governance system, involving all the key stakeholders in the development process, as well as ensuring equitable redistribution of a nation's wealth through the politics and policies of inclusion, social justice and rule of law. It requires a system of making states to avoid state failure and the crisis of governance. With the limited continent-wide knowledge on how GEC will impact on livelihoods, there is need to intensify analysis for understanding of the livelihood and food security impacts of GEC.

This section is intended to examine at least four key areas, namely: (a) investing in sustainable livelihoods: it is expected that this will increase the sustainable use of the ecosystem and reduce the vulnerability of the people to disasters and the crunches of underdevelopment. People's livelihoods are as important as physical defences; (b) Plugging the leaks: Ensure how

LIVELIHOODS - Sustainable Livelihoods			
	Key Research Questions	**Output**	**Activities**
1	What are the current and projected future levels of livelihood and livelihood assets? How does poverty and nonownership of assets make African communities more vulnerable to effects of GEC?	Baseline of states and trends in key livelihood asset bases in the continent Understanding of how poverty relates with vulnerability to effects of GEC on sustainable livelihoods	Ecosystems, local, national and regional assessments of capital base for livelihood sustainability Vulnerability assessment according to asset base and livelihood outcomes
2	What are the past, present and projected spatial and temporal variations of livelihood assets and outcomes as presented to Africa's societies? (What are the local and regional influences of climate change and variations on long-term changes of the quality and quantity of livelihood outcomes)?	Trends and spatial distributions of asset levels and livelihood strategies	Investment in sustainable livelihoods for sustainable use of the ecosystems and reduced vulnerability of the people and environment to disasters and the crunches of underdevelopment
3	How resilient and adaptable is Africa to the effects of the identified global environmental changes on sustainable livelihood strategies?	Indicators and levels of resilience and adaptation of livelihood strategies and communities to impacts of GEC	Explaining the impacts of global environmental change and climate change on Africa's nations and communities Development of resilience and adaptability indictors for different livelihood strategies
4	Which are the key livelihood strategies and diversification? How will these evolve in the future and what will the GEC impact on overall livelihoods be?	Sustainable livelihood strategies and their tradeoffs with ecosystems and GEC adaptation goals Plausible futures (scenarios) of GEC impact on livelihoods	Characterisation of Africa livelihood strategies, livelihood diversification and future effect of GEC Modelling of dynamics and variations in current and future GEC impacts
5	How does governance and macro-economic performance of countries relate to the severity of impact of GEC on livelihoods?	Institutional and capacity issues for sustainable livelihoods and their outcomes in Africa Governance and economic opportunities for sustainable livelihoods The role of civil society, NGOs and cultural organisations in the dynamics of livelihood and preservation of the ecosystem Vulnerability and adaptive capacities of different livelihood forms and communities to GEC	Enhancing the process of development within countries and the local communities for longer-term economic recovery and development and wealth creation Examining the role of diversified local and national economies to maximise employment and stimulate the economic, social and environmental priorities to all sectors of the economy
6	Which are the vulnerable areas/ countries and vulnerable groups in African society?	Vulnerability maps for livelihood strategies and groups	Targeted and interlinked macro, meso and micro-scale assessments of livelihood vulnerabilities to GEC

to re-circulate the process of development within the local community, rather than leaking out of it, and how such a process will help boost longer-term economic recovery and development; (c) Diversified local and national economies. This should maximise employment stimulate the economic, social and environmental priorities to all sectors of the economy; and (d) Impacts of globalisation and climate change, are draining the resources of poorer nation to deal with their developmental problems.

Food Systems

Food systems consist of activities related to the production, processing, distribution, preparation and consumption of food, as well as the outcomes of these activities contributing to food security (Figure 4). Global environmental change affects all components of the food system. For instance, droughts, land degradation and declining soil fertility affect food production, while destruction of infrastructure by extreme climatic events such as floods and tornadoes also disrupts the distribution process. The spread of disease vectors as a result of global environmental change and the move towards an export economy also affects consumption. Food insecurity is the ultimate manifestation of a crisis in the food system. Food security is achieved when all people, at all times have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active healthy life (FAO, 1996). Africa is currently characterized by pervasive food insecurity and sub-Saharan Africa particularly has the highest percentage of undernourished – 40% of the total population. Consequently, policy interventions that are required to improve the food system and ultimately food security in Africa should take account global environmental change issues.

Several anthropogenic and natural factors linked to GEC are rapidly eroding the capacity of the African ecosystems to support food production and provide food security to the population. The main factors affecting food security include political instability, poor governance, droughts, population growth, urbanisation, poverty, low economic growth, inadequate agricultural policies, trade terms and regimes, resource degradation and recently HIV/AIDS. Although different drivers shape the state of food systems in different countries, there is need to crystallize scientists, decision makers and producers understanding of GEC issues presenting challenges to food security which constrains ability to consider long term issues in food systems in the continent. A key challenge is the formulation of prudent policies that are informed by solid and scientific understanding of the links between GEC and food provision. Some of the research questions posed under this theme are reflections of those being addressed by the Global Environmental Change and Food Systems (GECAFS) initiative (GECAFS, 2006). The goal of this sub-theme is to foster greater understanding of the vulnerability of food systems to GEC and the adaptive measures that can reduce this vulnerability and increase the resilience of the food systems. It also seeks to assess the long-term social and environmental consequences of adaptation measures adopted to enhance food security in the continent.

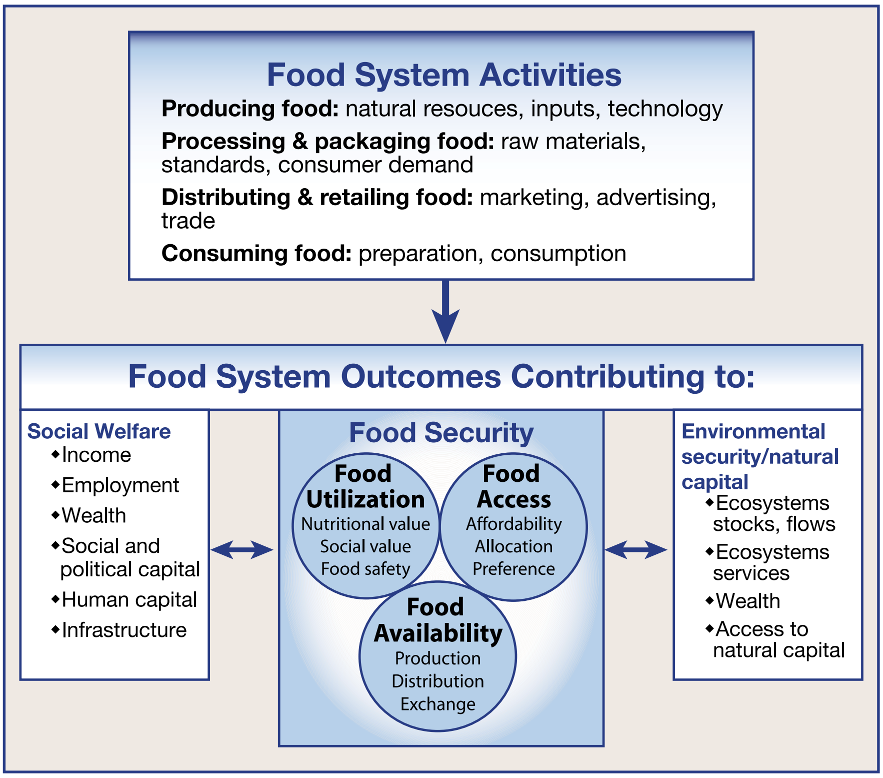


Figure 4. The main features of food systems (Adapted from GECAFS, 2006)

LIVELIHOODS - Food Systems			
1	What are the characteristics of Africa's food systems and how are they likely to evolve in the future?	Comprehensive understanding of Africa's food systems and their future evolution	Assessments of Africa's food systems
2	What methods are appropriate for understanding environmental and socio-economic tradeoffs in Africa's food systems?	Frameworks and methods for the analysis of environmental and socioeconomic tradeoffs in food systems	Conceptualization and development of food systems dynamics frameworks and methodologies for understanding the link between food systems evolution and GEC
3	What changes are anticipated in human wealth and food preferences and how will they interact with biophysical aspects of GEC impacts on food provision? How does the changing face of Africa food systems (scale and components) relate with GEC and vulnerability?	Scenarios and projections of changes in food preferences and consumption patterns and understanding how this will affect adaptations to GEC	Scenarios of future evolution of drivers of food system outcomes in Africa Analyses of changing human wealth and food preferences and interactions with biophysical models of GEC to produce new insights of sub-regions, nations and communities where food provision may be sensitive to GEC
4	How might societies and producers adapt their food systems to cope with GEC in Africa and what are the possible environmental and socio-economic consequences of the adaptations? How will various adaptation options feedback on environmental and socioeconomic conditions?	Food systems adaptability capacity levels and needs	Food systems adaptability capacity needs assessment
5	What biophysical and socio-economic indicators of vulnerability can be developed for assessing adaptations to GEC impacts on food systems?	Socio-economic and biophysical indications of adaptation of food systems to GEC	Methods to allow the appropriate level of aggregation of small-scale food production systems and disaggregation of global-scale scenarios and datasets to address regional and sub-regional issues
6	How will global environmental change affect the vulnerability of food systems in different parts of Africa?	Understanding of the link between GEC and vulnerability of food systems in Africa	Vulnerability assessment of future GEC: identification and mapping of the vulnerable areas, groups and products (crops and animals)
7	How might the projected climate change stresses further affect the food systems of Africa; what and where will be most vulnerable to these changes?	Possible impacts of GEC on food provision and vulnerability in Africa, including determinants of food provision in GEC context, food production, food distribution, trade and food aid, livelihoods and food security, and other aspects relevant to food production	Modelling of shifts in production belts / comparative advantages of major food systems (crops, livestock or aquaculture)

LIVELIHOODS - Food Systems (cont)			
8	What are the other key determinants of short and long-term food security that need to be addressed simultaneously with GEC?	Scenarios and models of future elements of Africa's food systems and their adaptations to GEC	Comprehensive review and assessment of non-GEC factors imposing restrictions of production and provisioning capacity of Africa's food systems
9	What measures can be put in place to minimise impacts of GEC and or take advantage of positive trends that may arise from these changes?	Policy priorities that enhance food systems competitiveness while limiting further environmental degradation; encourage food systems which enhance the social security of more vulnerable sectors and is gender sensitive; and create rural employment opportunities thereby reducing intra-continental and regional labour imbalances	Facilitating policy formulation, interpretation, implementation and monitoring in order to sustain competitive food systems that enhance the social security of more vulnerable sectors and is gender sensitive Integrating long-term GEC concerns and impacts in the short-term struggle to improve food production, distribution and provision Establishing an inventory of traditional knowledge on past GEC and vulnerabilities experienced at that time Inventory of traditional knowledge and (global) environmental change
10	How does GEC exacerbate food insecurity in Africa? What technical and policy options can adapt food systems in Africa to cope with GEC?	Food security and GEC early warning systems Understanding of impacts of GEC on food security in Africa	Developing combined socio-economic-biophysical indices of vulnerability Detailed assessment of GEC on the major food products of the region Detailed assessment of expected GEC impacts on the transport and food distribution infrastructure Identification of the areas with enhanced and reduced food production potential resulting from GEC

COASTAL CITIES

The human population has increased dramatically in the last century. For example, in 1900 only 15% of humanity lived in cities. Today 50% of the 6 billion human populations live in cities. Unfortunately, in the developing countries 70% of the city dwellers live in slums (Corvalan, et. al., 2005). The global environmental change evidence indicates that water scarcity will increase, food production may decline in some areas, frequency of disasters caused by drought and floods may rise and some vector borne diseases may be more prevalent in formerly colder areas in which no human immunity to such diseases have been built. The Intergovernmental Panel on Climate Change (IPCC) gives scenarios in which the global climate may change by 1.5 C to 4.5 C by the year 2100. The global heating will result in experiences of heat waves that will be exacerbated in urban areas. The increased emission of atmospheric particulates from vehicles, wind erosion dusts and other industrial activities will at some instances combine with island urban heat waves that may cause deaths. The collapse of social networks and adaptation strategies will enhance the morbidity and mortality from such events (Patz, 2002).

The IPCC scenarios also predict a sea level rise of about 1 m due to melting of icecaps. In addition, ocean thermal warming may make the effect of sea level rise much more pronounced. Most populations are living in the coastal areas. Intense and frequent storms and coastal floods will disrupt drinking water sources, displace people and destroy installed infrastructures. The predicted occurrences may make life in the coastal zones intolerable. It is not only floods and storms that will disrupt life, but drought may affect many inland areas, causing food shortages, famine and livestock deaths.

DISEASES AND PESTS

New and old infectious diseases may be accentuated by global environmental change. Africa is rapidly undergoing increasing urbanization and movement from rural to urban life-style is also increasing. Adaptation of the rural life to the city life will lag behind rapid changes taking place. This trend is also strongly affected by climate change, which alters living conditions. The issue of climate change is also linked with regional air pollution which damages the health of hundreds of millions of people in Africa. Migration from the country side to mega cities increases emissions and exposure to particulates and other harmful compounds. Hence, it is important to investigate the following and their effect on human health:

DISEASES AND PESTS			
	Key Research Questions	**Output**	**Activities**
1	How does climate change affect human diseases in Africa?	Estimate of changes in morbidity and mortality in Africa	Survey of human diseases in Africa and the association of climate change impacts to human morbidity and mortality
2	How does climate change affect wild life diseases in Africa?	Estimate on effect of climate change on wild life diseases	Survey of the amount of disease present in wild life populations
3	How does the changing climate affect spatial disease pattern in Africa?	Links between disease outbreaks and changes in biodiversity	Assessment of biodiversity changes and tracing links to disease outbreaks
4	How does climate change affect plant diseases?	Scenarios on future plant disease pattern in Africa	Investigation of linkages between plant diseases and climate change/ variability
5	Is it possible to forecast outbreaks of diseases linked to climate?	Understanding and documentation of the evolutionary consequences of GEC on hosts and pathogens	Assessments and simulations of temporal consequences of GEC on hosts and pathogens characteristics
6	How does climate change affect pathogens' genetic structures?	Information on possible changes in pathogens'	Investigations of genetic changes of pathogens triggered by climate change/variability

DISEASES AND PESTS (cont)			
7	Are the climate affected diseases interacting with other diseases like HIV?	Epidemiological data related to correlations between different diseases	linkage between HIV and climate change affected diseases
8	How does land use changes affect well- being in Africa?	Understanding of land use structure change effects to health and well-being	Investigations of land use/land cover changes and its impact on urban living environment given the high wind erosion, fast urban migration and changes in cultural coping mechanisms during heat stress
9	How does air pollution affect human health and how it is linked to climate change?	Climate change scenarios combined with climate models, air quality models and human exposure models	Investigations of air pollution loadings, their sources and effects on health
10	How do economic changes due to climate change affect human well-being?	Scenarios on changes in macro-economics	Investigations of how changing economic environment resulting from global change affect well-being
11	How might climate change-reduced nutrition sources be replaced?	Regional adaptation plan for the agriculture	Investigations of alternative nutritional sources that would form replacements or supplements to decreased food production resulting from climate change and variability

AFRICA AND THE EARTH SYSTEM

Atmospheric Pollution

Observations and models show that the tropospheric concentrations of most reactive chemical species are increasing in time and space over all of Africa. A series of research programmes (SAFARI 92, EXPRESSO, DECAFE, SAFARI 2000) have greatly advanced our understanding of this phenomenon. The potential for elevated concentrations of ozone is particularly high in many areas of Africa because of the combination of solar radiation and high emission of precursors, such as nitrogen oxides and volatile organic compounds, from both human and natural sources. Studies in Africa have shown that current day ambient air pollution concentrations are capable of inflicting significant damage to human health, crops, local vegetation and other materials. Severe visibility reduction, increased respiratory diseases and chest congestion complaints are widely reported. Nitrogen compounds, ozone and particulate matter are the main hazards regionally, with sulfur compounds becoming important in locations of smelting, power generation, high vehicle density and oil refineries.

Africa's Oceanographic Uniqueness

Equator-to-pole transfer of energy, in the form of the global oceanic thermohaline circulation, is the 'slow engine' of the global climate system and ultimately determines the regional distribution of terrestrial and marine air temperature and precipitation. Our understanding of its complex three-dimensional dynamics and the impact of its variability on the global and regional climate systems remain rudimentary. The oceanic region south of Africa is a critical crossroad for the inter-ocean communication for heat and freshwater, where exchange of water, salt, heat, biota and anthropogenic tracers occurs between the subtropical Indian and South Atlantic gyres.

A key question is the exact nature of exchange played by surface and intermediate water masses between the Indian and Atlantic oceans. In order to understand the nature and influence global climate change has on sub-Saharan Africa, one area that needs to be addressed is the quantification, physical understanding and long-term monitoring of the equatorward transfer of heat and salt into the South Atlantic from the Indian Ocean via the Agulhas Current System. Key aims include gaining a better understanding of Indo-Atlantic inter-ocean exchanges and their impact on the global thermohaline circulation and thus on global climate; the impact these exchanges have on the regional climate variability of the southern African subcontinent; studying air-sea-land exchanges and their role in the global heat and freshwater budget and examination of the role of the Indo-Atlantic connection on elevated biological activity and regional biodiversity, and as bio-geographic barriers to the distribution of plankton.

Understanding (and eventually predicting) changes in both the atmosphere and oceans around sub-Saharan Africa are needed to guide international actions, to optimise governments' policies and to shape industrial strategies. To achieve better predictions we need improved coupling of land-sea-atmospheric processes in models. Model studies have already highlighted the impact natural climate phenomena such as Benguela Ninos, Semi-annual oscillation, Atlantic and Indian SST dipoles, Angola-Benguela Frontal Zone have on climate and rainfall variability over southern Africa. The ICSU ROA strategy for oceans should be to build on this foundation through a network of sustainable oceanographic observations incorporating land-sea-atmospheric processes. Global systems of observations, modelling and analysis of marine and ocean variables (e.g. GOOS and ARGO) are already in place, but need to be rolled out and accessed throughout the region.

Sustained observations coupling atmosphere, oceans and land processes around sub-Saharan Africa will provide the only means to monitor the variability within this region. Direct linkages with current LME studies (outlined in 5.1) in operation along the sub-Saharan African coastline will lead to a better understanding of how the background circulation influences the nature of coastal habitats, their biodiversity and productivity. The ultimate aims of an LME study are to reduce coastal pollution, to restore damaged habitats and to recover depleted fish stocks, develop an ecosystem approach to global assessment and management of coastal waters as well as a better understanding of the background circulation. A coordinated regional framework is needed for sub-Saharan Africa to facilitate the securing and sharing of knowledge, data and information for the marine environment and its influence on global change, climate variability and ecosystem management.

Linkages to Other Palaeoscience Initiatives

AfricaNESS palaeoscience activities can be conducted in close collaboration with the PAGES (Past Global Changes) project of the IGBP (International Geosphere-Biosphere

Program), which has the mission to support research aimed at understanding the Earth's past environments in order to make predictions for the future. The African continent is and has been an area of scientific activity of PAGES. The recent synthesis book for the Europe-African Transect (Baterbee, et al. 2004) indicates that many of the African paleoscience archives were limited to the last glacial period or even the Late Quaternary. The Late Quaternary paleoclimate records demonstrate that Africa has provided some of the first reference sites for observing monsoon variability in response to orbital forcing. Moreover several reconstructions have shown major changes in lake levels during the last 10,000 yrs (the Holocene) providing powerful evidence from the tropics against the polar-centric view of the Holocene as a period of relative stability. Moreover during the last glacial Maximum, 20,000-15,000 years ago, it was found that the levels of several lakes fell dramatically, some, such as Lake Victoria, to the extend of drying out completely. Moreover the presence of several abrupt dry intervals during the Early Holocene humid period were shown. The nature of ecosystems responses and human adaptations to such events need to be studied and sites which served as refugium for life to continue existing must be distinguished.

Africa will have a lot to contribute and also benefit from the above scientific networking in palaeoclimatology such as understanding the monsoon variability at different timescales and mechanisms affecting it such as oceanic/atmospheric/cryospheric/land cover/land surface changes.

Palaeoclimate

Africa is located between the two major Oceans: Atlantic and Indian. The African continental data therefore will have the potential to be correlated with Oceanic processes affecting heat transfer across latitudes and to give information on how such processes can impact future regional climates in Africa, such as due to global warming.

Today the vulnerability of societies to climate change and particularly that of the Africans is rapidly increasing. The current social infrastructures (such as dams, drainage systems, coastal defense) particularly in Africa are designed for extremes that are observed over short temporal scales. Paleoclimatic and paleoenvironental records with annual to decadal resolution extend such perspectives into the past, providing important insight into system variability and extrema, e.g. the probability and vigor of a "hundred year flood".

Observational records of the recent years have also shown exceptional rainfall events over the Sahel and Eastern Africa, associated with factors such as ENSO that generated catastrophic floods and droughts (Nicholson, 1997). During the Sahel drought of the 1970s and 1980s mean annual rainfall declined by about 30% (Hulme, 1996) with severe cattle death and massive population migration. Although the amplitude of these recent events do not rival those of the past millennia (Gasse, 2000) as indicated above, their social and economic consequences were nevertheless dramatic. For example the exceptional long and intense rains in Ethiopia have generated a massive flooding affecting the livelihood of people in the recent past.

AFRICA AND THE EARTH SYSTEM - Palaeoclimate			
	Key Research Questions	**Output**	**Activities**
1	How do the past continental data correlate with Oceanic processes that have affected heat transfer across latitudes in Africa?	Past African palaeoclimatic data Heat transfer correlates across African latitudes	Obtain high resolution long records of at least the Last Glacial/Inter Glacial cycle on oceanic processes that correlate with latitude linked heat transfers
2	How can oceanic processes impact on future regional climates in Africa, such as due to global warming?	Trends and scenarios of regional climate changes in Africa in relation to continental and oceanic processes	Scenarios building for future regional climate as driven by selected oceanic and continental processes
3	What changes occurred in Africa during global to regional-scale abrupt climate anomalies and what was the nature of signal transfer to Africa?	Better understanding of changes caused by climate anomalies	Studies of regional changes related to climate anomalies
4	How vulnerable are African societies to climate change?	Understanding of climate change impacts on society Climate change vulnerable groups and communities	Vulnerability assessment of societies to climate change
5	What design features of African social infrastructures (such as dams, drainage systems, coastal defense) are necessary to withstand extremes over diverse?	Stable social infrastructures able to withstand extremes over diverse temporal scales	Design social infrastructure targeting climate change over varied temporal scales
6	What are the annual and decadal past Palaeoclimatic and paleonvironental changes and probability and frequency of climate change and variability and extrema, e.g. the probability and vigor of a "hundred year Flood"?	Past perspectives of Palaeoclimatic and palaeoenvironental records with high resolution Clear insight and understanding of palaeoclimatic and natural system variability, probability and frequency of climate extremes	Palaeo-studies of climatic and environmental indicators

Land ecosystem-atmosphere Interactions in Africa

Africa has experienced and is at an increasing pace going through large changes in land use and land cover, water availability and quality, air quality, and climate. As the changes take place simultaneously and affect the numerous processes in the land-atmosphere interface, from local to global scale, the integrated approach is very valid in Africa. Integration in this context includes the concomitant study of a variety of processes in soil, vegetation and atmosphere by extensive measurement programs at multiple scales, coupling of measurements with modelling, and combining biophysical modelling with biogeochemical and dynamic vegetation modelling. As an example, changes in land use and land cover affect surface exchange of reactive carbon and nitrogen compounds, spatial distribution of heat, moisture and energy, with subsequent effect on atmospheric composition, chemical environment, and climate feeding back to the land surface and changing vegetation dynamics (iLEAPS, 2005).

AFRICA AND THE EARTH SYSTEM - Land Ecosystem-atmosphere Interactions			
	Key Research Questions	**Output**	**Activities**
1	What is the extent of past, present and estimated future (natural and human-induced) change in land use and land cover in Africa? How do these changes relate to climate change?	Better understanding of anthropogenic influence on terrestrial ecosystems	Studies of ecosystem/atmosphere on different time scales
2	How do changes in land use and land cover affect the hydrological cycle, biogeochemical cycles, local and regional climate (interactions and feedbacks, in particular)? How much of the local to regional climate variability is due to change in land use?	Database for integrated measurements/data	Long-term integrated flux measurement sites at different ecosystems; current status, measurement programs, networks (Afriflux/CarboAfrica)
3	Where, how and to what extent do disturbances, such as drought, floods, and vegetation diseases, affect exchange of matter, fluxes, at the land-atmosphere interface?	Understanding of the effect of disturbances such as drought, floods, and vegetation diseases, on the exchange of matter, fluxes, at the land-atmosphere interface understood	Comprehensive studies on the effect of disturbances, such as drought, floods, and vegetation diseases, on the exchange of matter, fluxes, at the land-atmosphere interface
4	How does change in vegetation biodiversity affect emissions of reactive and long-lived compounds? What is the relative role of native and non-native plant species spatially and temporally?	Understanding of the effect of change in vegetation biodiversity on emissions of reactive and long-lived compounds Role of native and non-native plant species in land atmosphere interactions clarified	Assessments and biodiversity change on emissions Integrated studies on role of native and no-native species contribution to land emissions
5	How and to what extent do different types of aerosol particles (e.g., black carbon, biogenic particles, biomass smoke, desert dust) from a variety of sources, biogenic and anthropogenic, contribute to climate, radiative flux and cloud-precipitation processes, from local to regional scale?	An understanding of the contribution of different biogenic and anthropogenic aerosol particles (e.g., black carbon, biogenic particles, biomass smoke, desert dust) to climate, radiative flux and cloud-precipitation processes, at local and regional scales	Mulitscale studies of the contribution of different biogenic and anthropogenic aerosol particles (e.g., black carbon, biogenic particles, biomass smoke, desert dust) to climate, radiative flux and cloud-precipitation processes.
6	How and to what extent do changes in land atmosphere interactions in various parts of Africa relate to GEC?	Understanding of the link between regional changes and GEC	Studies linking land-atmosphere interactions to GEC
7	How do changes in vegetation affect precipitation patterns?	Identification of areas critical for regional climate	Detailed studies on land use changes and meteorology

INTEGRATED DEVELOPMENT

Water System

The focus of this theme is on water resources and associated aspects of the Earth System. The sum of these aspects and their interplay can be subsumed under the term 'Global Water System'. In the context of global change, the Global Water System (GWS) can be defined as the suite of physical, geo-chemical, biological and human components and their interactions (GWSP, 2005) which constitute and influence the fluxes of water on earth. Aspects of these interacting components include:

- **Human components:** water-related organisations, engineering works, and water use sectors. This component is not only a part of the global water system but also a significant agent of change within the system; in that society is not only exposed to changes in water availability but also takes various actions to mitigate or adapt to these changes.
- **Physical components:** physical attributes and processes of the global hydrologic cycle or "water cycle", including runoff, geomorphology, sediment processes, evapotranspiration, moisture transport, and precipitation. The global water cycle encompasses not only hydrologic processes over and under the land surfaces of the earth, but also in its oceans, coastal zones, and atmosphere.
- **Biological and biogeochemical components:** aquatic and riparian organisms and their associated ecosystems and biodiversity. These organisms are also integral to the geochemical functioning of the global water system and not simply recipients of changes in the physico-chemical system.

There are a number of internal and external drivers and feedbacks within the system, which govern the functioning of the system. They act at different space and time scales and are impacted differently by GEC, therefore there is a need to focus research on up-scaling and down-scaling of the processes (fluxes, circulation, etc). Human activities are significantly and rapidly changing the entire African water system. The causes and manifestations of these changes need to be factored in for an Africa-wide research agenda in order to counteract the current and future threats to public health, ecosystems integrity, economic progress, and biodiversity caused by GEC. By addressing the challenges the African water system is faced to, also specific scientific challenges do emerge; notably the need to take a global view of the water system since many water research and management efforts have hitherto been concerned with regional and local processes. Research in African water systems must also focus on the linkages and feedbacks in the system while giving attention to the many social science and natural science aspects of water resources.

Water-related aspects in African are an integral part of the Global Water System (GWS) and play a key role in the abiotic dynamics of the Earth System, for example by helping regulate the release and sequestration of CO2 and other radiatively-important gases through couplings with the carbon and other biogeochemical cycles. Besides being an essential aspect of the non-living dynamics of the Earth System, water-related aspects play a central role in human society. GWS has been defined by GWSP (2005) as the global suite of water-related human, physical, biological, and biogeochemical components and their interactions. Figure 5 illustrates its main components. The global aspects of the

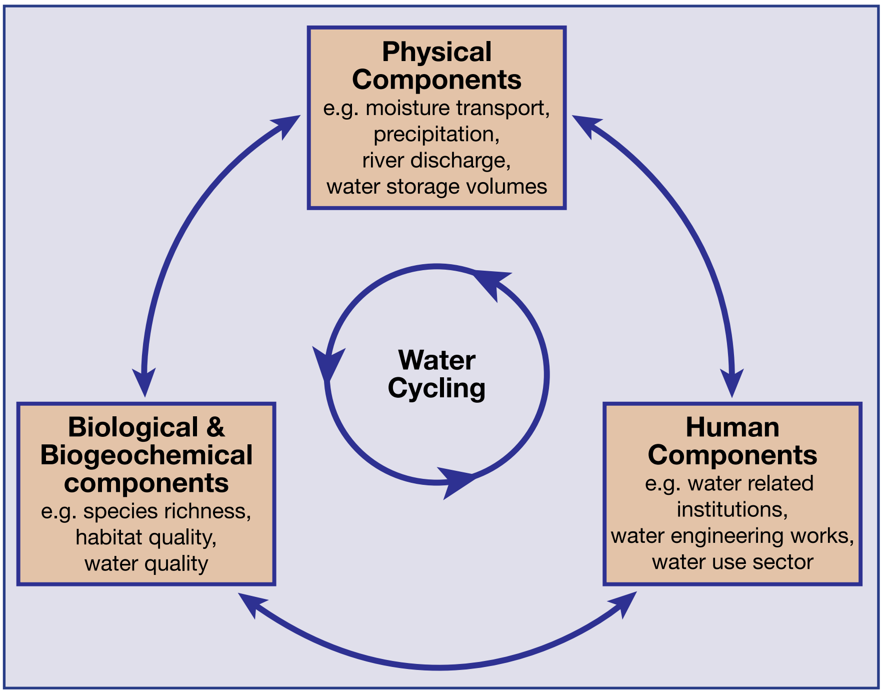


Figure 5. The main components of the global water systems (GWSP, 2005)

water system become more relevant due to GEC through economic, environmental, social, technological globalization. AfricanNESS believes that African water system research and management and the inherent human induced changes are increasingly getting global in extent, yet we lack an adequate understanding of how the system works and responds to disturbances, and how society can best adapt to rapidly-evolving new system states.

Natural aquatic ecosystems and the goods and services they yield sustain rural livelihoods across large parts of the African continent. Of particular importance are the fish resources of Africa's lakes and rivers that provide food and income to millions of people. The larger floodplains including the Inner delta of the Niger, the Sudd of the Nile, and Lake Chad, each yield up to 100,000 tons of fish per year and generate annual income in excess of US$ 20-25 million. The combined harvest from these extensive systems, the many hundreds of smaller floodplains that stretch across the continent, and the mainstream of rivers such as the Congo, is currently estimated to exceed 2 million tonnes/year. Lakes and reservoirs yield an additional 1.5 million tons/year, with the largest harvest in Lake Victoria.

Several global and regional initiatives in water system research and management could contribute to implementation of the outlined research agenda. The networking organisations of the Earth System Science Partnership (ESSP) are uniquely positioned to relate with AfricanNESS through the Global Water System Project (GWSP) and its research framework and implementation activities (GWSP, 2005). The organisations are also currently leading global efforts to understand both the natural science and social science aspects of global change. AfricanNESS, in the same approach, intends to catalyze interdisciplinary understanding of the role of water in the Earth System and the role of society as a key element in the adaptations to GEC in Africa. The research questions have been corroborated with the GWSP thematic questions in order to harmonise the global context of adaptations to GEC and impacts on biodiversity and ecosystem services, agriculture, health and sustainable development in the continent. This theme has close links with the Land-Ocean Interactions in the Coastal Zones (LOICZ) initiative of the IHDP and IGBP that contributes towards a better understanding of the Earth System in order to inform, educate and contribute to the sustainability of the world's coastal zone

Many human-induced changes of the Global Water System (GWS) and related problems can be observed in Africa. GWS-related changes and problems include not only those related to climate change (such as increased frequency of droughts or floods) but also those related to land-cover/use change and other socio-economic drivers (alterations of the quantity of water due to increased withdrawals or damming of rivers; changes in water quality due to land-use and land-cover changes; decrease of environmental flows; etc.). An in-depth study of the GWS-related aspects in Africa, e.g. through case studies based on river basins and linked to the planned GWSP Global Catchment Initiative, will contribute to an improved understanding of how the GWS works and how to adapt to anticipated changes.

The African continent plays an important role in the global water system (GWS). Specific continental-wide issues, which are also of special interest from the perspective of the Global Water System Project (GWSP, 2005), include the following:

- water-related institutions
- irrigation
- the role and impacts of dams
- environmental flows, freshwater biodiversity and ecosystem goods and services
- linkages between the regional and global scale

Institutional issues are important for managing water resources – especially, but not only, in water-scarce regions. Water related institutions (see text block) may be reflected, for example, in Integrated Water Resources Management (IWRM) mechanisms and plans, but also via different not directly water related legislations such as on land

Institution

The term 'institution' can be defined as '… the humanly devised constraints that structure political, economic, and social interactions. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights).' (North, 1991) use, environmental impact assessments or navigation. The types of water governance differ from country to country and from region to region. Some types seem to be more successful than others, i.e. in terms of ensuring a good water quality in rivers or the access to safe drinking water. An African-wide assessment of present governance structures and water-related institutions would improve the understanding of the underlying causes and resulting effects of the different types of water governance. Such an assessment may also support the development of adaptation and mitigation strategies that are needed under changed environmental and socio-economic conditions (caused e.g. by climate change, changes in the size of population or changed income and consumption patterns).

Irrigation plays an important role in arid regions of the continent (FAO, 1995). Irrigated areas as well as irrigation water requirements and the amount of water available for irrigation may alter as a result of climate change. In order to assess global change effects on agriculture, a detailed assessment of the current status of irrigation is needed. Based on national and regional statistics and on evaluations of remote sensing data, a detailed geographical overview of areas equipped and used for irrigation should be provided. In addition to the information about the actual areas a comprehensive dataset about the crops that are grown in these areas including their water requirements needs to be compiled, e.g. by synthesising available site-data. Furthermore, socio-economic data, for example about food-consumption patterns and food import/export relationships, need to be compiled.

Global change is and will further be effecting the irrigated agriculture – not only by a changed climate (long-term, as well as climate variability) but also by large-scale changes in land cover and land use and by alterations in domestic, industrial and agricultural water uses caused by changes in demography, consumption patterns, international food trade, and economic development. In order to assess such effects, scenarios of future irrigation and its potential for food production under changed conditions should be developed. These scenarios should draw from existing studies from the FAO, IFPRI, IWMI, IIASA, and other organisations and could, for example, be used to project the need and potential for expanding irrigated agriculture over the coming decades.

The current version of the FAO Database on African Dams (FAO, 2006) lists a total number of 586 **dams** that are built to store water for irrigation [1]. This number represents 46% of all the dams included in the database, which makes irrigation the main single purpose for dams in the database – followed by the purpose of water supply, which is given for 29% of the dams. Providing water for irrigation, domestic and industrial use is not the only reason for building dams: hydro-electricity (purpose of 11% of all listed dams), livestock rearing (6%), flood control (4%) and other purposes including navigation, recreation and pollution control (4% in total) are further drivers for the construction of dams.

Although dams serve the society in various respects, they also cause side effects and adverse impacts on the earth system. The impacts include: changes of physical aspects, such as water quality, erosion and sedimentation, local climate, geology and geomorphology, and the conditions of estuaries; changes of biological aspects, such as aquatic live, flora, fauna, river ecology; and changes of socio-economic aspects, such as human environment, resettlement of people, public health, and fisheries.

There are still questions to be answered related to the role of dams, for example related to the hydrology (How do dams affect the local and regional water balance?), agriculture (How much do dams/irrigated areas contribute to global or regional agriculture?), water supply (How many people – and other water use sectors – are dependent on reservoir water supply?), or the occurrence of health problems (What are the effects of reservoirs on water-borne or water-related diseases?). In order to get a holistic view on the role of dams in Africa, a detailed assessment considering the different aspects involved is needed. The GWSP has established a related network of scientists and stakeholders through its series of workshops on dams and reservoirs. Close co-operation with this international project is therefore very promising.

Dams and other obstacles in rivers fragment ecosystems and affect **environmental flows, freshwater biodiversity and the provision of ecosystem goods and services** all over the world – a global overview of dam-based impacts on 292 large river systems by Nilsson et al. (2005) shows that over half of these systems are affected by dams. For Africa the study shows that 15 out of 24 large river systems are affected, including the Zambezi, which spans eight biomes and belongs to the eight most biogeographically diverse large river systems on earth. Strategic questions related to biological aspects that need to be answered include the following: Where are priority dams for re-operation of removal? Where are dam-based current and future threats to biodiversity? Where are proposed and planned dams? Where are remaining wild rivers? Which dams or dammed basins have most severe impact on coastal biodiversity due to flow alterations (sediment, nutrient, etc.)?

In addition to changes induced by dams other global changes, such as climate and land-use change, affect environmental flows, biodiversity and ecosystem goods and services. Assessments need to be carried out to better understand the causes and effects of these changes and to find strategies for adaptation or mitigation of adverse impacts. This work may include a continental-wide inventory of freshwater biodiversity, studies on the relationship between ecological integrity of freshwater and human well-being and studies on environmental water allocation (the mimicking of natural hydrological variations to minimise environmental effects of changed water volumes) and its application in Integrated Water Management plans. Ongoing studies and initiatives, such as the WWF Mara River Basin Management Initiative [2] could serve as starting points for setting up these kinds of assessments.

Local changes in the water system may have impacts on the regional scale and the sum of many of these changes may even have impacts on a global scale. One example of **regional-global linkages** is a change in local land use that results in an alteration of runoff, the quantity and quality of water in rivers and local climate. The sum of local land-use changes can have affects on the characteristics of remote areas, such as the coastal zone, as well as on different spatial scales, e.g. by altering the regional or global climate. In addition to local drivers that cause regional or global impacts there are changes on the global level, such as climate change, that impact regional and local characteristics of watersheds.

Extensive analyses are needed in order to better understand the interlinkages of local, regional and global changes. One way to carry out these analyses that is suggested by the GWSP is to define a set of uniform questions that can be applied to different case study regions. Examples for such questions are: What are the types and magnitudes of potential changes in particular watersheds? What teleconnections (climatic as well as those associated with international food trade) are observable? How do different water-related institutions and governance systems compare between watersheds? What are the environmental, socio-economic and other factors that determine the adaptive capacity to changes in the watersheds?

Following the idea of the GWSP, the analysis could be based on ongoing or published case studies, such as those carried out by the GLOWA projects. Projects (see text block) which are funded by the German Ministry of Education and Research, the basin studies of the UNESCO initiative HELP (Hydrology for the Environment, Life and Policy), which is led by the International Hydrological Programme, or the basin studies of the Global International Water Assessment (GIWA) (UNEP, 2006c).

Key Questions, Outputs and Activities: Water System

In order to address the overarching scientific question of "How human actions are changing the African water system and what environmental and socio-economic feedbacks arise from anthropogenic changes in the system?", the AfricanNESS scientific plan proposes four questions that make up the sub-themes of the water systems research and capacity concerns.

Footnotes

1. In the FAO database not all but 71% of the dams are associated with at least one purpose (50% are associated with exactly one purpose, 15% with 2, 5% with 3, and 1% with 4 purposes)
2. WWF Mara River Basin Management Initiative
   See http://www.panda.org/about_wwf/where_we_work/africa/index.cfm?uProjectID=9F0749 for further information about this project

INTEGRATED DEVELOPMENT - Water System			
	Key Research Questions	Output	Activities
1	What are the magnitudes of anthropogenic and environmental changes in the African water system and what are the key mechanisms by which they are induced?	In-depth understanding of changes in water availability, water uses, pollution, irrigated areas, etc. Water governance and the water system as they impact on global and regional water use and water services A systematic database on water governance systems and their influence on the global water system An analysis of the impacts of changes in continental land use/ cover on global water resources An analysis of nutrient and sediment transport. Models of sediment and nutrient fluxes in the water system An analysis of the impacts of WS changes on, coastal ecosystems, atmosphere, and other components of the earth System	Comparison and classification of systems of water governance, analysis of their impact on water resources, and cataloguing of governance systems Analysis of historical patterns of land and water use in the continent and in major river basins Compilation of trajectories of land use /cover change for different basins and sub- regions taking into account demographic, economic, cultural and other driving forces Scenarios of future land use impacts on the water system and its implications to adaptations to GEC and the hydrological regime, water quality and the integrity of freshwater ecosystems Analysis of the impacts of climate change and variability on water use and availability, including feedback mechanisms between anthropogenic climate change and the water system Analysis and quantification of the cumulative consequences of large water diversions on regional and basin hydrologic regimes including their impacts on biodiversity and the services that aquatic ecosystems provide to society Identification of key variables and functional relationships describing nutrient and sediment transport and an assessment identification of regional hot spots contributing to nutrient and sediment transport and hot spots of nutrient and sediment accumulation, as well as an assessment of the effect of demographic, cultural and other factors and the implications of this water transport on ecosystem structure and services and human health.

INTEGRATED DEVELOPMENT - Water System (cont)			
2	What are the main linkages and feedbacks within the earth system arising from changes in the African water system?	An analysis of local influences to regional or continental climate; long-term changes of the quality and quantity of groundwater; etc. Linkages at different spatial and network scales in the African water system An analysis of human and natural interactions in the African water system	Series of river basin studies to examine the historical interactions between river basins and their human inhabitants with the aim to better understand spatial and temporal connectivity Develop a general framework for analyzing these WS connectivity Examination of the international trade in virtual water. Research on the "legacy effects" of human natural interactions in the African Water System including ecological effects Develop a conceptual framework for studying "legacy effects" on different types of water systems and their feedback loops with GEC and regional water models to study such legacy effects
3	How resilient and adaptable is the African water system to change, and what are the requisite sustainable water management strategies?	A study about chances to implement IWRM or other water-resources management strategies; institutional capacities of dealing with identified changes/problems; identification of vulnerable groups An analysis of water requirements (flow regime and quality) for nature and humans in a changing global environment Understanding of the adaptive capacity and vulnerability of the African water system in relation to environmental, social, and other factors Enhanced adaptive approaches and approached to improved governance for improved water systems research and management	Develop a framework for the regional assessment (at different scales) of tradeoffs between environmental water requirements and the goods and services provided by freshwater resources in changing global environments Identification and quantification of the factors (e.g. population and land use changes, institutional and industrial transformation) that influence adaptive capacity of the African water system Examination of how water governance affects the adaptive capacity of society to these changes and how different concepts of governance can help with managing water in a sustainable way at the global level Systematic valuation of ecosystems goods and services provided by water systems and evaluation of the impact of global change and society's activities on the provision of these services

INTEGRATED DEVELOPMENT - Water System (cont)			
4	How should Africa's capacity for water resources management, water systems research and GEC adaptation be developed?	Improved water resources management strategies and scientific understanding of the water cycle through joint cooperation and research with GWSP, UNESCO-HELP, SIWI, GLOWA, etc. Improved water governance strategies Improved capacity to adapt to impacts of GEC on water systems White papers for use by policy-makers and other stakeholders.	Encourage and promote knowledge-sharing and provide capacity-building and the transfer of technology Support African countries in their efforts to monitor and assess the quantity and quality of water resources, e.g. through the establishment and / or further development of national monitoring networks and water resources databases and the development of relevant national indicators Support the diffusion of technology and capacity building for non-conventional water resources and conservation technologies to African countries and regions facing water scarcity conditions or subject to drought and desertification, through technical support and capacity building Support, where appropriate, efforts and programmes for water governance, integrated water resources management (IWRM) and other related socio-economic sciences. Conducting stakeholder-dialogue workshops, for example with NEPAD, AU and other water systems networks

Sustainable Energy

Africa has a landmass of just over 30.3 million km^2, an area equivalent to the United States of America, Europe, Australia, Brazil and Japan combined (ICSU, 2006). As of 2004 Africa housed 885 million people (AfDB, 2006) in 53 countries of varied and diverse sizes, socio-cultural entities and resource endowments, including fossil and renewable energy resources. Most of these energy resources are yet to be exploited; a contributing factor in making the continent, the least consumer of energy. If Africa is to achieve its economic growth and development objectives in line with rising population growth, its energy consumption should grow in order to fulfil fundamental social needs (e.g. providing food, education, etc). On average, African countries have difficulties in meeting their energy requirements, and have the lowest per capita energy consumption in the world. Moreover, low-income levels characterize most countries, and the significant proportion of the overall energy consumed is from the most environmentally detrimental biomass energy source compared with modern energy forms. Overall, hydroelectric power is the only important grid connected renewable energy source. The increase in energy requirements has implication not only on poverty levels, energy security, stability, and on ensuring economic growth development. But the increase in energy should be efficient, environmentally friendly and promote social equity. Exploiting renewable energy offers a practical solution to the energy problem.

Most of Africa's population lives in rural areas and use various forms of biomass (firewood, animal waste, charcoal, etc) for cooking, and is a significant source of pollution. Studies show a correlation between exposure to smoke and disease, and that the poorest segments of the population are most exposed to these risks. Wood is traditionally used for cooking, heating, and providing light. Due to the depletion of wood resources, wood for fuel is scarce and this places a burden on women and children who travel long distances to collect it from areas of surplus rather than using their time more productively on other more fulfilling tasks. Despite the continent having about 14% of the world's population and producing 7% of the world's commercial energy, it consumes only 3%, with more than half of its production being exported (UNECA, 2006; ICSU, 2006; Karakezi, 2006). Furthermore, the current reserves-to-production ratio for natural gas and coal are above the world average (Davidson and Conteh, 2006). While the population of Africa has grown by more than 3% annually for some years now, its global share of total primary energy supply has only increased from 3.5% to 5.2% between 1973 and 2003 (IEA, 2005), indicating reduction in energy access on a per capita basis.

The use of modern energy forms such as electricity and kerosene is limited. Electricity consumption levels are low, and where available poorer residents use electricity almost exclusively for lighting. Electricity does not satisfy all energy needs, and multiple fuel use is widespread, with households selecting fuels for different end-uses, as well as using more than a single fuel for the same end-use. The bulk of paraffin purchased is used for cooking with much of the rest used lighting purposes and heating. Paraffin consumption is largely attributable to accessibility and its relative low price. Paraffin, like wood, is also smoky, inconvenient, and expensive, with health and safety risks. But access to paraffin brings greater benefit to the poor since it does not require long hours of collecting as wood.

The movement from biomass to modern forms of energy is known as the 'energy ladder' and can be argued to be a function of economic growth and development. Although we expect fuel switching in favour of electricity for cooking, lighting and other household purposes to increase as income levels rise and distribution improves, evidence elsewhere suggests that complete displacement occurs in a minority of homes. Electricity is typically considered an additional fuel in low-income households, does not always replace other fuels, but rather adds to the fuels used. Undoubtedly, electric lighting is more efficient and of a better quality than that provided by other fuels, but poverty limits the uses of this clean energy. Sustainable development will best be achieved with sustainable energy services. Fortunately Africa has abundant and potential energy sources to exploit and that offer better choices. Africa has an additional advantage of energy resources that are constantly replenished by the sun in the form of wind, waves, light, heat and bioenergy that can be exploited with benefits that promote both economic growth and development. After all, Africa has the best sunshine compared with the other continents in the world. The renewable energies feed a number of cutting edge technologies, which include wind turbines, wave and current power stations, hydropower, photovoltaic (PV), solar thermal and many others.

Best results may be obtained by integrating renewable energies and

energy efficiency. The energy problem in Africa is compounded by inefficient energy conversion to obtain desired services and not by scarcity of energy per se. As a result, most of the energy produced ends up being harmful pollution. It is therefore not surprising that African countries have higher energy intensities than the world average because energy is used inefficiently and probably explaining why they are not competitive. While Africa has energy intensive primary industries, the social and environmental costs are not accounted for and conventional energy is perceived to be cheap. The theme is closely linked to the activities of ICSU and its partners in the energy sector which are mainly driven by three bodies, namely: the International Union on Pure and Applied Physics (ICSU-IUPAP), the International Science Panel on Renewable Energy (ICSU-ISPRE), and the ICSU Working Group on Energy and Sustainable Societies.

The AU has an energy initiative that aims at developing the vast African energy resources in a sustainable manner to ensure increased productivity, wealth creation and improved quality of life for all Africans. This initiative is articulated in NEPAD with specific energy projects and plans that underpin AfricanNESS sustainable energy theme: the formulation of suitable energy policies aimed at cooperation for sub-regional development; electricity grid interconnection between countries and a possible pan-African electricity grid; oil and gas pipeline projects; resource development (especially major hydropower sites); and the Energy Information Development Project. When related to GEC the energy challenges facing the continent and possible policies to overcome them this theme engages science and society in addressing energy issues for poverty reduction with the hope of identifying key energy targets for achieving the Millennium Development Goals (MDGs).

Key Questions, Outputs and Activities: Sustainable Energy

It is thus important to note that the energy issues is intricately linked with other issues, and can provide a fundamental input to satisfying needs such as health, education, sanitation, achieving equity in energy access, job creation, income growth, while at the same time promoting productivity, economic growth and achievement of millennium development goals through macroeconomic stability and governance.

INTEGRATED DEVELOPMENT - Sustainable Energy			
	Key Research Questions	**Output**	**Activities**
1	What is the role of energy in sustainable development in Africa? How can a substantial increase in guaranteed energy supply be development in the background of GEC? How can sustainable rural and urban access to energy be guaranteed in Africa?	Understanding of the role of energy in sustainable development Policies to promote equity in energy access Varied decentralized and renewable energy sources that offer less expensive and more environmentally acceptable energy solutions especially where grid based electricity is not feasible in a changing global environment	Development of renewable technologies, for households and other sectors in the economy, combined with energy efficiency that best responds to GEC in Africa Provision of substantial increase in reliable and sustainable energy access for rural and urban areas to enhance adaptability GEC Review of existing energy and energy related activities to identify gaps and to distil key lessons for scale up strategies for GEC adaptation in the energy system Studies on promotion of energy efficiency programmes Assessments to promote the identification and implementation of flagship energy supply projects including renewable energy and large hydro projects that ensure demand growth and adaptation to GEC Use modern information technology such as GIS (Geographical Information System) to develop energy databases Develop suitable national standards, or sustainability benchmarks for the energy sector to meet local expectations and improve adaptation to GEC Review and develop energy policies and measures to improve energy access for poverty reduction and for integration Studies to improve the understanding of how GEC is influencing and is influenced by energy production and consumption patterns in sub-Saharan Africa

INTEGRATED DEVELOPMENT - Sustainable Energy (cont)			
2	What policies and institutional arrangements should be developed to strengthen and retain human and institutional capacity for sustainable energy development?	Human and institutional capacity for sustainable energy development and energy GEC adaptation	Strengthening and retention of human and institutional capacities Prompt scientific, technical and policy interventions in different energy sectors by specialised individuals and institutions regardless of their country of origin. Specific dialogue, discussion and information exchange on the latest knowledge in the energy and energy-related sectors through organised network of energy experts in Africa with linkages to those on other continents Develop a database, including websites, on regional energy experts, resources and projects, that is easily accessible to governments and relevant organisations Develop mechanisms and policies for retaining trained energy expertise and programmes that reverse brain drain from the region Build capacity in the energy and related sectors throughout Africa to ensure reliability, sustainability and adaptation to GEC

INTEGRATED DEVELOPMENT - Sustainable Energy (cont)			
3	What is the future of African energy systems and how will this interact wi th projected GEC in the continent?	African energy models and scenarios African energy responses to projected GEC Stimulation of timely energy demand growth	Development of African energy models and scenarios Efficacy of the system reliability and capacity reserve criteria applicable to each country in Africa Setting up a coordinating base for effective modelling and scenario building in energy and energy related matters Collecting and organising the data needed for simulation including utility for adaptation to GEC Environmental scoping in the energy sector to highlight environmental management constraints, including legislation, general public concerns, and sensitive areas in energy production and use Review and updating of Africa electricity load forecasts Identify risks and uncertainties relating to the energy and related sectors in relation to GEC Detailed financial, socio-economic and environmental modelling for the energy sector in Africa Capacity building for energy and energy-related modelling and scenario development

MARINE

With a 25,600 km long coastline, the African continent benefits from a number of quite diverse coastal and marine ecosystems, the main ones being mangroves and coral reefs (including cold coral reefs). It is recognized that 40% of the Africa's population depends on these coastal and marine ecosystems and resources for their livelihoods. Major economic activities like fisheries and tourism depend on these resources. However, the continuous coastal concentration together with the development of major coastal urban centres increase the pressures on these ecosystems, many of them being now threatened. These anthropogenic pressures are superimposed on natural changes that affect the ecosystems and their functioning. The main sources of ecosystems degradation are pollution, overexploitation of resources, degradation of habitats, coastal erosion, siltation, salinization, etc. In some parts of the coastal zone, like for example along the Mediterranean coast, industrialization is a major source of degradation of the ecosystems.

The expected sea level rise due to climate change, together with other changes in climate parameters, will exacerbate these trends and could seriously threaten many coastal and marine ecosystems. This could have important socio-economic impacts (losses in revenues and infrastructure). It is thus of prime importance that the impacts of global change on the marine and coastal ecosystems be assessed and appropriate adaptation measures be identified. This must be based on achieved and ongoing projects and programmes addressing these questions in the continent and elsewhere as articulated by Barange and Harris (2003).

This research agenda in this sub-theme will couple and have linkages with other initiatives including the LOICZ, different initiatives to protect coastal and marine ecosystems (IUCN, WWF, Wetlands International), sub-regional programmes (PRCM in West Africa), LME projects (Benguela current LME, Guinea LME, Canary LME), fisheries commissions, IOC projects, UNEP/Regional Seas and GPA, COSMAR.

In order to exploit the results of these activities, there is a need, as feasible as possible, to use common methodologies, scenarios and tools (software or models). These must be based on existing methods (DPSIR framework, GIWA methodology, etc.).

MARINE			
	Key Research Questions	**Output**	**Activities**
1	What changes are occurring in coastal and marine ecosystems and what are the drivers of these changes?	Qualitative and quantitative changes in coastal and marine ecosystems Identification of the main causes of changes	Identification (qualitative and quantitative) of major changes taking place in the main coastal and marine ecosystems (mangroves, coral reefs, upwellings). (for all regions in Africa) Determination of primary, secondary and root causes of these changes
2	What are the major human activities that are affecting coastal and marine ecosystems (river damming, urbanization, exploitation of resources)?	Quantification of the impacts of human activities on coastal and marine ecosystems	Assessment of the impacts of human activities like river damming, pollution, urbanization on the coastal and marine ecosystems (mainly in urbanized coastal areas
3	What is the vulnerability of coastal and marine ecosystems and species to global change (particularly sea level rise, ocean warming)?	Maps of the main vulnerable coastal and marine ecosystems and species	Identification of the main ecosystems and species threatened by sea level rise, ocean warming and other major future changes Prioritisation of the most vulnerable ecosystems by region and of the most vulnerable species

MARINE (cont)			
4	What are the risks arising from global change for economic activities and livelihoods of populations living along the coasts?	Links between economic activities and coastal and marine ecosystems Identification of main thresholds for exploitation of resources, etc. Goods and services from coastal and marine ecosystems Impacts of global change on economic activities and livelihoods in the coastal zones	Definition of the links between coastal and marine ecosystems and some economic activities (fisheries, tourism for example). Identification of critical thresholds regarding exploitation of resources, levels of pollution, etc. Assessment of the benefits specific coastal populations (particularly fishermen communities, small islands communities) derive from coastal and marine ecosystems for their livelihoods Evaluation of the consequences of global change (especially climate change) could have on economic activities and coastal livelihoods.
5	What are the impacts/effects of the different management measures (marine protected areas, integrated coastal zone management) on these ecosystems?	Evaluation of the efficiency of the main policies applied to coastal and marine resources Identification of the main causes of successful or failed management policies Main impacts of the policy measures on ecosystems identified	Assessment of the results of management measures in selected marine protected areas and coastal areas under integrated coastal management policies Assessment of the impacts of fisheries regulations on marine ecosystems Based on different experiences, assessment of the impacts of coastal protection measures on coastal ecosystems
6	What are the adaptive measures that could reduce the vulnerability of these coastal and marine ecosystems to global change?	Adaptation measures to reduce the vulnerability of coastal and marine ecosystems to global change	Identification of potential adaptation measures/policies that could reduce the vulnerability of coastal and marine ecosystems to global change

Annex B Glossary

Adaptation

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001a). It refers to the ability of biological and societal systems to change their current state as a result of changes in boundary conditions or external inputs. Adaptation implies that the basic functions and overall integrity of the system are maintained.

Adaptive Capacity

The ability of a socio-ecological system to cope with new situations without losing options for the future. The adaptive capacity in ecological systems is related to genetic diversity, biological diversity, and the heterogeneity of landscape mosaics (Bengtsson, *et al.*, 2003). In social systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility and play an important role in adaptive capacity (Berkes and Jolly, 2002). Adaptive capacity is also linked to ` to resources while resilience is key to enhancing it.

Biodiversity

The numbers of entities (genotypes, species, or ecosystems), the evenness of their distribution, and the differences in their functional traits and their interactions. The term encompasses a broad spectrum of biotic scales, from genetic variation within species to biome distribution on the planet. Often has been used as a synonym for species richness; different components of biodiversity (richness, composition, presence/absence of key species) can have different effects on ecosystem properties. Also refers to the variety of living things on earth and their interactions with the environment. Scientists often categorise biodiversity into three components, i.e. species, genes and ecosystems. The UN Convention on Biological Diversity defines biological diversity as 'the variability among living organisms from all sources including…terrestrial, marine and aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems. Biodiversity is an attribute of life, distinguished from biological resources which 'include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity'.

Climate Change and Climate Variability

Refers to the variation in global or in regional climates over time. It describes changes in the variability or average state of the atmosphere—or average weather—over time scales ranging from decades to millions of years. These changes may come from processes internal to the Earth, be driven by external forces (e.g. variations in sunlight intensity) or, most recently, be caused by human activities.

Climate Change

The change in climate attributed directly or indirectly to human activity that alters the composition of global atmosphere and which is in addition to natural variability observed over comparable time periods (UNFCCC).

Climate Variability

Refers to the variation in the regional climates over time. It describes changes in the variability or average state of the atmosphere, or average weather, over short time scales usually a decade or less. These changes may come from processes internal to the Earth, be driven by external forces (e.g. variations in sunlight intensity) or, most recently, be caused by human activities.

Coupled Human-Environment System

A bounded, integrated unit on the land comprised of human, ecosystem/biological, and environmental components. The coupled system reinforces analysis and assessment focussed on the synergy and reciprocal relations among people, physical environment, and biota, emphasizing feedbacks between the human and natural subsystems. This approach contrasts with traditions of study that separate coupled systems into their components.

Earth System

The Earth System is the unified set of physical, chemical, biological and social components, processes and interactions that together determine the state and dynamics of Planet Earth, including its biodata and its human occupants. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability. The understanding of the natural dynamics of the Earth System has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.

Ecosystem Services

Benefits derived by humans as a result of ecosystem processes and functioning. Ecosystem services can be classified in four categories (MEA, 2005): provisioning services, cultural services, supporting ser ices and regulated sercives. Regulating services include benefits obtained from regulation of ecosystem processes, such as climate regulation, disease control, flood control and detoxification. Provisioning refers to services produced or provided by ecosystems, such as food, fresh water, fuel wood, fibre, biochemicals and genetic resources. Cultural and non-material benefits obtained from ecosystems include spiritual, recreational, aesthetic, educational, communal and symbolic services. Services that maintain or support conditions for life on earth include soil formation, nutrient cycling, pollination, and biodiversity.

Ecosystem

An ecosystem is a combination of all the living and non-living elements of an area. Ecosystems are the smallest level of organisation in nature that incorporates both living and non-living factors.

Food Security

The state achieved when food systems operate such that 'all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 1996). Food security is underpinned by food systems and is diminished when food systems are stressed. This stress can be caused by a range of factors in addition to GEC (e.g. conflict, changes in international trade agreements and policies, HIV/AIDS) and may be particularly severe when these factors act in combination (GECAFS, 2006).

Food Systems

Food Systems encompass (i) activities related to the production, processing, distribution, preparation and consumption of food; and (ii) the outcomes of these activities contributing to food security (food availability, with elements related to production, distribution and exchange; food access, with elements related to affordability, allocation and preference; and food use, with elements related to nutritional value, social value and food safety) (GECAFS, 2006).

Global Environmental Change (GEC)

The set of biophysical transformations of land, oceans and atmosphere, driven by an interwoven system of socio-economic and natural processes (Gobel, 2005).

Global warming

Greenhouse gases (GHGs) such as carbon dioxide, carbon monoxide and methane that are emitted into the atmosphere through human activities trap thermal radiation, heating the planet.

Global Water System (GWP)

Global water system as the global suite of water-related human, physical, biological, and biogeochemical components and their interactions.

Livelihood

A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base.

Resilience

The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

Sustainability

Sustainability refers to the development of systems capable of ensuring that future generations will have coupled human-environment systems capable of providing goods and services for the long-run, without degradation in structure or function.

Vulnerability

Vulnerability is taken to refer to the "exposure to contingencies and stress, and the difficulty in coping with them" (Chambers, 1989). Kasperson and Dow (2005) highlight the three major dimensions of vulnerability as: exposure to stress/perturbations; the sensitivity of people/places to these perturbations, including their capacity to anticipate and cope with stress; and the resilience of exposed people/places, in term of their capacity to absorb shock, while maintaining function. It is an indication of peoples' exposure to external risks, shocks and stress and their ability to cope with and recover from the impacts (DFID, 2004). It refers to the sensitivity of a system to detrimental changes in its state caused by changes in the boundary conditions or external inputs which affect the basic functions and the overall integrity or vitality of the system.

Well-being

Human well-being has multiple constituents, including basic material for a good life, freedom and choice, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, which has been defined as a "pronounced deprivation in wellbeing." The constituents of well-being, as experienced and perceived by people, are situation-dependent, reflecting local geography, culture, and ecological circumstances.