ICSU Regional Office for Africa

AFRICA SCIENCE PLAN

Global Environmental Change

Strengthening international science
for the benefit of society

INTERNATIONAL
COUNCIL FOR SCIENCE
REGIONAL OFFICE
FOR AFRICA


Source: https://watercharity.com/tags/rpcv?page=2

Authors

Prof Jonathan Matondo, University of Swaziland, Swaziland
Dr Regina Folorunsho, Nigerian Institute for Oceanography and Marine Research Victoria Island, Nigeria
Dr Joseph K Kanyanga, Meteorological Services of Zambia, Zambia
Prof Chris Gordon, University of Ghana, Ghana
Prof Babatunde Agbola, University of Ibadan, Nigeria
Prof Abdelkader Allali, Ministry of Agriculture and Marine Fisheries, Morocco
Mr Cheikh Kane, Africa Monsoon Multidisciplinary Analyses, Niger
Prof Joshua Olowoyo, Sefako Makgatho Health Sciences University, South Africa
Dr Carl Palmer, Applied Centre for Climate and Earth Systems Science, South Africa
Dr Jean Pierre Sandwidi, University of Ouagadougou, Burkina Faso
Prof Robert Scholes, University of the Witwatersrand, South Africa
Dr Albert K Sunnu, Kwame Nkrumah University of Science and Technology, Ghana
Dr Daniel Nyanganyura, ICSU Regional Office for Africa, South Africa

We wish to acknowledge, with appreciation, the early contributions to this document provided by Prof Coleen Vogel of the University of the Witwatersrand, Johannesburg, South Africa.

All correspondence concerning this Africa Science Plan should be addressed to:
Dr Richard L.K. Glover *r.glover@icsu-africa.org* *and*
Dr Daniel Nyanganyura *d.nyanganyura@icsu-africa.org*

Published by:
ICSU Regional Office for Africa
Pretoria, South Africa
+27 (12) 349 7731
www.icsu.org/africa

January 2017
ISBN 978-0-620-74573-4

Editor:
Hanlie Griesel, University of Pretoria and freelance writer/editor

Design, layout and printing:
Garnett Design Studio, Pretoria

Preamble

The International Council for Science (ICSU) is a non-governmental organisation with a global membership that includes 113 National Scientific Bodies, 29 International Scientific Unions, and other affiliated bodies. The long-term ICSU strategic vision is for a world where science is used for the benefit of all, excellence in science is valued, and scientific knowledge linked effectively to policy-making.

The ICSU Strategy promotes the Council's contribution in strengthening international science for the benefit of society in three overlapping areas:

- *International research collaboration* – ICSU plans and coordinates major research programmes in key areas such as: (a) global environmental change; (b) monitoring and observation of the Earth System; (c) collection, preservation, and dissemination of scientific data and information.
- *Science for policy* – ICSU seeks to ensure that science is integrated into international policy development and that relevant policies take into account both scientific knowledge and the needs of science. Consequently, ICSU represents the science community in important intergovernmental forums such as the (a) 2002 (Johannesburg) World Summit on Sustainable Development; (b) 2003 (Geneva) and 2005 (Tunis) World Summits on the Information Society; (c) UN Commission on Sustainable Development; and (d) Earth Observation Summits.
- *The universality of science* – The principle of the universality of science is embodied in ICSU's statutes: "The practice of science should be equitable and without discrimination." Thus the primary aim of ICSU is to enhance the pluralism of science and reach out to all countries, by (a) ensuring that scientists can associate and communicate freely; (b) providing equitable access to data and information; (c) enabling equitable access to research materials and facilities; (d) building scientific capacity; and (e) bringing nations and disciplines together.

The ICSU Regional Office for Africa (ICSU ROA) was inaugurated on 1 September 2005 for the purpose of promoting and coordinating the activities of the ICSU family in sub-Saharan Africa. Such an undertaking will always consider the priorities and the specific realities of this region. In April 2006, the ICSU Regional Committee for Africa (ICSU RCA) selected four priority areas on which its Regional Office would focus its activities in the period 2006–2009 (and beyond). These are: (a) sustainable energy; (b) health and human well-being; (c) natural and human-induced hazards and disasters; and (d) global environmental change, including climate change and adaptation.

ICSU ROA coordinated the development and publication (in 2007 and 2008) of science plans in the above thematic areas to ensure that the voice of African scientists influences the international science agenda, and that scientists from the continent are fully involved in international research guided by continental priorities. Since the publication of these documents, ICSU ROA has been working with international consortia of scientists and major stakeholders to develop and implement projects from them. It has become necessary to review and update the science plans to reflect current and emerging trends in each thematic area at international, regional and national levels. The review process was carried out in two phases: an electronic consultation (February to May 2015) and a physical workshop in Pretoria South Africa (June 8 to 10, 2015). The electronic consultation phase was meant to reach out to and get input from a wider range of scientists, including those who could not attend the workshop. The workshop consolidated all the electronic contributions and generated an updated version of each science plan, aligned with the ICSU Strategic Plan 2012–2017, new developments in the global research agenda of each thematic area, and the Future Earth initiative. Moreover, cognisance was taken of the post Rio+20 Agenda; the Sustainable Development Goals (SGDs); the Science, Technology and Innovation Strategy for Africa 2024 (STISA 2024) and African Union Agenda 2063. The revised

https://pixabay.com/en/desert-drought-dehydrated-clay-soil-279862/

Africa Science Plan for Global Environmental Change also accommodates ideas from both the current ICSU ROA Global Environmental Change (including climate change and adaptation) and the African Network for Earth System Science (AfricanNESS) science plans. The bulk of the information/text in this revised Science Plan comes from the first ICSU ROA Science Plan, with some additions and modifications to reflect current topical issues.

Some of the proposed flagship projects cut across the four priority areas, and underscore the critical importance of multi- and interdisciplinary approaches and international cooperation for the positive realisation of the objectives of the four science plans of the ICSU ROA.

ICSU believes that science provides the critical underpinning for innovation, technological and social development. It offers necessary, although not sufficient, input to ensure sustainable socio-economic development of societies. At the same time, it offers evidence-based science to inform rational and prudent public policy formulation and decision-making. Accelerated development of scientific knowledge and skills are therefore key factors in the reduction of poverty and improvement of the quality of people's lives in Africa. The great achievements recorded by ICSU in the developed countries should inspire African scientists to apply science, technology and innovation (STI) in solving Africa's socio-economic problems.

Dr Daniel Nyanganyura
Regional Director, ICSU Regional Office for Africa

Executive Summary

This document describes the areas of global environmental change research (GECR) that are of particular importance and interest to Africa. It describes some of the basic research needed to support cogent decisions, for example to climate change adaptation and mitigation, and to provide reasonable options for the support structure required to facilitate and implement the research. It is not a blueprint or framework for all work on this topic in Africa, but rather a guide as to where the particular strengths of ICSU ROA can be brought to bear on this important issue.

Global environmental change research encompasses the interlinked issues of social, economic, political and technological change; their consequences for the land surface and its water systems, the oceans, and the atmosphere; the resultant changes in the climate; and the impact of all the above on plant and animal biodiversity and human well-being. Africa is particularly vulnerable to global environmental change (GEC), partly due to its location, and also because of its limited adaptive capacity (Boko, *et. al*, 2007). The continent has significant capacity to conduct GECR, but is not reaching its full and necessary potential in this arena.

This Science Plan considers, from an African perspective, the most pressing GEC-related research needs, the unique opportunities offered for GECR, and the capabilities to conduct world-class research. A small number of large, integrative projects in four broad areas are suggested: (a) Land degradation, biodiversity loss, and human well-being; (b) The impact of climate on rainfall water resources; (c) Air pollution and the impact on health in urban areas; and (d) Africa's oceanographic uniqueness.

The implementation of this Science Plan will involve a number of partners, including the ICSU-associated international GECR programmes, such as: the Future Earth initiative; the SysTem for Analysis, Research and Training (START); national/international GECR programmes and institutions; United Nations agencies such as the UN Environment Programme (UNEP), the UN Educational, Scientific and Cultural Organization (UNESCO), the Food and Agriculture Organization (FAO), the World Health Organization (WHO), the UN Convention to Combat Desertification (UNCCD), and the World Meteorological Organization (WMO); other international research bodies working on GECR in Africa, notably centres of the Consultative Group on International Agricultural Research (CGIAR); and international donor agencies across the spectrum from research to development.

https://pixabay.com/en/meander-river-england-1462370/

Contents

Preamble i

Executive Summary iii

1. Introduction 3

2. The African Context 5

   2.1 Global Environmental Change Challenges in Africa 5

   2.2 Status of Global Environmental Change Research in Africa 8

3. Vision, Objectives and Principles 11

4. Capacity Building Needs 15

5. Proposed Research Activities 19

   5.1 Land Degradation, Biodiversity Loss, and Human Well-being 21

   5.2 Climate Systems in Africa 21

   5.3 Food and Nutrition Security 24

   5.4 Water Resources Security 25

   5.5 Urbanisation and Atmospheric Pollution 27

   5.6 African Ocean Links 29

   5.7 Fisheries and Coasts 31

6. Implementation of the Science Plan 32

7. Strategic Partnerships 33

8. Conclusion 35

References 37

Definitions of Terms 40

Acronyms and Abbreviations 41

Source: https://pixabay.com/en/industry-sunrise-clouds-fog-611668/

Source: Prof Dave Berger, Department of Plant Sciences, University of Pretoria

1. Introduction

Global environmental change (GEC) refers to the set of transformations of land, oceans and atmosphere driven by interwoven socio-economic and natural processes (see Figure 1). Concurrent with the contemporary phenomenon of globalisation (the growing and accelerated interconnectedness of the world), people have to some extent begun to induce planetary-scale changes in the Earth's life-support system.

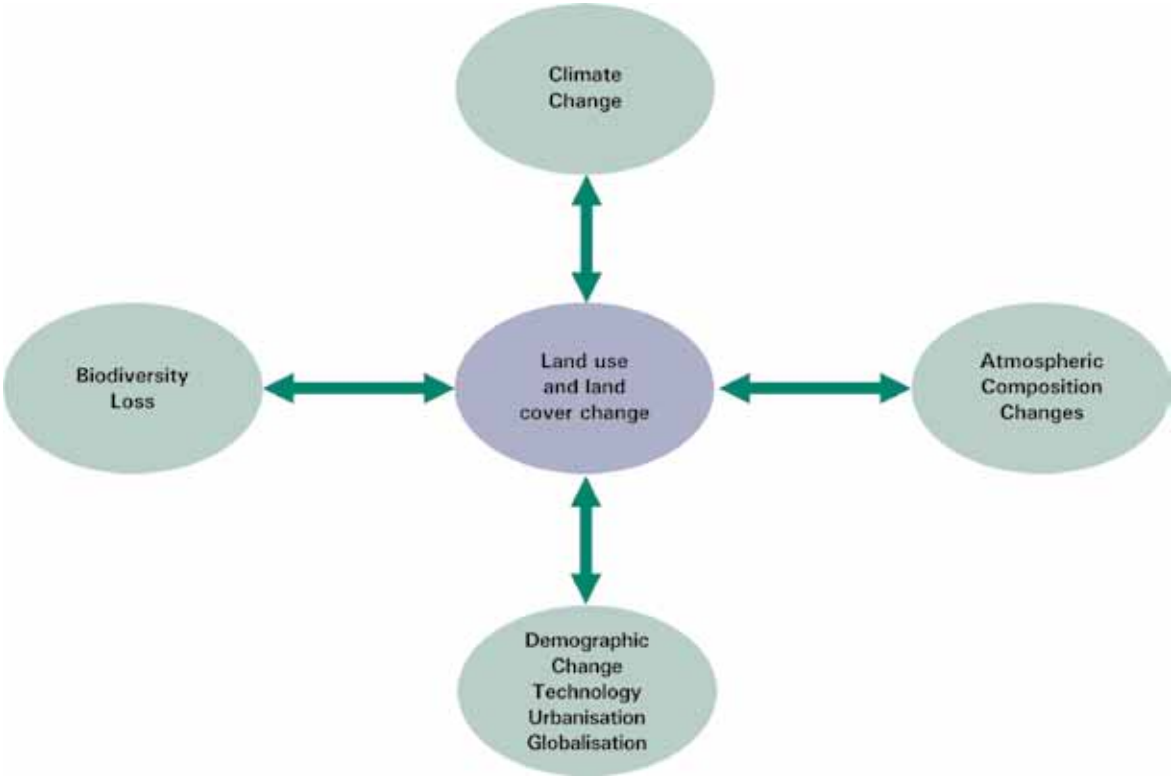

Figure 1. The complex of issues that make up the global change syndrome

The growing demographic pressure and increased demand for food, fibre and water have dramatically transformed the land surface, from quasi-natural cover to cultivated lands. The carbon dioxide released during this process combines with emissions from the burning of fossil fuels to change the composition and radiant energy balance of the atmosphere, leading to a warming of the Earth's surface, changes in the distribution and quantity of rainfall, and a rise in the mean sea level (McCarthy *et al.*, 2001; Boko *et al.*, 2007). Waste products from human activities result in air and water pollution, leading to an over-abundance of nutrients in freshwater and coastal systems, accumulated toxins on land, and deteriorating air quality (MEA, 2005). Unsustainable harvest pressures and loss of habitat for wild species have precipitated loss of biodiversity and, at the same time, a small number of invasive species are increasing their dominance.

Human activities now 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). About half of the world's ice-free land surface has been altered by human actions (Foley *et al.*, 2005), which now cause more nitrogen fixation than is normally

encountered in nature (Galloway *et al*., 2004). Particles emitted by anthropogenic activities alter the energy balance of the planet, and have adverse effects on human health (Charlson *et al*., 1992; Pope III and Dockery, 2006). Anthropogenic changes to the structure, composition, or function of large natural bio-geophysical 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*., 2004).

According to the Intergovernmental Panel on Climate Change (IPCC, 2013), the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, the sea level has risen, and the concentrations of greenhouse gases have increased in the Northern Hemisphere with the 1983–2012 period the warmest 30-years over the past 1400 years. 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 people's activities. These perturbations are exacerbated by global climate change, and together, they compromise livelihoods by constraining resources in poorer communities, in particular, and by, for example, affecting tourism and the range of other goods and services that ecosystems provide (MEA, 2005). Human societies are themselves changing, from rural to urban and from locally-focused to globally-connected.

This Science Plan focuses on five key issues of concern for global environmental change research in Africa, namely:

- Land degradation, biodiversity loss and human well being
- The impact of climate on rainfall and water resources
- Transforming agriculture in Africa for food security in a changing climate
- Air pollution and its impact on health in urban areas
- Africa's oceanographic uniqueness.

The four focus areas are influenced by various interconnected drivers of change, including *land cover change* resulting largely from agriculture, forest clearing and infrastructure development; *atmospheric composition change* as a result of anthropogenic emissions of greenhouse gases, aerosols and nitrogen- and sulphur-containing trace gases; the *climate change* that, taken 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*.

The purpose of this Science Plan is to describe the areas of GECR that are of particular importance and interest to 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. The Science Plan is not a prescriptive framework for all GECR work in the region, but it is expected that the strategic plans of ICSU affiliates and programmes will take it into consideration in their own planning, and that research funding agencies and Africa-orientated researchers will, where appropriate, coordinate their activities so that they contribute to or complement those identified here.

In preparing this document, as noted earlier, the reviewers took into consideration the ICSU Strategic Plan 2012–2017, new developments in the global environmental change research agenda, the Future Earth initiative, and the Science, Technology and Innovation Strategy for Africa 2024 (STISA 2024). The revised Africa Science Plan for Global Environmental Change has also incorporated ideas from both the current ICSU ROA Global Environmental Change and the AfricanNESS Science Plan.

2. The African Context

2.1 Global Environmental Change Challenges in Africa

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 – for example, desertification, biomass burning and global warming – can have global consequences. In turn, processes occurring in other regions of the world can have influences in Africa. A good example is the El Niño phenomenon in the Pacific Ocean that affects rainfall patterns in Africa.

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 is the second most populous continent of Earth, with an estimated population of 1.166 billion in 2015.[1] The continent has a population growth rate of 2 4%, which is twice the global mean. As a result, Africa's population, according to some projections, will exceed that of Europe, North and South America combined by 2030 (UN Habitat, 2014), and is projected to be around two billion by 2040.

Population growth will also be accompanied by extremely rapid urbanisation. The urban transition, including the shift of people from rural to urban areas, has been cited by some to be the most decisive phenomenon since independence in most African nations (UN Habitat, 2014). This population growth, mainly in the urban areas, will exacerbate existing problems of human settlements in urban areas, infrastructure, food security as well as the provision of services such as safe water, education, health, and more. It also adds ecological stresses to the glaring economic pressures evident on the continent.

Africa's economic growth has, however, been robust and in 2013, Africa maintained an average growth rate of 4% as compared to 3% for the global economy (ADB, OECD and UNDP, 2014). The growth has, however, been varied. Domestic economic performance has been good in many African countries (e.g., Angola, Ethiopia and Nigeria), with others showing sustained economic growth (e.g., Ghana, Kenya, South Africa and Tanzania). However, the situation in most countries on the continent remains a challenge (UN Habitat, 2014). A major challenge for Africa as a whole is to preserve both political and social stability (ADB, OECD and UNDP, 2014).

The key challenges facing Africa, arguably to a greater extent than other regions of the world, include the following:

- *Poverty*. Poverty levels are falling and incomes are rising. The Human Development Index (HDI) shows a 1.5 per cent annual growth with several countries (15) now being considered as having medium to high human development (ADB, OECD, and UNDP, 2014). Despite the economic gains, many in Africa still face challenges of poverty. Gender equality and environmental sustainability, together with the need for more equitable and socially-inclusive economic growth, remain key challenges (ADB, OECD and UNDP, 2014).
- *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 1 000), and life expectancy at birth is only about 54 years or lower. A large portion of the population suffers from diseases such as malaria, HIV/AIDS, cholera, and tuberculosis, which are largely under control elsewhere in the world. Recent outbreaks of Ebola, for example, have shown that health monitoring and global support is still critical in ensuring a healthy African population. In some reports (WHO, January 2015), in excess of 21 000 reported confirmed,

[1] http://worldpopulationreview.com/continents/africa-population/

probable and suspected cases of Ebola had been reported mainly in West Africa. In southern Africa, cholera has been endemic in Malawi, Mozambique, Zambia and Zimbabwe since 1998. The cholera outbreaks in Angola in 2006 2007, and in Zimbabwe in 2008 2009, were extensive and required humanitarian assistance (Holloway *et al.*, 2013). Despite these grim revelations, other health challenges have been improved on, including river blindness that has been eliminated as a public health problem, and polio that is close to eradication (WHO, 2015).

- *Hunger*. Hunger, poverty, disease, and vulnerability to environmental change are all closely linked. Great strides have been made by some African countries (FAO, 2014), but overall, the continent is reported to be making slow progress in achieving international hunger targets. This has been the result of a number of factors, including conflict and disasters. One in four people are estimated to remain undernourished in sub-Saharan Africa (FAO, 2014).
- *Armed conflicts*. These threaten lives and livelihoods, increase vulnerability to natural hazards and disease, and spawn refugees who degrade the environment for lack of other resources. The number of armed conflicts have been reduced since 2000 but this has been replaced by an increase in internal public protests and civil violence (ADB, OECD and UNDP, 2014; UN Habitat, 2014) that threaten to become larger scale when they transgress national boundaries.
- *Lack of education*. Education in Africa remains a key driver of development (Lutz *et al.,* 2014). Notwithstanding poverty on the continent, there are now far more children going to school than in previous generations, including substantial gains in secondary school education (Lutz, *et al.,* 2014). Declines in fertility and early mortality could accompany such education advancements.
- *Desertification*. Dry lands cover 43% of the continent, and harbour a third of the population (UNDP/ UNSO, 1997; WWF, 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, deforestation amounted to 5.2 million ha/yr (0.78% of the forested area annually) for the period 1990–2000 (WTO, 2003). The humid savannahs of Africa are currently a major region of agricultural intensification and clearing for the provision of charcoal to city populations.

Africa is subject to all the GEC drivers already outlined, to varying degrees. The existing work on GEC and its impacts in Africa has recently been comprehensively assessed (Boko *et al.*, 2007 and Niang et al., 2014), and it will not be reviewed here.

One key driver of change is the climate system. In summary, the climate of Africa is diverse, and controlled by complex interactions between the oceans, land and atmosphere at local, regional and global scales. On average, Africa is hotter and drier than most other regions of the world, and has a less dependable rainfall. As a consequence, and considering the fact that livelihoods at all levels (from individual households to the regional economy) depend heavily on climate, several studies have concluded that Africa is among the most vulnerable continents to the climate changes that threaten even higher temperatures and greater variability in future (Fischer *et al.*, 2002 and 2005; McCarthy *et al.*, 2001; Boko *et al.*, 2007; Stern, 2007). Large areas on the continent are projected to become drier, with more variable rainfall than at present.

Additional change stresses include socio-economic drivers. The second African Environment Outlook (AEO) report (UNEP, 2006) illustrates, for example, how growth within the environment, society and economy can

influence the role of GEC in attaining development goals. Low incomes and vulnerability to systemic changes, such as desertification, as well as increasing extreme events make adaptation to climate and environmental change particularly difficult. Because of these vulnerabilities, GEC is likely to increase poverty further, and to reduce the ability of households to invest in a better future (Low, 2005; Boko *et al.*, 2007).

Present-day Africa is demonstrably vulnerable to both droughts and floods, which are detrimental to food production, human health, water resources and natural resource-based livelihoods, and which exacerbate the degradation of land and coastal zones. The continent's vulnerability is likely to increase in future. However, the adaptive capacity of local, national and regional institutions in Africa is relatively low, owing to limited economic, human, infrastructural, and information resources and governance, and various types of conflict that exacerbate the situation. These limitations have informed our selection of focal issues and research themes described in this Science Plan.

One key additional stressor is human capacity. A recent report on GECR activities and capacity in Africa, for example, 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 based in only five countries namely: Cote d'Ivoire, Ghana, Kenya, Nigeria and South Africa (Scholes *et al.*, 2006a). The African researchers represent about 2–5% of the global research effort in GEC, but their publications constitute only 0.5–1% of the papers in leading international GEC journals. More recent assessments undertaken for the International Social Sciences Council (ISSC, 2013) echo these earlier findings and also show that capacity for global environmental change is growing but remains a challenge in Africa. Available assessments of science on the continent undertaken in 2010 (all science outputs), reveals that South Africa dominates all scientific publications (comprising 46.4% of the sub-continent's share) followed by Nigeria (11.4%) and Kenya (6.6%) (Urama *et al.*, 2010, 26).

African social scientists have also begun to add to the prioritisation of GEC-related research by identifying some key challenges facing Africa in the 21st century, thereby expanding the field of research that has been dominated by physical scientists. They include, for example, complex neo-liberal globalisation; inter-cultural relations; poverty and climate change; gender and intergenerational relations; the evolution of spirituality and contemporary forms of religion; emerging powers in the South; the history of GEC interactions; gender mainstreaming (13th CODESRIA Assembly, 2011; see also extensive coverage of various areas of research in the 2013 ISSC/UNESCO, World Social Science Report; Chanie, 2013; Vogel, 2013). The range and variety of issues call attention to social phenomena and processes that need to be understood when identifying environmental drivers, conditions or states.

Publications on climate change and broader GEC themes in Africa and in the sub-Saharan region also reflect the shifts in GEC research that have taken place over the past decade (Table 1). These sources include only those found on the Web of Science (WoS) database and point to the need to take cognisance of the so-called 'grey literature' and those in languages other than English that are not reflected in these assessments shown in Table 1. Themes include 'vulnerability and resilience'; 'modelling energy systems' and 'environmental governance' with noticeable gains between the period 1990/99 and 2000/2011 (e.g., 405 articles on 'vulnerability and resilience' (2000 2011) compared to 28 (1990 1999).

Table 1. Publication counts for articles published on Climate Change and Global Environmental Change by themes in the sub-Saharan Region as registered in the Web of Science Data Base

Article themes	Number of articles	
	Period 1990-1999	Period 2000-2011
Climate change impacts	7	48
Energy resources	1	33
Modelling energy systems	4	146
Sustainable rural development	5	30
Sustainable urban development	22	66
Vulnerability and resilience	28	405

Note: Actual full publication counts noted. See Waltman in annex to the ISSC 2013 report, source for data Web of Science, Annex B, Table B.7, World Social Science Report, 2-13 (Vogel 2013).

The GEC researchers in Africa are organised into multiple overlapping networks, including several existing acknowledged centres of excellence (e.g. Applied Centre for Climate and Earth Systems Science (ACCESS); Southern African Science Service Centre for Climate Change Adaptation and Adaptive Land Management (SASSCAL)). There is a growing engagement on social science research and development related research spurred on by the formation of Future Earth, and by Future Earth Africa. There is an equally large research community that works on, but is currently disconnected, for the most part, from development-related issues that are highly relevant to GEC.

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

The emphasis of GECR in Africa is also shifting from an impact-led approach (one that describes the physical hazards associated with change, with an emphasis on predictions and assessments), to a vulnerability-led approach. The latter is focused on understanding the socio-economic, institutional, cultural and biophysical factors that increase or decrease vulnerability, and it 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 (Adger *et al.*, 2006; Brooks, 2005), and links between environmental change (including climate change) and development (Huq *et al.*, 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 current and future needs. This revised Science Plan, therefore, attempts to present a vision for how some of these possibilities could be realised.

2.2 Status of Global Environmental Change Research in Africa

Over the years, a number of African scientists have been actively involved in global environmental change activities through the ICSU Regional Office for Africa. Scientists on the continent have been taking part in international research projects linking global environmental change research in the region to land-use and

cover-change, land-ocean interactions in the coastal zone, urbanisation and human health, climate change and water resources management.

ICSU-associated activities

At an international level, ICSU initiated (in the 1980s) four major GECR programmes: the World Climate Research Programme (WCRP); the International Geosphere-Biosphere Programme (IGBP); the International Human Dimensions Programme (IHDP); and the international programme of biodiversity science (DIVERSITAS). For a portion of their agendas, these programmes worked together under the framework of the Earth System Science Partnership (ESSP). The international programmes themselves have also had research based in Africa, both in the form of individual projects, and in large coordinated campaigns, such as the Southern African Regional Science Initiative (SAFARI, 2000), the study of wildfires, or the Africa Monsoon Multidisciplinary Analyses (AMMA) study of monsoons. Further, at the 29th ICSU General Assembly, the recommendation was made to establish a new interdisciplinary Programme on Ecosystem Change and Society (PECS) with a mission to foster coordinated research to understand the dynamic relationship between humans and ecosystems.

As a way forward, Future Earth has recently been established (including setting an Africa Future Earth Committee (AFEC)) to build on the success of existing global environmental change programmes seeking to develop the knowledge for responding effectively to the risks and opportunities of global environmental change, and for supporting transformation towards global sustainability in the coming decades. Aligning the regional global environmental change programmes to Future Earth can help in developing a stronger and broader community, and in promoting and coordinating innovative science research that informs and improves societal responses to global environmental change.

International activities not coordinated by ICSU

Official Development Assistance (ODA) agencies have had active GECR programmes in Africa for more than a decade. Many are associated with developing capacity to satisfy the reporting requirements of the UN Framework Convention on Climate Change (UNFCCC), a role that in recent years has largely been taken over by the Global Environmental Facility (GEF), working through the UN Environment Programme (UNEP).

The highly successful Assessments of Impacts and Adaptations to Climate Change (AIACC) programme funded by GEF and administered by UNEP and the Academy of Sciences for the Developing World (TWAS), was completed in 2007. It supported 24 regional study teams to conduct three-year investigations of climate change impacts, adaptation and vulnerability in 46 developing countries, and helped in the understanding of climate change issues among stakeholder groups in developing countries.

The UK Department for International Development (DFID) and the Canadian International Development Agency (CIDA), working together, have also developed and monitored, between 2006 and 2012, a major programme in Africa, the Climate Change Adaptation in Africa (CCAA) Programme. The programme has contributed to build organisational capacity significantly, and in improving the adaptation capacities of African researchers and local communities and organisations.

Today, at the continental level, the Climate for Development in Africa (ClimDev-Africa) Programme is a joint initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (ECA) and the African Development Bank (AfDB), mandated by the African Union Summit of Heads of State and Government to create a solid foundation for Africa's response to climate change.

In addition, the ClimDev-Africa is supporting a new initiative on a Pan-African Climate Research for Development (CR4D), hosted by ACPC, with a joint oversight of the ClimDev-Africa programme, the African Ministerial

Conference on Meteorology (AMCOMET) and the World Meteorological Organisation (WMO). The main objective of CR4D, in working with various partners, is to identify and support the enhancement of climate research in priority areas to serve development needs in Africa.

Outside Africa, the European Union (EU) is one of the main donors supporting the African countries for GECR programmes, at the national, regional and continental levels, through the European Development Fund (EDF), the new Pan African Programme (PanAf 2014–2020, within the framework of the Joint Africa–EU Strategy, JAES), or other sectorial research projects via Directorates-General for Research and Innovation, and for which third countries can participate to the calls.

The Global Framework for Climate Services (GFCS) is a new initiative dealing with GECR with long-term outcomes and benefits for the user communities to make climate-smart decisions and for the climate information to be disseminated effectively. It started its activities from 2012, with national and regional projects in Africa. Research, modelling and prediction comprise one of the five pillars of the GFCS and aims at ensuring that climate observations and other data, necessary to meet the needs of end-users, are properly collected, managed and disseminated.

Several new regional programmes are starting or have been on-going in Africa, supported by bilateral cooperation. For example, new DfID-funded programmes include weather and climate information and services for Africa (WCISA), focusing on resilience to natural disasters and climate change by improving early warning systems. The Future Climate for Africa (FCFA) programme supports world-leading science to enhance understanding and predicting African climate and bringing this knowledge into use in informing major decisions. The main focus of the Building Resilience and Adaptation to Climate Extremes and Disasters programme (BRACED) will be to build resilience to disasters, while the Unlocking the Potential of Groundwater for the Poor (UPGP) programme aims at delivering robust evidence on the opportunities and constraints to sustainable, long-term groundwater use in Africa.

There is also a significant presence of the Consultative Group on International Agricultural Research (CGIAR) in Africa, and many of its Centres (e.g., IWMI) have active GECR programmes. Several African institutions, including the AU, NEPAD and the UNEP Regional Office for Southern Africa (UNEP-ROSA), have been active in securing the political will and commitment of African governments and leadership. Other UN agencies having GEC activities in Africa include the UN Educational, Scientific and Cultural Organization (UNESCO), the Food and Agriculture Organization (FAO), the UN Convention to Combat Desertification (UNCCD), the World Meteorological Organization (WMO); and the World Health Organization (WHO).

National and local activities

Most researchers in Africa engaged in GECR are involved in studies motivated nationally or in their own institutions. In addition, there is a large community of researchers in health, development, resource management and agriculture, mostly at this scale, who do not consider themselves primarily involved in GEC studies, but whose activities are highly relevant to GECR. However, the national endeavour for research in general, and GECR in particular, is weak in African countries, and typically with a strong reliance on the foreign aid. Universities, national agriculture research systems (NARS) and other research centres are the main places where the GECR research activities take place at the national level.

Regional bodies like Regional Climate Centres (RCCs) and River Basin Organizations (RBOs) are other places where the national GECR activities of the member countries are also considered, usually with the backing of their Regional Economic Commissions (RECs).

3. Vision, Objectives and Principles

The research envisioned in this Science Plan aims to enhance significantly our knowledge of global environmental change (including climate change) in Africa, and our ability to address such change. In particular, it will provide a more robust understanding of:

- The processes underlying the observed and projected changes (particularly where they are to some degree uniquely African or especially important in Africa), their spatial pattern and likely temporal evolution.
- Interactions between the multiple concurrent factors that shape and configure the environment (which include biophysical, societal, cultural and economic dimensions).
- The impacts and implications of the projected changes for African populations, and the adaptive and mitigating actions needed to influence impacts.

The areas selected represent our view of the intersection of African research needs, capabilities, and opportunities (see Figure 2).

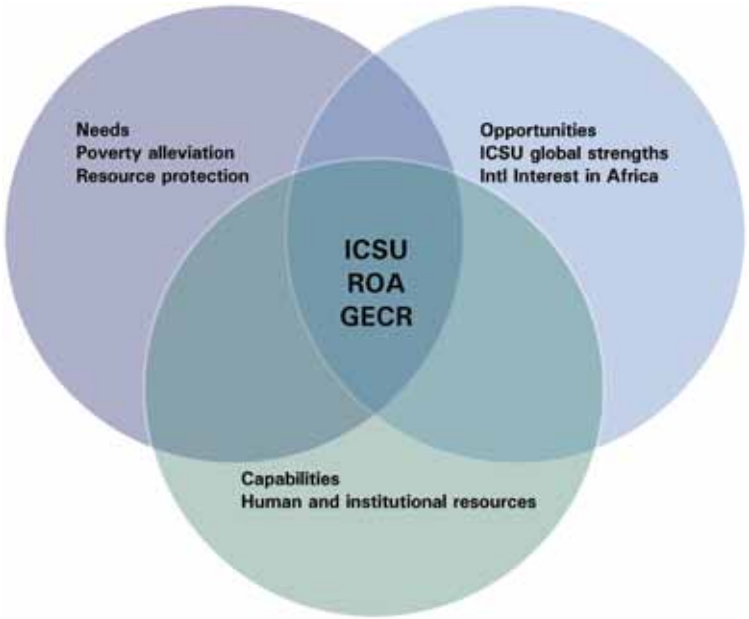

Figure 2. The comparative advantage of ICSU ROA global environment change research in Africa lies at the intersection of what is most urgently needed, what is scientifically feasible, and what is best done in Africa.

The challenges and issues of sustainable development and poverty alleviation in the African context, and the need to find new ways of ensuring excellence and sustainability of scientific activities into the future, guided the preparation of this Science Plan which is rooted in four principles:

1.) *Design a few large-scale, long-term, regional and sub-regional programmes.*

The African Science Plan for GECR focuses on a maximum of six 'broad' questions or research themes to be tackled in the period 2016–2020 and beyond, rather than short-lived, sporadic research topics, so

Souce: http://www.montybrett.com/category/courses/

that long-lasting and sustainable research and capacity can be generated. These topics take into account the strategies of ICSU and the Future Earth initiative, and exploit Africa's comparative advantages within them, so as to draw as much global research effort into the African sphere as possible. The key research themes are described in this Science Plan, with flexibility for new ideas and themes to be pursued.

2.) *Encourage interdisciplinary and multi-institutional projects/ programmes.*

Where appropriate, research agendas should be framed in an interdisciplinary and transdisciplinary manner (where relevant) to capture the multiple causality of environmental change in Africa. Successful interdisciplinary research requires competence within disciplines. The Earth systems science approach is inherently interdisciplinary, 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 on their own. Epistemological approaches derived from the social, political, health, cultural, and economic sciences provide new avenues for the GECR community to consider (Airhihenbuwa, 1995). A greater challenge for a science-based organisation such as ICSU, but very relevant in Africa, is the creation of links to various forms of knowledge creation, for example, 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 would also add new insights globally.

3.) *Science–practice–policy interfaces.*

Whereas there is clearly a need and a critical role for ongoing fundamental science-led research, the realities of the continent require a pragmatic, user-focused approach to real-world problem solving in priority settings. Such efforts can be assisted by adopting transdisciplinary approaches. 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 (Guston, 2001). These must also ensure that knowledge gaps identified by the user community are promptly and effectively researched. Institutions need to change from being knowledge consumers to becoming knowledge creators, to be well-structured to ensure knowledge transfer to where it is needed, and in the form in which it can be used.

Such interactions between science and society are messy and usually are not only linear and 'bridges' between science and use are needed. The diversity of power relations between actors is thus a key issue (Miller, 2001). A range of 'brokers' and institutional designs that can both convey and receive information between producer and user groups are suggested (Jasanoff, 1987; Cash and Moser, 2000; Cash, 2001; Guston, 2001; Miller, 2001; Vogel *et al.*, 2007). Existing modes of science-policy interactions are useful examples to be adopted or emulated; for instance, assessment processes such as the Intergovernmental Panel on Climate Change (IPCC) and Millennium Ecosystem Assessment (MEA), and more recently, the International Panel of Experts on Sustainable Food Systems (IPBES-Food).

The products of scientific research also need to be credible, salient and legitimate (Cash, 2001). This means that, in addition to greatly improving the dissemination of results after the research is conducted, the research agenda needs, at the outset, to be negotiated with the users as relevant and appropriate. It is no trivial effort to balance the needs of relevance and rigour in such initiatives, and much thought, reflection, and research is required for this activity alone.

4.) *Build human and institutional capacity.*

Capacity building includes not only training and developing the next generation of scientists (and thus strengthening human capacity), but also ensuring that institutional capacity is enhanced in Africa. This requires a multi-faceted, coordinated, and deliberate effort, including the creation of institutions for advanced study and training ('centres of excellence'); supportive networks in areas such as modelling; engagement of non-African experts in local training; improving the retention of skills in Africa; creating incentives for temporary or permanent repatriation or participation of African experts in the Diaspora; encouraging regional mobility of experts and mutually beneficial North–South and South–South cooperation; and developing receptive capacity in the end-users of research and the research communicators ('extension workers') who link to them.

http://maxpixel.freegreatpicture.com/Elephant-African-Animals-African-Bush-Elephant-748288

4. Capacity Building Needs

Capacity building is a challenge in all countries, but there are particular issues in developing countries, where limited financial resources and an absence of universal education systems amplify the problems. There is wide and growing acceptance, internationally, of the need to build capacity to adapt to global environmental 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 for its analysis are native to Africa. As a result, Africa is faced with the necessity of dealing with a complex economic, scientific and social issue, but without the scientific background, the necessary tradition of public awareness and mobilisation, or the financial resources and implementation structures to do so. Capacity building here means providing frameworks for project identification, formulation and implementation, and maximising the use of existing skills and resources.

The six crucial challenges to building scientific capacity with reference to Africa are:

1.) *Building and strengthening human capital*. Finding effective ways to bolster and promote PhDs and entrepreneurial training in Africa. Establishing an enabling environment via fast-tracking mechanisms that enhance the growth and development of young scholars; for example, supporting them to attend global change committee meetings so that they can be exposed to and learn networking and knowledge building skills and techniques.

2.) *Providing research infrastructure, adequate remuneration and incentives for researchers, so as to retain capacity*. Infrastructure is needed both for enhancing access to information, and to research and training. 'Hard' infrastructure is needed in the form of access to data and technology (e.g., *Ubuntu* – enhanced and fast access to internet and high speed computing). Ways could be found to share infrastructure in Africa, such as equipment and other resources when brought into Africa via large funding and donor programmes (e.g., in big field campaigns). Such resources could be leased and shared among Africans so that these resources remain in Africa and are used by Africans. 'Softer' infrastructure is needed to support and create incentive structures for young graduates to engage in science. Recruiting talent into science is a concern. Attracting, developing, and retaining talent in science and technology must be a priority for the scientific community.

3.) *Communicating more effectively between science and society*. Finding effective and appropriate ways to share science with society, and also to engage with society around science (e.g., citizen science) is a priority. Cases on science relevant to diet and nutrition, among others, provide examples for science communication and relevance for society. Science communication and citizen science require careful thought and design systems as well as institutional frameworks with capacity to enhance and support global environmental change knowledge production and co-engagement with various GEC epistemic communities.

4.) *Developing a culture of strong links between science, policy and practice*. This includes business involvement in science, for example, in risk-based weather insurance mechanisms for effective disaster risk reduction involving science, government and society. To illustrate, in 2012, 26 African Union Member countries established the African Risk Capacity (ARC) agency to provide its members with rapid funds in the event of drought. ARC is based on the quantification of drought risk from each participating country, in order to determine how to manage the risk transferred to ARC, and how to make payments to member countries. The African Union Commission (AUC) has worked with the

World Food Programme to develop a software application called Africa Risk View (ARV), aiming at monitoring and quantifying, in US$, the weather-related food security risk in Africa. ARV uses climate change scenarios as an input and allows the evaluation of the future impact of climate variability on critical issues like the food security and the overall performance of the envisaged risk management system. A further priority is finding ways to valorise African research through, for example, the co-design of start-ups and small transformation engagements that can involve universities and the public sector.

5.) *Strengthening the links between education and research, and among researchers in different parts of the continent*. In order to establish critical mass, enhanced efforts are needed in building access to formal education, and also in supporting other forms of educational access (e.g., social media, development of books etc.).

6.) *Developing clear national strategies for capacity building*. It is important that existing and successful capacity building efforts in Africa are made more visible; for example, to government, business and other potential funders and partners.

Capacity building activities should be country- and demand-driven, to ensure their outcomes are sustainable. Without the financial resources, new technologies, parts for equipment, and know-how needed for equipment maintenance, the outcomes of programmes would be limited to the short-term, and are unlikely to be sustained over the long term. The loss of trained staff who take up more attractive offers outside the public sector results in a brain drain, and compromises future capacity development. Without well-functioning institutional, policy and legal frameworks, efforts to build capacity are limited to the people directly involved in the process, and broader policy level outcomes are unlikely (Table 2 below shows some of the barriers and how they could be overcome).

Capacity-building activities in the public sector should be integrated into the overall public-sector reform processes. In the interests of sustainability, it is important that responses to environmental risks be mainstreamed within nationally-owned strategies, such as those designed to reduce poverty, 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.

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 to transcend the diversity of experiences, and enable constructive dialogue about the risks and benefits of scientific discoveries and new technologies.

Table 2. Obstacles and Enablers for Capacity Building in Africa

Obstacles to Capacity Building	Enablers and Objectives for Capacity Building
Inadequate scientific infrastructure and funding for science education.	Create an enabling environment for science education by providing adequate infrastructure and funding for the conduct of science. Science education is critical and, in particular, requires strengthened research capabilities in academic institutions. It is important to link these tertiary institutions to contemporary research so as to promote and sustain national innovation.
Lack of motivation and continuity plans	Provide incentives for human capacity retention. Senior scientists need motivation to stay in their jobs and provide mentorship to younger colleagues, so as to ensure smooth succession and continuity.
Lack of requisite information on climate and other natural resources.	Facilitate systematic observation involving all sectors of society in recording information on climate and natural resources (for example, rainfall, fish landing, soil quality, crop yields, and vegetation cover).
Inadequate disaster vulnerability assessment.	Assess societal vulnerability and adaptation by using community-based techniques to measure and record information and assess vulnerability to global change and training researchers to assess better the risks due to these changes.
Inadequate institutional capacity building to respond to disaster and its aftermath.	Enhance institutional capacity so as to enable local, regional and national authorities and civil society to respond to disasters, to adapt to global environmental change, and to plan and adopt mitigation measures. .
Lack of technology transfer in addressing disaster.	Provide enabling environment for technology transfer by introducing appropriate technologies to aid adaptation (flood control systems and emergency shelters, for example) and mitigation (energy efficiency and reforestation, for example); and strengthening the capacity to adopt and maintain new technologies.
Communication difficulties among key stakeholders involved in capacity building activity.	Ensure effective communication among the agencies, institutions, governments, NGOs and community groups responsible for tackling key environmental issues. Technical data should be made available for these agencies to encourage securing cross-border and inter-regional cooperation.
Lack of awareness creation on the adverse effects on global environmental issues (pollution).	Foster and raise awareness of the causes and effects of global environmental change and possible responses, at all levels from primary schools to universities and in civil society through non-governmental organisations (NGOs) and community groups. Media sensitisation is also key.
Failure of stakeholders to implement policies on environment and climate change.	Integrate the adaptation responses into national development strategies, through capacity building and assessment of the response to climate change event. This includes reducing the risk of climate impacts on infrastructure investments ('climate proofing'), improved disaster preparedness, use of traditional knowledge and new technologies, and coordinated regional response.
Lack of an integrated or cross-sectored approach.	Raise awareness of global environmental issues that need to be addressed throughout the public and private sectors in order to achieve a consolidated approach.
Lack of high level political commitment.	Provide central budgetary allocation and financial resourcing to climate and environmental issues at the local, regional and national levels.

Obstacles to Capacity Building	Enablers and Objectives for Capacity Building
Complex institutional policies and difficulties in getting key advisors for training opportunities.	Reduce cumbersome or overly-bureaucratic systems or procedures as far as getting prompt response to environmental issues are concerned.
Failure by donors to integrate global environmental change adequately into development cooperation policies and programme.	Help integrate formulated global environmental policies into the development agenda at the national level. Donors must also ensure that proposed programmes see the light of day.

Closing knowledge gaps will require putting in place national strategies for science and technology development that are linked to effective policies. There is paramount need to present political leaders and governments with advice and recommendations about policies derived from national strategies to guide education, research and innovation.

Capacity building should involve both institutional and human resource development. These, combined with external financial and technical support, are normally required to achieve sustainable results. Institutional capacity building should involve decision-makers at the highest level. This is necessary to ensure continuous support for capacity development after the initial programme is completed. In local and regional programmes it is essential to have appropriate regional and national authorities and institutions on board to ensure full acceptance of, and support for, the initiative. Both donors and host countries should 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.

The international global change SysTem for Analysis, Research and Training Secretariat (START), through its Pan African Secretariat (PASS) activity, played a leading role in GECR capacity development in Africa, and needs to continue to do so. It is also worth noting the approach of the French Institute of Research for Development (IRD, formerly known as OSTORM), which has been present for more than 60 years, in around 90 developing countries around the world, mainly in Africa, through the tools developed or co-constructed with its local partners. These include Joint International Research Units, Regional Pilot Programs (RPP), young local teams associated with the French National Institute for Research for Sustainable Development (IRD) flagship programme and long-term environmental research observational and experimental systems (SOERE). Individual training supports are also provided through programmes, such as the 'thesis research grants in the South' (ARTS programme) or the 'research and technology exchange' (BEST programme).

There are other programmes within networks of universities such as the Transdisciplinary Training for Resource Efficiency and Climate Change Adaptation in Africa (TreccAfrica) which provides doctoral and master's training to 80 postgraduate students in Africa at six leading African universities with the support of the Intra-ACP Mobility Scheme. This, in turn, enables the next generation of academics and professionals to address an interlocking set of real challenges for Africa's future development: climate change and resource depletion. The Carnegie Corporation of New York and the Cambridge Africa Partnership for Research Excellence are supporting the Next Generation of African Academics (NGAA). NGAA provides a platform to showcase the activities and achievements of the four participating universities: Makerere University (Uganda, Eastern Africa), University of Ghana Legon (Ghana, West Africa), University of Cape Town and University of Witwatersrand (both in South Africa). The objectives of this initiative are to provide high quality graduate training and the sharing of training resources across universities as scholarly and scientific communities that enhance the development and retention of 'next generation' academics.

5. Proposed Research Activities

The African Science Plan on GECR focuses on a selected subset of research topics presented below. These were arrived at by a consultative, but ultimately subjective, search for a limited set of coherent, highly integrative themes that satisfy the principles and objectives outlined above. Additions or extensions to these themes will no doubt arise during the review and implementation of this Science Plan, which is meant to be indicative rather than prescriptive. The desired outcome is at least one new, large-scale flagship project in each thematic area within the next five years.

It is typical of GECR that everything is connected to everything else (see Figure 3). We are aware of this, and have even relied on it to assist in crafting a synergistic, coherent programme rather than a set of independent projects. There is no perfect way to disentangle these interconnections and at the same time carve such a wide field into manageable chunks. What follows is one scheme. The evolving research will largely organise itself in the way that makes best sense at the time.

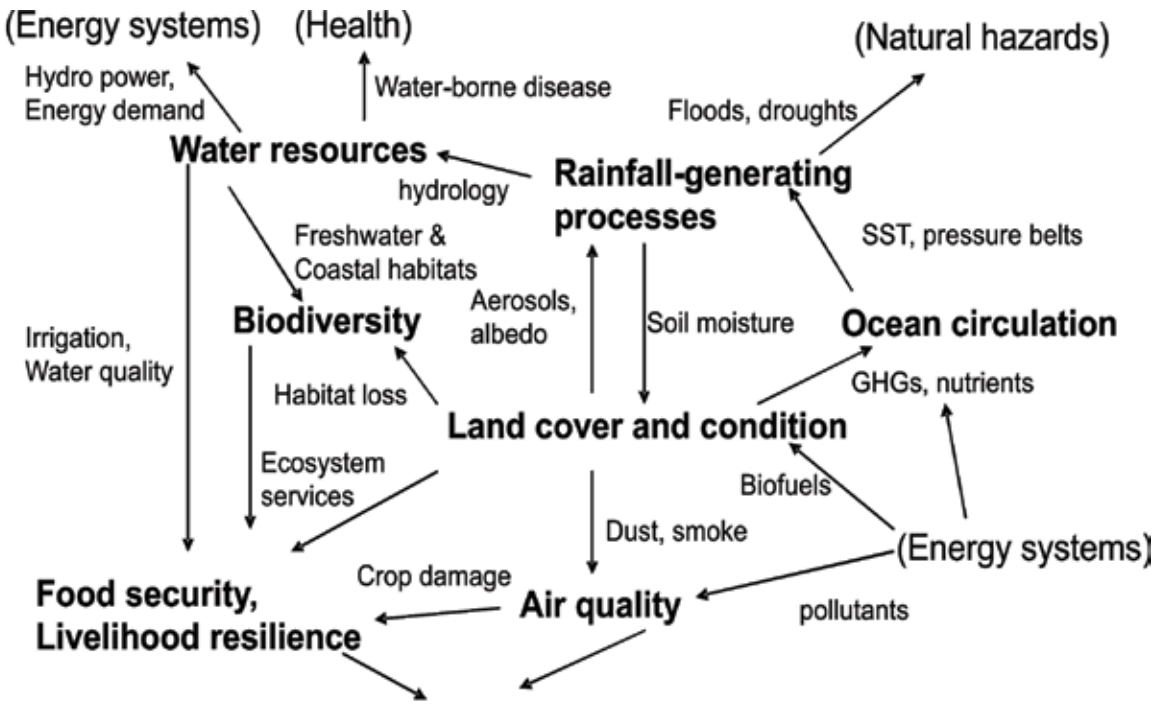

Figure 3. The main links between the research areas proposed in the GEC Science Plan (bold) and among them and other ICSU ROA driven science plans (in brackets)

Similarly, we are keenly aware of the links between this strategy and the strategies outlined in the ICSU ROA driven science plans for Sustainable Energy, Health and Human Well-being, and Natural and Human-induced Hazards and Disasters. We do not consider these links to be duplications or redundancies, but rather as opportunities for building synergies and linkages.

Source: https://pixabay.com/en/forest-fire-blaze-smoke-trees-1161868/

5.1 Land Degradation, Biodiversity Loss, and Human Well-being

Three land change processes are simultaneously taking place in Africa, to a degree perhaps more acutely than in any other region. The first is *land degradation* – the decline in the capacity of the land to support life. This is a longstanding concern, particularly in populous but dry African countries, that led to the Convention on Combatting Desertification. The second is the rapid pace of *urbanisation*, projected to lead to the emergence of hundreds of medium-to-large dense settlements in places where previously there was farmland or villages. The third is *deforestation*, specifically the conversion of sub-humid woodlands into agricultural land.

Africa is the last major global frontier for agricultural expansion for food and biofuels. The result of these processes is a widespread change in the way land is used, which has global and local drivers and consequences; among the latter are altered land cover, emissions of carbon, and reductions of some ecosystem services and increases in others.

Some of the key issues are:

- The need to pass through a stage of land degradation and reduced natural capital in order to achieve high development status, at which time restoration can take place.
- The need to preserve biodiversity and human well-being by comparing the intensification of low-input agriculture, and intensification accompanied by land-sparing.
- The needs of the urban population for water, energy and food to be met, using opportunities that urbanisation offers to reorganise the landscape in more sustainable ways.
- The use of ecosystem restoration and protection that assist in adaptation and mitigation to climate change.

There are strong direct linkages from these topic areas into global research programmes such as the Global Land Programme (GLP), Global Carbon Project (GCP) and the Integrated Land-Ecosystem Atmosphere Process Study (iLeAPS), and indirect links to the Global Water System Project (GWSP) through water resources, the Analysis, Integration and Modeling of the Earth System (AIMES) through climate, ecoServices and ecoHEALTH through biodiversity, PECS, the Environmental Growth Chambers (EGC), and the Integrated History and future Of People on Earth (iHOPE) through environmental governance, the Climate Change, Agriculture and Food Security (CCAFS) through food security, and the Urbanization and Global Environmental Change (UGEC) through urbanisation.

5.2 Climate Systems in Africa

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) affirms that the warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia (IPCC, 2014). Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions, and between wet and dry seasons, will increase, although there may be regional exceptions.

For Africa the most crucial climate change issue for decision-makers at all levels, from households to the African Union, is rainfall, and, in particular, its variability at all timescales (CDKN, 2014). Climate variability refers to fluctuations in climate or deviation from the long-term meteorological average over a certain period of time; for example, over a specific month, season, or year. Periods of drought and flood, heat and cold, have occurred interchangeably in the past (Ropelewski and Halpert, 1987; Nicholson and Grist, 2001; Tyson *et al.*, 2002).

Although climate variability is a normal phenomenon in Africa, it has been exacerbated in its manifestation by climate change. Climate variability in general and rainfall variability in particular threatens the developmental agenda of the continent as it impacts negatively on livelihoods, and on the socio-economic sectors of the continent. Rainfall variability in Africa manifests mostly in the following patterns:

- Irregularity in the onset and cessation of rainy seasons (irregular periods of rainy seasons)
- Increased frequency and severity of weather and climate extremes (droughts and floods);
- Irregular distribution of rainfall within the rainy season (flash floods and dry spells)

Almost all African countries depend on natural resource-based economic activities that are directly or indirectly dependent on rainfall. These include agriculture, natural resources (including wild life), water resources, energy and tourism. Infrastructure and other support services sectors are also largely influenced by rainfall regimes.

The IPCC AR5 Report finds that for the remainder of the 21st century, climate change – and rainfall variability, in particular – will pose challenges to food security, livelihoods, health and well-being, and that Africa as a region will be the most affected, due to its low levels of income and technological base. For example, the agriculture sector in Africa is mainly rain-fed and practised mostly by rural farming communities. Any change in rainfall patterns therefore directly results in a negative impact on agricultural productivity and livelihoods.
The IPCC AR5 reveals that changes in rainfall regimes over the continent differ from region to region. In particular, projections for rainfall are less certain than projections for temperature (IPCC, 2014). Most parts of Africa do not depict significant changes in the average annual rainfall under low-emissions scenarios. However, under high emissions scenarios, projections do show a very likely decrease in the average annual rainfall over parts of southern Africa, beginning in the mid-21st century and expanding substantially by the late 21st century. In contrast, a likely increase in average annual rainfall is projected over parts of central and eastern Africa, beginning in the mid-21st century for the same high-emissions scenario.

The effect of a range of climate extremes in Africa – including heavy rainfall, heat waves and droughts as the impact of climate change becomes more dramatic (IPCC, 2014) – will play an increasingly significant role in the impacts of disasters. Further, the geographical location of Africa renders it highly uncertain when assessing the nature of rainfall variability. It spans across the Equator and is affected by diverse regional climate phenomena: Intertropical Convergence Zone (ITCZ), El Niño Southern Oscillation (ENSO), and Monsoons, among others. These have different characteristics that may not easily be detected by a single climate model.

IPCC AR5 indicates that there will be a likely increase in the frequency of hot and dry days across the Sahara and parts of west, east and southern Africa. Eastern and south-eastern Africa will likely experience more heavy rainfall with more extreme wet days by the mid-21st century, and greater potential for intense flooding, partially driven by possible changes in landfall of cyclones originating in the Indian Ocean.

IPCC AR5 identifies adaptation as the only effective option to manage the inevitable impacts of climate change that mitigation cannot reduce. It describes adaptation as 'the process of adjustment to actual or expected climate and its effects'. Adaptation enables societies and communities to moderate the harm of current and future climate risks, or to take advantage of new opportunities. For example, Africa can gain from adaptation actions such as disaster risk reduction, and social protection that reduce the impacts of climate variability and climate change, which are already being felt across the continent, and from building resilience around critical

sectors such as water, energy and agriculture. IPCC AR5 emphasises that integrating climate information to support adaptation into planning and decision-making can create and enhance disaster risk reduction, reduce climate risks, build climate resilience and thereby contribute to sustainable socio-economic development.

The foregoing assumes sharpened and effective climate information early warning systems that generate and disseminate accurate and reliable climate data. Information data gaps in the weather and climate observations is one of the major challenges in climate variability and climate change assessments and research in Africa (WMO, 2015). Most African National Meteorological Services (NMSs) have had constraints in maintaining observational networks, equipment is often obsolete with irregular repairs, maintenance and calibration taking place.

For climate data to be of value to research, the associated climate observations must meet high standards defined by a number of important criteria. These include: climate observations need to account for the full range of elements that describe the climate system; and an observation at a particular time needs a reference climate against which it can be evaluated, that is, a reference climatological period. Therefore, observations from stations that exist for a short period (less than 30 years) and relocate frequently will have less value. Further, a climate observation should be associated – either directly or indirectly – with a consistent set of data (metadata) describing the conditions in which climate observations were collected. These provide users with information on how the observations can be interpreted and used.

Currently, climate observations in Africa are derived from numerous meteorological and related observational networks and systems that underpin applications such as weather and climate monitoring and forecasting, air pollution modelling, and environmental impact assessments (WMO, 2015). Under the auspices of the World Meteorological Organisation (WMO), the WMO Integrated Global Observing System (WIGOS) and the WMO Information System (WIS) serve as the basis for all members and WMO programmes in the provision of access to accurate, reliable and timely weather, climate, water, and related environmental observations and products.

Arising from the above, the ICSU Science Plan on Global Environmental Change (including climate change) in the area of rainfall in Africa could focus its priorities on:

- Support to NMSs to strengthen their capacity for surface and upper air observations, which will entail the modernisation and automation of observation networks.
- Support to NMSs for climate data rescue and management (including metadata documentation, data quality control and assurance, data storage, processing and archiving).
- Build capacity among African climate scientists for use of geo-spatial data technologies for rainfall estimates to fill the data gaps.
- Build capacity for climate modelling in Africa.
- Build capacity for cost analysis of socio-economic impacts of climate variability and climate change on climate sensitive sectors for down-scaling.
- Build capacity for the interpretation and application of climate/weather information in planning and decision-making in Africa.
- Build capacity in NMSs in Africa for sector specific climate services in line with Future Earth and the Global Framework for Climate Services (GFCS), and thereby support adaptation and mitigation strategies across sectors.
- Support research in the role of tele-connections and global climate factors such as ENSO in future regional climate change.

Source: http://zesterdaily.com/cooking/cassava-the-sleeping-beauty-of-the-african-kitchen/

5.3 Food and Nutrition Security

Reducing the vulnerability of Africa to global environmental change requires building the resilience of Africa's social and ecological systems, particularly through food security in the region. Food and nutrition security exists when all people at all times have physical, social and economic access to food of sufficient quantity in calories and quality in terms of variety, diversity, nutrient content and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, education and care (FAO, 2009). Food security includes issues of both 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 – for example, initially the UN Millennium Development Goals (MDGs), and now the Sustainable Development Goals (SDGs) – need to take into account global environmental change, including climate change. 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.

Integrated research needs to be carried out at three levels: a) at the household and community levels, where vulnerability is usually more clearly expressed; b) at the sub-regional level, so that the interaction of policy and vulnerability of food systems can be addressed; and c) 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.

The FAO should assist the AU in developing an African Action Plan on the sustainability of food systems in Africa that will guide member countries in implementing relevant policies and action plans, as a matter of urgency. The AU Commission could initiate strategic partnerships with civil society and other actors to promote and implement green and sustainable agriculture.

The regional organisations (e.g., SADC, ECOWAS, COMESA) should attempt to assist in the implementation of policies and action plans on sustainable and green economy. Additional financial resources from the national, regional and international

levels, including climate-related funds, should be made available to assist in the implementation of policies and action plans on food system resilience. In addition, the trade policies of African agricultural products should be amended to be more supportive of ecological and organic, agro-ecological agriculture.

The institutions involved in ecological agriculture should be mobilised to pool their expertise and identify ways to establish an African centre of excellence on food system resilience and agricultural research innovation. Research priorities along the value chain, including key food crops and animals, best practices, economic aspects, main problems and solutions to these problems, should be identified in a participatory manner at the sub-regional and local levels.

There is a need to include the mass media in awareness-raising efforts and encourage consumers to appreciate the values of local organic products. Guidelines must be developed for the training of trainers on watershed environmental management strategies and climate change adaptation practices through food systems resilience agriculture.

ICSU ROA would assist the scientists in mobilising financial resources for pilot projects on sustainable agriculture to be established in each African country to promote awareness about benefits of food systems resilience, food security and rural livelihoods.

A programme and calendar of training and technical assistance needs in relation to food system resilience should be identified and a list of experts compiled and targeted for continued capacity-building and training. Several broad, overarching questions and issues are now emerging from the substantial research on food security (GECAFS, 2006), such as:

- Global environmental change that will exacerbates food insecurity in Africa.
- The technical, social and policy options that will assist in Africa's food systems adapting to global environmental change.
- The balance in trade-offs that needs to be considered for agriculture in Africa with respect to land use for food production, and land use for renewable energy.
- Feedback is needed with respect to the various adaptation options to existing environmental and socio-economic conditions, with 'adaptations' referring to both large-scale, global adaptations that may be needed to ensure sustainable food security for Africa, and localised options that are currently practised but may be insufficient, given future environmental changes.
- The potential for crop and cropping systems diversification options needs to be considered, in order to reduce the risks associated with GEC, and to increase the adaptive capacities of communities.

Several of these issues are highly contested and therefore will require the engagement of both the natural and social sciences on issues of the ethics of food production, issues of food power relations, and more.

5.4 Water Resources Security

In the period of the Science Plan, at least half of the 48 countries that are expected to be facing water shortages will be in Africa. The implication is that in 10 years, 16% of the projected population (230 million Africans will be living in water-scarce areas with about a third in water-stressed areas (460 million) (ISD, 2007). Africa is losing 5% of its GDP as a result of poor water and sanitation infrastructure, 2% to power outages, between 5%–25% to drought and floods, and perhaps a further 5% to the (future) impact of climate change.

The estimated amount of investment required to meet Africa's deficient water situation is US$ 50 billion per annum for the period from 2015 to 2030, and US$ 30 billion annually for the following thirty years (ISD, 2007).

Groundwater is extremely important in Africa. It is estimated that over 40% of Africans use groundwater as their main source of drinking water, particularly in north and southern African countries. However, there is inadequate information regarding the recharge of groundwater, and the relationships between rainfall variability, land cover change, and land use.

The decline of water resource quality is due to land- and sea-based anthropogenic activities, such as the disposal of domestic sewage and industrial wastewater, toxic leachates from mining, and the effects of agricultural runoff containing sediments, nutrients and pesticides. The impacts accumulate down the drainage basin, with 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.

The key focal challenge is how to deliver water, energy, and food for all, and manage the synergies and trade-offs among them, by understanding how these interactions are shaped by environmental, economic, social and political changes. Solutions to these multifaceted problems require a transdisciplinary approach, combining bio-physical and social sciences with expertise in arts and culture. In particular, it needs the greater appreciation of all researchers of the respective strengths of their disciplines and the creation of systems that promote cross-disciplinary engagement where environmental, social, institutional, political, and economic variables interact. The overarching needs based on various gap analyses that take place in Africa on GEC research fall into four categories: a) assessments; b) knowledge management; c) governance; and d) capacity building. So to achieve sustainable water resource management, Africa requires the creation and enhancing of research and development programmes at all levels (national, sub-regional, regional and international). Such programmes need to make full use of local expertise – including indigenous knowledge and internally generated resources, and should be appropriate for the needs of the country or countries concerned.

Governments need to accept that water has an economic value in all its competing uses and should be recognised as an economic good. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources. The use of economic instruments in water resources management are more cost efficient than other instruments, and useful in mitigating diffuse pollution of water resources which supports 'the polluter pays' principle.

Key global environmental change research issues for water in Africa can be grouped as those that contribute to: observing, assessing and the attribution of changes in water; the understanding of processes, risks and thresholds; mitigating the inequities of water security on the continent and to meeting basic human and ecosystem needs; and identifying sustainable behaviours.

Apart from the basic quantification of the water resources base in Africa, research needs to focus on:

- The effect of spatial and temporal interactions in the water cycle (feedback, tele-connections and systemic risks) on food, urban and financial systems across Africa.
- The impact of environmental change on the dynamics of water availability, and on ecosystems and societies.
- The tracking and use of innovative technologies to facilitate scientific assessments of water resources.

- Identification, prediction and mapping of potential conflicts over water use under projected demographic and environmental change.
- The promotion of equitable water access through synergies and trade-offs between water use, food production and energy.
- The impact and trade-offs of agricultural intensification (including aquaculture) on aquatic ecosystems, their functions and on human well-being.
- The identification of critical areas and opportunities for researching adaptive strategies relating to water, and strengthening capacity to conduct such research.
- The strengthening of stream flow and reservoirs monitoring networks and information management at sub-national, national and international levels, through GCOS, the World Hydrological Cycle Observing System (WHYCOS) and similar strategies.
- Integrated water resources development and management, as a framework for informed decision-making and ensuring a sustainable share of scarce water resources to all users.
- The monitoring of water infrastructures (hand pump boreholes, dams and natural reservoirs) and stream flow for subsequent rehabilitation actions for malfunctioning and preventive actions from sedimentation.
- Project and programme development to provide sufficient water infrastructure to ensure the supply of drinking water for a growing population, and for production purposes.

Capacity and skills to tackle these research areas so as better to manage Africa's water resources and water infrastructure will depend on appropriate governance and institutional arrangements for high-level academic training, and education and awareness-raising initiatives. Educational and training curricula should be practical, and teachers should be trained to deliver water education from the levels of pre- and primary schools to PhD levels, with strong links created between research institutions, schools, water companies, city managers, relevant government ministries, and NGOs.

5.5 Urbanisation and Atmospheric Pollution

Africa is undergoing rapid urbanisation and industrialisation (The Economist, 2012). These dual processes are leading to growing problems of air pollution, particularly in urban areas due to the use of obsolete technologies, weak regulations, inefficient waste disposal systems for domestic, industrial and electronic wastes, dust from the use of non-tarred roads and construction sites, biomass burning, land degradation and a reduction in the re-uptake of carbon dioxide emissions (Epa.gov., 2010). Observations and models show that the

http://maxpixel.freegreatpicture.com/Factory-Plant-Industry-Power-Energy-Industrial-1827886

Source: http://extension.msstate.edu/news/feature-story/2005/katrina-leaves-damaged-crops-fuel-frustrations

Source: https://pixabay.com/en/waterfall-jungle-cliff-stream-1030737/

Source: https://pixabay.com/en/guise-waste-line-costs-coast-beach-1533852/

tropospheric concentrations of most reactive chemical species are increasing in time and space throughout Africa. Several research programmes, such as South African Fire-Atmosphere Research Initiative in 1992, SAFARI 2000, the Experiment for Regional Sources and Sinks of Oxidants (EXPRESSO), and the Dynamic and Atmospheric Chemistry in the Equatorial Forest (DECAFE), 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 can significantly damage human health, crops, local vegetation, and other materials. Severe reductions in visibility, and an increase in respiratory diseases and chest congestion complaints, are widely reported. Nitrogen compounds, ozone, and particulate matter are the main hazards on a regional scale, with sulphur compounds becoming pronounced in locations of smelting, power generation, high vehicle density, and oil refineries.

The problems are compounded by poverty and may be exacerbated by rising global temperatures. Warm temperatures with high relative humidity and high frequency of precipitation increase the potential corrosion damage.

On the one hand, dose-response functions obtained in Europe cannot be directly transferred to the developing countries located in tropical regions. On the other, data available in Africa are not sufficient to permit the reliable quantification of hazards, or to enable accurate assessment of the economic cost and development of cost-efficient strategies for reducing air pollutants. Standardised methods to investigate such impacts have not yet been broadly established, although the success of the Deposition of Bio-geochemically Important Trace Species (DEBITS) project on rainfall chemistry shows how this can be achieved in Africa. In general, the air quality data that have been collected to date are not suitable for making regional assessments. The problem is now being addressed by the Air Pollution Information Network for Africa (APINA).

It would be appropriate to develop a network of atmospheric pollution researchers across Africa, building on the networks mentioned above, that will assess current knowledge of pollution impacts on people, crops and natural systems. Specific activities would include:

- The development of experimental and observational protocols for African conditions, which would enable socio-economic risk assessments to be conducted.
- The provision of introductory training courses in atmospheric chemistry and physics, pollution due to combustion processes, laboratory analysis, modelling, auditing, and weather monitoring.
- A focus on integrated measurement and the modelling of a few urban case studies, particularly those away from the sea.
- The design of systems to reduce anthropogenic atmospheric pollution.
- The design of systems to mitigate the impact of natural air pollution including filters for the nose and mouth.

5.6 African Ocean Links

The African continent is bordered by the Atlantic Ocean on the west and the Indian Ocean on the east. The two oceans are linked in the south by the Southern Ocean. The Atlantic Ocean is dominated by deep ocean basins which act as a driving force for the thermohaline circulation of the world's ocean. The primary productivity in

Source: https://www.foe.co.uk/blog/what-has-eu-done-uk-fish

the open ocean is low but increases from North to South and towards the shore. The biodiversity is high, but several species in the area are endangered with the lack of sustainable fisheries management regarded as one of the most important threats to biodiversity.

The Indian Ocean extending from the tropics to the Southern Ocean shares similar characteristics with the Atlantic Ocean. The landlocked nature of the ocean along its northern boundary and the resultant seasonally reversing wind and surface circulation patterns are the unique monsoon features of the Indian Ocean. This monsoon effect has a significant impact on the climatology of the northern Indian Ocean and the eastern coast of Africa which, in turn, affects the biological productivity of the east African coast that accounts for more than 25% of the global coral reef cover and about 40,000 km^2 of marine flora with numerous estuaries. Important issues that will need to be addressed under the African Ocean links include the following:

- Oceanographic changes in the Atlantic and Indian Ocean (Canary, South equatorial and North equatorial currents, Agulhas and Mozambique currents, and monsoon Drift).
- Biological productivity of upwelling areas off the West African, Angola and Namibia and the southern areas.
- Climate and environmental changes in Africa.
- Sea-level changes and ecosystem modification on the various Large Marine Ecosystems (LME).

5.7 Fisheries and Coasts

Fishing is an important source of income and of protein for people living in Africa. On the one hand, fishing provides direct income for about 10 million people (half of whom are women) while, on the other, it contributes to the food supply of over 200 million people. On average, people living in Africa get ca. 22% of their protein from fish (World Fish Centre) In some countries, the rate is as high as 70 per cent. Coastal areas are a focus of human activities, and not just in terms of fishing but also for some important non-renewable resources, such as phosphate, oil, gold, and diamonds.

These high levels of socio-economic activity within the coastal zones of Africa stem from the fact that coastal zones have a variety of natural habitats such as wetlands, mangroves, estuaries and coastal lagoons which boost fisheries resources. These resources are now threatened by dwindling fish stocks as a result of overfishing, and of unreported and illegal fishing activities. Ocean acidification is also a serious threat to ecosystems.

Proposed research areas to better the state and impact of African fisheries resources in terms of overfishing and environmental changes include:

- Re-evaluating large marine ecosystems in terms of MPAs for fishing activities
- Establishing and strengthening links with international programmes
- Assessing ecosystem health
- Undertaking research into economically important species
- Monitoring coastal pollution
- Assessing ocean acidification and the impact on shellfish.

In order to undertake the necessary research and achieve these goals, data and information for better management are needed for improving and sustaining the livelihoods of millions of Africans.

6. Implementation of the Science Plan

Historically, the respective agendas of natural and social scientists, and of policy-makers and resource managers, have been relatively isolated from one another. Translating policy requirements into relevant science questions and delivering results in a way that is useful to aid policy formulation are therefore challenging. There are several global programmes and initiatives involving a conglomerate of institutions, scientific organisation, funding agencies, and other actors engaged in the science of global environmental (including climate) change. The implementation of this Science Plan is therefore not expected to happen in isolation. It is envisaged to tap into and complement these initiatives with a special focus on the Future Earth initiative.
For this Science Plan to be realised, significant financial support is required and, importantly, which should be supported with commensurate coordination and focus. The Plan is scheduled to be implemented in two principal ways:

1.) International networks for conceptual and methodological research on environmental change, that would include ecological systems, vulnerability analysis, scenario construction and decision support; and
2.) Regional projects for research on a range of global environmental change issues.

Network of research partners

There is an established tradition of much of the ICSU-linked GECR in Africa. However, as competence is patchy and thinly spread, a good mechanism to carry out the research proposed in this Science Plan will be to establish and maintain a distributed network of institutions and scientists facilitated by the ICSU ROA, with 'nodes' of excellence and delegated responsibilities for coordination in particular regions or domains.

Regional large-scale distributed research projects

The implementation of the Science Plan for GECR in Africa will mainly take place through the brokering of large-scale, long-term research projects, either as African-led, or as part of international research consortia. ICSU ROA will serve as a catalyst of research activities in the thematic areas identified. It is expected that international partners will incorporate aspects from this Science Plan into their work plans and their strategic planning process where there is congruence with their national overseas development assistance agendas. It is also expected that ICSU ROA will incorporate aspects of this Science Plan into the agenda of its network of international agencies.

Like most areas of research in Africa, GECR is chronically underfunded with little if any national sources of support. International competitive grants are often unattainable because of their entry barriers which marginalise and disenfranchise African scientists. These barriers include communication difficulties, accounting and 'previous successful application' requirements, and complex and time consuming proposal processes. There are African and international funding bodies that can support GECR in Africa if agreement is attained on efficient and transparent strategies for the partitioning of large blocks of 'wholesale' funding into smaller 'retail' opportunities.

To do so effectively, it is important to have a well-structured and coordinated large-scale research agenda (such as this Science Plan) for which consolidated funding can be obtained and guaranteed. This would offset the administrative bottlenecks encountered in fragmented proposal evaluation, grant allocation and accountability, by bringing in economies of scale. Within a three to five year time frame, the African GEC

Science Plan aims to advance the process of delivering:

- Regional assessments and characterisation of GEC, including both bio-physical and societal issues.
- Enhanced concepts and typologies for GEC studies specifically designed for Africa.
- Improved understanding of vulnerability to GEC, based on a range of case studies.
- Comprehensive, regional scenarios of future socio-economic and environmental conditions involving socio-economic and demographic factors, and environmental and ecological data.
- Decision support systems and other tools or mechanisms to aid decision-making by policy makers in response to GEC.
- The documentation of new insights in research design for human benefit.

The science products from this Science Plan will be delivered in a number of ways, including:

- Scientific output in peer-reviewed literature, complemented by the adoption of new methods in regional case studies.
- Reports containing standardised descriptions and analyses of GEC in different regions of Africa, and factors affecting them.
- Guidelines on stakeholder involvement in GEC research relating to Africa's development.
- Policy-relevant output in terms of policy briefs and the enhanced consideration of both environmental and socio-economic feedbacks in policy formulation.
- Multi-actor capacity building and information exchange between ICSU ROA and regional research institutions, communities, and the social and natural sciences.

7. Strategic Partnerships

Global environmental change, including climate change, is an area where research involves a large number of players who interact in complex networks. In Africa, these include programmes within the ICSU family, as well as a full range of unaffiliated or partly affiliated activities with national links or ties to development agencies, as illustrated in the schematic representation in Figure 4. To avoid overstretching the scarce African GECR capacity, it is important to have some degree of coordination in this constellation but, at the same time, to avoid the burdens of over-connectedness.

Given the ICSU mandate and comparative advantage, the key strategic partners for GECR in Africa would be the following:

- The shared capacity building programme START (and its Africa office, PASS), and the limited-duration, multi-institutional research campaigns they launch.
- UN agencies such as UNEP, WMO, UNESCO, FAO, WHO, UNCCD, UNFCCC, and the UN Economic Commission for Africa (UNECA).
- National research authorities, agencies, centres and universities in African countries where the interest in GECR is already strong.
- Large international research agencies with a specific commitment to Africa and GECR. In particular, the CGIAR centres are good examples of such partners.
- Donors with a strong record or expressed wish to be involved in global environmental change research in Africa, such as DfID, CIDA, the German Technical Cooperation Agency (GTZ), the United States Agency for International Development (USAID), and others; and the coordinating body for global change research funding agencies, the International Group of Funding Agencies (IGFA).

https://pixabay.com/en/wheat-field-wheat-cereals-grain-640960/

8. Conclusion

The Africa Science Plan presents a forward view of the challenges of global environmental change (including climate change and adaptation) from an African perspective, and highlights key research areas in which attention is needed, and where ICSU has a comparative advantage in addressing the challenges. In proposing the research themes herein, cognisance is taken of the proposals made in the other three ICSU ROA derived Science Plans (Sustainable Energy; Health and Human Well-being; and Natural Human-induced Hazards and Disasters), and an attempt is made to establish synergies among the four Science Plans, while avoiding duplication. The successful implementation of this Science Plan will result in the production of valuable scientific knowledge to inform policy- and decision-making, as well as generate improved skills to develop appropriate strategies of mitigating the impact of global environmental change, including climate change, on the livelihood and well-being of people living in Africa.

Effective implementation of this Science Plan will also require substantial mobilisation of human and financial resources and facilities for research, training and outreach, including community education. Extensive collaboration, partnership and networking at the national, sub-regional, regional and international scales will be essential to achieve the objectives of the plan.

ICSU ROA will promote, facilitate and coordinate the implementation of this Science Plan and its concomitant projects dealing with issues of global environmental change (including climate change) in Africa.

Source: https://pixabay.com/en/sunbeam-afterglow-morgenrot-pond-292987/

Source: https://pixabay.com/en/ocean-bird-water-nature-sea-blue-1209839/

References

Adger W.N., Paavola J., Huq S., and Mace M.J. (2006). *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge, MA. and London.

African Development Bank Group, OECD Development Centre, UNDP (2014). *African Economic Outlook, Global Value chains and Africa's Industrialization.*

Airhihenbuwa C.O. (1995). *Health and Culture beyond the Western Paradigm*. SAGE Publications, London and New Delhi.

ATPS – African Technology Policy Studies Network, 2010. Urama, K., Ogbu, O., Bijker, W., Alfoinsi, A., Gomez, N. and Ozor, N. (eds). *The African Manifesto for Science, Technology and Innovation*, Nairobi, Kenya.

Andreae M.O. (1995). Climatic effects of changing atmospheric aerosol levels. In Henderson-Sellers A. (ed.), *World Survey of Climatology, Vol.16. Future Climates of the World: A Modelling Perspective*. Elsevier, Amsterdam.

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

Brooks N. (2005). Cultural heritage and conflict: the threatened archaeology of Western Sahara, *Journal of North African Studies* 10 (3–4), 413–439.

Carruthers J. (2005). Africa's environmental history. *IHDP Update* 02/2005, 8–9. Available at: www.ihdp.org/updatehistory05/references.htm

Cash D.W. (2001). In order to aid in diffusing useful and practical information: agricultural extensions and boundary organisations. *Science, Technology and Human Values* 26 (4), 431–453.

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

CDKN – Climate and Development Knowledge Network (2014). Annual Report 2014: Inspiring climate compatibility development. Available at http://cdkn.org/2014/08/cdkn-annual-report-2014/?loclang=en_gb

Chanie, P. (2013). Global environmental change and the social sciences in eastern and southern Africa. In ISSC/UNESCO, *World Social Science Report 2013: Changing Global Environments*, OECD Publishing and UNESCO Publishing.

Charlson R. J., Schwartz S. E., Hales J. M., Cess R. D., Coakley J. A., Hansen J. E., and Hofmann D. J. (1992). Climate forcing by anthropogenic aerosols, *Science* 255, 423–430.

Duce R.A. (1995). Sources, distributions and fluxes of mineral aerosols and their relationship to climate. In Charlson R.J. and Heint-zenberg J. (eds.), *Aerosol Forcing of Climate*. John Wiley, New York, 43–72.

The Economist (2012). Urban life: Open-air computers. 27 October 2012. Retrieved 20 March 2013. Available at http://www.economist.com/news/special-report/21564998-cities-are-turning-vast-data-factories-open-air-computers

Epa.gov (17 November 2010). Heat Island Effect. Retrieved on 7 April 2014. Available at https://www.epa.gov/heat-islands/heat-island-webcasts

FAO – Food and Agricultural Organization, United Nations, (2014). State of Food Security in the World. 20.

FAO – Food and Agricultural Organization, United Nations (2009). Declaration of the World Summit on Food Security, WSFS 2009/2, FAO, November 2009.

Fischer G., Shah M., and van Velthuizen H. (2002). Climate Change and Agriculture Vulnerability. Report prepared for the World Summit on Sustainable Development. International Institute for Applied Systems Analysis, Vienna. 152.

Fischer G., Shah M., Tubiello N., and van Velthuizen H. (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080, *Philosophical Transactions of the Royal Society* 360, 2067–2083.

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

Freire P. and Faundez A. (1989). *Learning to Question: A Pedagogy of Liberation*. New York: Continuum.

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

GECAFS (2006). GECAFS Southern Africa Science Plan and Implementation Strategy. GECAFS Report No 3. GECAFS, Oxford.

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

Guston D. (2001). Boundary organisations in environmental policy and science: an introduction. *Science, Technology and Human Values* 26 (4), 399–408.

Holloway A., Chasi V., de Waal J. *et al.* (2013). *Humanitarian trends in southern Africa: Challenges and Opportunities.* Regional Inter-Agency Standing Committee, Southern Africa. Rome: FAO.

Huq S., Reid H. and Murray L. A. (2006). *Climate Change and Development Links*. GateKeeper Series 123. International Institute for Environment and Development, London.

Jasanoff S. S. (1987). Contested boundaries in policy relevant science, *Social Studies of Science* 17(2), 195–230.

ISD – Institute of Sustainable Development (2007). Fifth Meeting of the Africa Committee on Sustainable Development (ACSD-5) Regional Implementation Meeting (RIM) for CSD-16 Addis Ababa 22-25 October 2007

ISSC/UNESCO (2013). *World Social Science Report 2013: Changing Global Environments*, OECD Publishing and UNESCO Publishing.

IPCC – Intergovernmental Panel and climate change (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC, Intergovernmental Panel and climate change (2013). Summary for Policy Markers, Working Group 1, October 2013, IPCC, Switzerland.

Low, P. S. (ed.) (2005). *Climate Change and Africa*. Cambridge University Press, Cambridge.

Lutz, W., Butz, W. and Samir, K.C., (2014). *World Population and Human Capital in the Twentieth First Century*, Wittgenstein Centre and IIASA.

McCarthy J. J., Canziani O.F., Leary N.A., Doken D.J., and White K.S. (eds.) (2001). *Climate Change2001 – Impacts Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

MEA – Multilateral Environmental Agreement, (2005). *Ecosystems and Human Well-being: Current State and Trends*. Millennium Ecosystem Assessment, Vol. 1. Island Press, Washington, DC.

Miller C. (2001). Hybrid Management: Boundary Organizations, Science Policy, and Environmental Governance in the Climate Regime, *Science, Technology and Human Values* 26 (4), 478–500.

Nicholson S. E. and Grist J. P. (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.

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

Pope III C. A. and D. W. Dockery (2006). Health Effects of Fine Particulate Air Pollution: Lines that connect, *Journal of Air and Waste Management Association* 56, 709–742.

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

Scholes R. J., Olago D., and Sigha-Nkamdjou L. (2006a). *Global Change and the New Partnership for African Development*. NEPAD, Pretoria.

Scholes, R. J., Kuper W., and Biggs R. (2006b). Biodiversity. In UNEP, *Africa Environment Outlook 2: Our Environment, Our Wealth*. United Nations Environment Programme, Nairobi. 226–261.

Siegenthaler U., Stocker T. F., Monnin E., Lüthi D., Schwander J., Stauffer B., Raynaud D., Barnola J. M., Fischer H., Masson-Delmotte V., and Jouzel J. (2005). Stable carbon cycle – climate relationship during the late Pleistocene, *Science* 310, 1313–1317.

Spahni, R., Chappellaz J., Stocker T. F., Loulergue L., Hausammann G., Kawamura K., Flückiger J., Schwander J., Raynaud D., Masson-Delmotte V., and J. Jouzel (2005). Atmospheric methane and nitrous oxide of the late Pleistocene from Antarctic ice cores, *Science* 310, 1317–1321.

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

Stern N. (2007). *The Economics of Climate Change. The Stern review*. Cambridge University Press, Cambridge.

Swilling, M. and Annecke, E. (2012). *Just transitions - Explorations of sustainability in an unfair world*, Cape Town, UCT Press.

Thirteenth Assembly of CODESRIA. (2011). *Africa and Challenges of the 21st Century*, 5-9 December, 2011, Rabat, Morocco.

Thompson Klein, J. (2010). *Creating interdisciplinary campus cultures, a model for strength and sustainability*. San Francisco: Association of American Colleges and Universities.

UNU-IHDP – United Nations University and the International Human Dimensions Programme on Global Environmental Change (2011). *Survey of Social Science Scholars on Engagement in GEC*. A.K. Duraiappah, A.K. and Rogers, D.S., 31 August, 2011.

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

UNDP/UNSO (1997). *Aridity zones and dryland populations: an assessment of population levels in the World's drylands*. United Nations Sudano-Sahelian Office/United Nations Development Programme, New York.

UNEP (2006). Africa Environment Outlook 2: Our Environment, Our Wealth. United Nations Environment Programme, Nairobi.

UN Habitat for a better Urban Future (2014): The State of African Cities 2014 – Re-imagining sustainable urban transitions, ICLEI and UCLG Africa.

Urama, K., Ozor, N., Kane, O. and Hassan, M. (2010). *UNESCO Science Report 2010, United Nations Educational, Scientific and Cultural Organization, Division for Science Policy and Sustainable Development*, UNESCO, Paris.

Vogel C., Moser S.C., Kasperson R.E., and Dabelko G.D. (2007). Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. *Global Environmental Change* **17**, 349–364.

Vogel, C. (2013). Social science perspectives on global environmental change in sub-Saharan Africa. In ISSC/ UNESCO, World Social Science Report 2013*: Changing Global Environments, OECD Publishing and UNESCO Publishing.*

World Fish Centre. Available at http://worldfishcenter.org/.

WHO – World Health Organisation (2015a). The African Regional Health Report: The Health of the People.

_____(2015b). Ebola Situation Report, 21 January, 2015.

WMO – World Meteorological Organization (2015). WMO Statement on the status of the global climate in 2015. Available at https://public.wmo.int/en/resources/library/wmo-statement-status-of-global-climate-2015.

WTO – World Trade Organization (2003). Annual World Trade Report. Available at https://www.wto.org/english/ res_e/booksp_e/anrep_e/anrep03_e.pdf

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

Definitions of Terms

Climate change and climate variability	Terms used to refer to the variation in the Earth's global climate or in regional climates over time. They describe changes in the variability or average state of the atmosphere – or average weather – over timescales ranging from decades to millions of years. These changes may come from processes internal to the Earth, be driven by external forces (for instance, variations in sunlight intensity) or, most recently, be caused by human activities.
Ecosystem	A natural unit consisting of all living organisms (biotic factors) in an area functioning together with all the non-living physical (abiotic) factors of the environment.
Vulnerability	The conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of a community to the impact of hazards.
Resilience	The capacity of a system, community, or society that is potentially exposed to hazards, to adapt by resisting or changing so as to reach and maintain an acceptable level of functioning and structure; the ability to recover quickly from illness or change. Resilience is determined by the degree to which the social system is capable of organising itself to increase its capacity for learning from past disasters, so as to protect itself better in future, and to improve its risk reduction measures.
Adaptation	The change in living organisms that allows them to live successfully in an environment, and that enables them to cope with environmental stresses and pressures.
Global environmental change (GEC)	The set of transformations of land, oceans, and atmosphere that is 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 of it, people have begun to induce planetary-scale changes in Earth's life support systems.

Acronyms and Abbreviations

ACCESS	Applied Centre for Climate and Earth Systems Science
ADB	Africa Development Bank
AEO	Africa Environment Outlook
AFEC	African Future Earth Committee
AfricanNESS	African Network for Earth System Science
AIACC	Assessments of Impacts and Adaptations to Climate Change
AIDS	Acquired immune deficiency syndrome
AIMES	Analysis, Integration and Modelling of the Earth System
AMCOMET	African Ministerial Conference On Meteorology
AMMA	Africa Monsoon Multidisciplinary Analyses
APINA	Air Pollution Information Network for Africa
ARC	African Risk Capacity
ARGO	Array for Real-Time Geostrophic Oceanography
ARV	Africa Risk View
ATPS	African Technology Policy Studies
AU	African Union
AUC	African Union Commission
BRACED	Building Resilience and Adaptation to Climate Extremes and Disasters (Programme)
CCAA	Climate Change Adaptation in Africa (Programme)
CCAFS	Climate Change, Agriculture and Food Security
CDKN	Climate and Development Knowledge Network
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
ClimDev Africa	Climate for Development in Africa programme
COMESA	Common Market for Eastern and Southern Africa
CR4D	Climate Research For Development
DEBITS	Deposition of Biogeochemically Important Trace Species
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 of biodiversity science

ecoHEALTH	The International Association for Ecology and Health
ecoServices	A research project of Future Earth
ECOWAS	Economic Community of West African States
EDF	European Development Fund
EGC	Environmental Growth Chambers
ENSO	El Niño Southern Oscillation
ESSP	Earth System Science Partnership
EU	European Union
EXPRESSO	Experiment for Regional Sources and Sinks of Oxidants
FAO	Food and Agriculture Organization
FCFA	Future Climate For Africa
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GEC	Global environmental change
GECAFS	Global Environmental Change and Food Systems
GECR	Global environmental change research
GEF	Global Environment Facility
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GHG	Greenhouse gas
GLP	Global Land Programme
GOOS	Global Ocean Observing System
GTZ	Gesellschaft für Technische Zusammenarbeit (Germany) [German Technical Cooperation Agency]
GWSP	Global Water System Project
HDI	Human Development Index
HIV	Human immunodeficiency virus
ICLEI	International Council for Local Environmental Initiatives
ICSU	International Council for Science
ICSU RCA	ICSU Regional Committee for Africa
ICSU ROA	ICSU Regional Office for Africa
IGBP	International Geosphere-Biosphere Programme

IGFA	International Group of Funding Agencies
IHDP	International Human Dimensions Programme (on Global Environmental Change)
IHOPE	Integrated History and Future of People on Earth
ILeAPS	Integrated Land Ecosystem-Atmosphere Processes Study
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth Assessment Report
IPBES-Food	International Panel of Experts on Sustainable Food Systems
Intra-ACP	The intra-ACP academic mobility scheme – between countries in Africa, the Caribbean and the Pacific (ACP)
IRA	Institute of Resource Assessment Institute of Resource Assessment
IRD	French Institute of Research for Development (formerly known as OSTORM)
IRD ARTS (programme)	IRD thesis research grants in the South
IRD BEST (programme)	IRD research and technology exchange
IRD SOERE	IRD long-term environmental research observational and experimental systems
IRG	Independent Regulators Group
ISD	Institute of Sustainable Development
ISSC	International Social Science Council
ITCZ	Intertropical Convergence Zone
IWMI	International Water Management Institute
JAES	Joint Africa-EU Strategy
LME	Large Marine Ecosystem
LMI	Joint International Research Units
MDGs	Millennium Development Goals
MPAs	Marine protected areas
MEA	Multilateral Environmental Agreement
NARS	National Agriculture Research Systems
NEPAD	New Partnership for Africa's Development
NGAA	Next Generation of African Academics
NGO	Non-governmental organization
NMSs	National Meteorological Services
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development
PanAf (programme)	Pan African Programme

PACOM	Pan-African Committee (for START)
PASS	Pan African START Secretariat
PECS	Programme on Ecosystem Change and Society
PIRATA	Prediction and Research Moored Array in the Atlantic
RBOs	River Basin Organizations
RCCs	Regional Climate Centres
RECs	Regional Economic Commissions
ROSA	Regional Office for Southern Africa (UNEP-ROSA)
RPP	Regional Pilot Programs
SADC	Southern African Development Community
SAFARI	Southern African Regional Science Initiative
SASSCAL	Southern African Science Service Centre for Climate Change Adaptation and Adaptive Land Management
SGDs	Sustainable Development Goals
SST	Sea surface temperature
START	SysTem for Analysis, Research, and Training
STI	Science, technology, and innovation
TOGA	Tropical Ocean-Global Atmosphere
ToR	Terms of Reference
TreccAfrica	Transdisciplinary Training for Resource Efficiency and Climate Change Adaptation in Africa
TWAS	The Academy of Sciences for the Developing World
UGEC	Urbanization and Global Environmental Change
UGLG	United Cities and Local Governments
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Program
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNEP-ROSA	United Nations Environment Programme Regional Office for Southern Africa
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNU-IHDP	United Nations University and the International Human Dimensions Programme

UPGP	Unlocking the Potential of Groundwater for the Poor
US$	United States dollars
USAID	United States Agency for International Development
WCISA	Weather and Climate Information and Services for Africa
WCRP	World Climate Research Programme
WHO	World Health Organization
WHYCOS	World Hydrological Cycle Observing System
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WMO WIS	WMO Information System

https://pixabay.com/en/car-desser-alone-sunset-africa-722255/



Strengthening international science for the benefit of society

INTERNATIONAL COUNCIL FOR SCIENCE
REGIONAL OFFICE FOR AFRICA

ICSU Regional Office for Africa
1st Floor Block C, The Woods
41 De Havilland Crescent
Persequor Technopark 0020
Pretoria
South Africa
+27 (12) 349 7731
www.icsu.org/africa