



SARUA Leadership Dialogue Series Volume 2 Number 4

CLIMATE CHANGE, ADAPTATION AND HIGHER EDUCATION: Securing Our Future



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CLIMATE CHANGE, ADAPTATION AND HIGHER EDUCATION: Securing Our Future

Series Editor: Piyushi Kotecha

FOREWORD

As a borderless, multifaceted and unpredictable phenomenon, which will ultimately impact on the lives of all of us in the future, climate change poses a significant challenge; to governments, international agencies, scientists, scholars and ordinary citizens world-wide. On the southern tip of Africa, although there may be some small moral comfort in not producing the scale of industrial emissions that are alleged to be behind many of the changes in global weather patterns we are currently witnessing, we shall not be spared any of its effects, in fact we may be more vulnerable than many other regions.

What does this mean for the public universities in the countries of sub-Saharan Africa, committed as they are, through an association such as SARUA, to responding to the development challenges of the region? How can the universities through their core mission of teaching, research and community engagement contribute to a better understanding of both the phenomenon itself and, more importantly, to building the capacities that will enable the region and its peoples to prepare for and to cope more effectively with some of its effects? What changes will be required in pedagogical approaches and in the epistemological models currently employed by our universities, and how can the universities of the region collaborate to ensure that scarce resources and expertise on these matters are leveraged to the best effect?

It was to address questions such as these that SARUA drew together a number of leading experts within their fields, from across the SADC region, to present and to discuss their views with Vice Chancellors at a two day dialogue event titled '*Climate Change, adaptation and Higher Education: Securing our future*' held 21-22 October 2010 in Mauritius. The papers presented at this conference have been reproduced in full in this publication together with a 'Framework for Action on Climate Change,' which emerged on the second day as a result of the work of the various commissions of Vice-Chancellors and the experts.

Collectively the papers give an overview of the likely impacts and effects of climate change on the southern African region, its peoples and the biodiversity of its flora and fauna, over the next decade and beyond. Specific challenges and vulnerabilities are highlighted in the areas of agriculture, food security, water security and public health together with strategies and actions that can be taken by governments and other agencies to reduce such vulnerabilities, and to better prepare their populations to survive and to prosper in the changing environments of the future.

More importantly, from the university perspective, the discussion goes beyond the outward manifestations of the problem to a critical examination of what this means for universities in terms of curriculum and teaching, research and knowledge production, and engagement with their communities in the broadest sense. There is much food for thought here; the epistemological challenges and indeed the opportunities, go beyond climate change as a particular 'subject' or focus area, and can be applied to any of a number of complicated theoretical and 'real world' issues, requiring multidisciplinary approaches involving a high degree of uncertainty, complexity and risk. Perhaps this is best summed up by Heila Lotz-Sisitka in the conclusion to her paper, that such complex issues require both a

... transformation in teaching epistemologies, away from transfer oriented epistemologies of certainty, to more complex teaching epistemologies that recognise uncertainty, and risk.



... a re-orientation of community engagement, from models of reactive responsiveness to a more pro-active, preventative engagement with potential future risks.

Such re-creative engagement with the realities of our environment and the capacity of universities to make a difference lie at the core of academic enquiry and purposeful action. It is envisaged that the Framework for Action will spur relevant developmental inter-university initiatives and collaboration within the SADC region. As such the Framework for Action included here should be viewed as an open invitation for funders, specialist agencies and governmental Research and Development units to partner on this theme.

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SARUA is a not-for-profit leadership association of the heads of the public universities in the 15 countries of the SADC region. Its mission is to promote, strengthen and increase higher education, research and innovation through expanded inter-institutional collaboration and capacity building initiatives throughout the region. It promotes universities as major contributors towards building knowledge economies, and towards national and regional socio-economic and cultural development, and also the eradication of poverty.

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ABBREVIATIONS

ACRE	–	African Climate Research and Education Network
ADPC	–	Asian Disaster Preparedness Centre
AEO	–	African Environment Outlook
ANU	–	Australian National University
AOGCM	–	Atmosphere Ocean Global Climate Model
ARIES	–	Australian Research Institute in Education for Sustainability
CCAA	–	Climate Change Adaptation in Africa
CCAFS	–	Climate Change, Agriculture and Food Security
CGIAR	–	Consultative Group on International Agricultural Research
CIAT	–	International Centre for Tropical Agriculture
CIP	–	International Potato Centre
CP	–	Challenge Programme
CSAG	–	Climate Systems Analysis Group
DALY	–	Disability Adjusted Life Years
DPLG	–	Department of Provincial and Local Government
DST	–	Department of Science and Technology
DVCs	–	Deputy Vice Chancellors
ESSP	–	Earth System Science Partnership
FSTAU	–	Food Security Technical and Administrative Unit
GCMs	–	Global Climate Models
GHA	–	Greater Horn of Africa
IAC	–	Inter Academy Council
IIED	–	International Institute for Environment and Development
IPCC	–	Intergovernmental Panel on Climate Change
IPDM	–	Integrated Pest and Disease Management
MESA	–	Mainstreaming Environment and Sustainability in Africa
NAPA	–	National Adaptation of Programmes of Action
NARS	–	National Agricultural Research Systems
NERICA	–	New Rice for Africa
RCMs	–	Regional Climate Models
REDD	–	Reducing Emissions from Deforestation and Forest Degradation
SADC	–	Southern African Development Community
SAMJ	–	South African Medical Journal
SARUA	–	Southern African Regional Universities Association
SARVA	–	South African Risk and Vulnerability Atlas
SAVI	–	Southern African Vulnerability Initiative
SEI	–	Stockholm Environmental Institute
START	–	Global Change System for Analysis, Research and Training
UNEP	–	United Nations Environment Programme
UNESCO	–	United Nations Education, Science and Cultural Organisation
UNFCCC	–	United Nations Framework Convention on Climate Change
WCRP	–	World Climate Research Programme
WDR	–	World Disaster Report
WG1	–	Working Group 1
WG2	–	Working Group 2
WGCCD	–	Working Group on Climate Change and Development
WHO	–	World Health Organisation
YES	–	Youth Encounter on Sustainability Course



INTRODUCTION

While the contribution of higher education in confronting the challenges faced by humanity in the first decade of the 21st Century is acknowledged, its role in creating the capabilities and the knowledge needed to adapt to current and future vulnerability as a result of climate change is less certain. Higher education institutions globally, like other institutions in society, have to take stock of their contribution to climate change and they also have to gauge their relevance to the worldwide efforts to develop the pathways to adapt to the vulnerability associated with climate change.

Higher education institutions in Africa, while recognising that Africa's contribution to the damage inflicted on the global climate regulatory system is less when compared to developed regions of the world, nevertheless have an important responsibility given the precarious position of Africa as one of the most vulnerable continents to climate change. This responsibility pivots around educating and preparing present and future leaders and members of society, through scholarship and scientific research, with the ideas and imagination as well as the social, technical and managerial capabilities for creating the conditions for long-term sustainability.

SARUA, in partnership with the University of Mauritius, hosted a Southern African Higher Education Leadership Programme to review the present contribution of higher education in southern Africa and to explore opportunities for scaling up existing initiatives so that it can make a meaningful impact on the way the region responds to climate change, adaptation and sustainability. This leadership dialogue sought to take advantage of increasing the momentum gained, the relationships formed, and the knowledge created by a number of recent initiatives, to explore the nexus between climate change, adaptation and higher education¹. The aim of the leadership dialogue was to determine the progress made in regard to integrating climate change into higher education teaching and learning, knowledge production and community engagement.


TEACHING AND LEARNING

Climate change is a planetary phenomenon. The scale and complexity of the underlying challenges of adaptation, vulnerability, mitigation and sustainability is such that the traditional disciplinary epistemological frameworks may appear to be inadequate to develop the conceptual, methodological and analytical tools necessary to understand developments in a range of interdependent knowledge domains. The workshop explored the trends pertaining to: the integration of climate change and adaptation concerns in curriculum development or curriculum re-orientation; the development of new or specialised training programmes; the nature of inter-, trans-, and multi-disciplinary programmes; developments in the establishment of joint programmes and student exchange programmes; and the innovations in teaching.

RESEARCH AND KNOWLEDGE PRODUCTION

Knowledge is the foundation on which the three traditional missions of academic teaching, research and social engagement is built. Academic teaching involves the transfer of knowledge from the academic to the student; research involves the process of undertaking scientific and social science research and publishing the results thereof, while community engagement provides an opportunity for applying the knowledge generated through these processes. The main challenge in this context is producing locally relevant research by African researchers in African institutions. The workshop

¹ Education, Capacity Building and Climate Change Forum held in Tanzania on 27 June – 1 July 2010 aimed at developing a strategy for education and adaptation in Africa; Consultative Conference on the Role of Higher Education in Adapting to Climate Change: Africa held on 16 – 18 October 2009 in Ghana; and the Association of African Universities 12th General Conference on Sustainable Development in Africa: The Role of Higher Education held on 4 – 9 May 2009 in Abuja, Nigeria.



examined the evolving mode of climate change, adaptation research and knowledge production with specific reference to the sites of knowledge production, the research funding, the type of research undertaken, the methodological challenges and concerns, how this research is communicated, and how it is used for teaching and for social engagement purposes.

COMMUNITY ENGAGEMENT AND COLLABORATION

No single institution has all the resources, both human and otherwise, to address the key challenges presented by climate change in the different knowledge domains. A range of North-South and South-South collaborative initiatives and activities at the global and regional levels have emerged that bring together experts from across the world. The workshop assessed the nature of these collaborative activities and reflected on; the role-players and stakeholders involved; the motivations for these collaborations; the types of initiatives and activities; and the support available to sustain these actions.

INSTITUTIONAL MANAGEMENT

Institutions support the integration of climate change and adaptation concerns into the curricula, research and collaborative activities of academia in many different ways. Good practices are emerging that can provide key lessons and insights. The workshop examined the role played by the executive leadership of universities in the region, reviewed examples of the type of leadership and management support made available, and assessed the constraints and possibilities for enhancing existing initiatives and investments.

TOWARDS A FRAMEWORK FOR ACTION

The workshop brought together Vice Chancellors and senior scientists to review the extent to which climate change and adaptation concerns are being integrated into teaching, research and community. The scientists provided expert inputs to stimulate and to provoke discussion among university leaders. Prof Yanda synthesised the main concepts, themes, developments and latest research on climate change impacts, vulnerability and adaptation. Prof Hewitson examined the issues pertaining to generating regional information on climate change. Dr. Makungwa and Prof Mazvimavi considered the extent to which climate change issues have been integrated into the field of agriculture and food security, and into the field of water resource management, while Prof Lotz-Sisitka examined climate change curriculum development and knowledge production in the field of public health. Prof Vogel raised the need for more creative designs in climate change curriculum development. The proposed Framework for Action on Climate Change, Adaptation and Higher Education emerged from the deliberations among Vice-Chancellors as a guide to universities in southern Africa.

December 2010



CLIMATE CHANGE IMPACTS, VULNERABILITY AND ADAPTATION IN SOUTHERN AFRICA

1

INTRODUCTION

It has been revealed that climate change and variability is taking place due to natural and anthropogenic processes that change atmospheric conditions and processes. These changes have brought significant changes in rainfall and temperature patterns, which manifest through drought, dry spells and floods. These outcomes have caused differentiated impacts on communities, both in the developed urbanised cities, and in the developing, mostly poor ruralised communities. Severe impacts have been experienced in developing countries, mostly Africa, southern Africa in particular, due to technological and economic constraints in coping and in adapting in the changing world. It has also been established, through research and projections that climate change impact on Africa is likely to be severe because of these adverse direct effects; the high agricultural dependence, and the limited capacity to adapt. Although direct effects from climate changes vary widely across the continent; with some areas (e.g. eastern and southern Africa) predicted to get wetter, much of southern Africa is getting drier and hotter; dependence on the agricultural sector for economic and for livelihoods will aggravate the impacts beyond the capacity of the community to cope or to adapt to the potential and the revealed changes. Crop yields will be adversely affected and the frequency of extreme weather events will increase.

While climate change already poses significant impacts on the agricultural sector, there has been little commitment to make adaptation a national priority among nations south of the Sahara. In most cases, adaptation to climate change is primarily a private-sector response mostly involving the relocation of people, or involuntary migration, as well as changes in the sectoral structure of production, and changes in crop patterns. It has been revealed that the key role of the government is primarily to provide information, incentives, and the economic environment to facilitate such changes. In general, there has been very little effort to address climate change impacts in most developing countries. These drawbacks in adaptation are attributed to; low scientific development and poor social and economic infrastructures as well as Africa's fragmentation into small countries and ethnic groups, and also poor business environments. Universities have a role to play in advancing research in climate change issues and in mainstreaming climate change in university curricula so as to equip students with climate change knowledge.



CLIMATIC CONDITION AND CHANGES IN SOUTHERN AFRICA

Background

Climate change is reported to be a reality affecting both social and natural systems. It is important to also note that every member of the society, including institutions in the society such as higher education, has a role to play in addressing climate change challenges. For many years now the contribution of higher education in addressing emerging issues has been well acknowledged. This paper provides an analysis of climate change impacts, vulnerability and adaptation in the region and assesses its implications for higher education.

General overview of climate change

Climate change impacts have been undermining social and economic systems of poor and agricultural dependent communities in southern Africa. According to IPCC (2007), the warming trend observed in the region over the last few decades has been consistent with the global trend of temperature rise in the 1970s, 1980s and particularly in the 1990s. According to the IPCC (2001), temperatures in the region have risen by over 0.5° C during the last 100 years. The nearby Indian Ocean has also warmed more than 1°C since 1950, a period that has also witnessed a downward trend in rainfall (NCAR 2005). Below-normal rainfall years are becoming more frequent and the departure of these years from the long-term normal is becoming more pronounced (USAID 1992). Over 15 drought events were reported between 1988 and 1992 in various areas of southern Africa; and there has also been an increase in the frequency and intensity of El Niño episodes. Prior to the 1980s, strong El Niño's occurred on average every 10 to 20 years. However, the early 1980s marked the beginning of a series of strong El Niño events: 1982/1983; 1991/1992; 1994/1995; and 1997/1998. The episodes of 1982/1983 and of 1997/1998 were the most intense in the last century. Paradoxically though, the 1991/1992 El Niño, which was considered as a moderate event, caused a major drought throughout southern Africa (Glantz et al. 1997; UNEP & ICRAF 2006).

There is widespread acceptance that the climate of southern Africa will in future be hotter and drier than it is today. By 2050, the average annual temperature is expected to increase by 1.5-2.5° C in the south and by 2.5-3.0° C in the north compared to the 1961-1990 average (Ragab & Prudhomme 2002). Temperature rises will be greater in the summer than in the winter, exacerbating stress on crops. Recent studies reveal 'very clear and dramatic warming of the Indian Ocean into the future, thus more droughts for southern Africa' (NCAR 2005). Studies further show that monsoons across southern Africa could be



The Pacific warming of 1991/1992 over southern Africa caused the worst drought of the last century (Glantz *et al.* 1997). The resulting crop losses and the death of cattle herds led to widespread food shortages and devastated the fragile economies of various countries. The regional maize production in 1992 was approximately 5 million tonnes (the lowest since 1961), putting an estimated 30 million people at the brink of famine (Battersby 1992; Chiledi 1992; Harsch 1992). This was 60% below the 1991 level (an already below average production year) and the 1991-2000 average. Damage to the herd was also great. For example, in Zimbabwe the drought resulted in the death of an estimated 423,000 cattle out of 4.4 million and the doubling of the normal *o*-take. Even the animals that could be sold only fetched a pitiful Z\$24 per head as compared to an average normal price of Z\$500 per head (Thompson 1993; UNEP & ICRAF 2006).

In Botswana, the national herd was reduced by a third (Government of Botswana 2001). Then following an El Niño-related drought in 1995, the regional cereal production was only 15.7 million tonnes, a time when direct consumption needs were 23.3 million tonnes. Only 9 million tonnes of maize (half of the previous year's production) were produced in the entire region, an output comparable to that of the early 1960s. Maize deficit represented 4.9 million tonnes out of the 7.6 million tonne deficit for all cereals (SADC/FSTAU 1993; UNEP & ICRAF 2006). Since 2001, consecutive dry spells in some areas of southern Africa, have led to serious food shortages in many countries. In 2001/2002 six countries namely; Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe, faced a food deficit to the tune of 1.2 million tonnes of cereals and non-food requirements at an estimated cost of US\$611 million (SADC 2002; UNEP & ICRAF 2006). The 2002/2003 drought resulted in a food deficit of 3.3 million tonnes, with an estimated 14.4 million people in need of assistance. The World Food Program (WFP) analysed the food situation in the southern African region in 2001/2002 and identified 7 major factors that were contributing to the crisis, two of which were climate related factors (WFP 2002). These, climate related factors included severe dry spells/drought in: Malawi, Mozambique, Zambia and Zimbabwe; and heavy rain/floods in: Lesotho, South and Central Mozambique.

Temperature changes

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001) states that climate change scenarios indicate a future warming of 0.2 to 0.5 °C per decade across Africa. This warming is greatest over the interior of the semi-arid margins of the Sahara and central southern Africa. A more recent Global Circulation Model suggests that by the 2070-2099 periods, maximum warming in southern Africa is expected to be up to 7° C (Ruosteenoja *et al.* 2003). However, Hudson and Jones (2002), show that regional climate models for southern Africa give slightly different results due to their improved ability to predict climate variability. They predict a 3.7° C increase in summer mean surface air temperature and a 4°C increase in winter by the 2080s (UNEP & ICRAF 2006).

Changes in precipitation

Precipitation projections are generally less consistent, but most simulations in southern Africa indicate reduced precipitation in the next 100 years and most models project that by 2050 the interior of southern Africa will experience significant decreases during the growing season (IPCC 2001). Southern African monsoons are projected to weaken during the 2000-2049 period, and precipitation is expected to decrease. By the 2080s, a drying, over much of the western sub-tropical region (which includes northern Namibia) due to fewer rainy days and less intense rainfall, is predicted (Hudson & Jones 2002;



Hulme *et al.* 2001; IPCC 2001; Ruosteenoja *et al.* 2003). Kigotho (2005) adds that the climate change induced warming of the Indian Ocean is likely to lead to persistent droughts in southern Africa in the coming years, and the monsoon winds that bring seasonal rain to sub-Saharan Africa could be 10-20% drier than the 1950-2000 averages.

Changes in evaporation

In Africa, water supplies from rivers, lakes and rainfall are already threatened by unsustainable use, and climate change could impose additional pressures on water availability. Global warming is predicted to reduce soil moisture in sub-humid zones and reduce runoff. De Wit and Stankiewicz (2006) calculated that decreases in perennial drainage will significantly affect the present surface water access across 25% of Africa by the end of this century; with significant runoff reduction by 2050 in southern Africa (Arnell, 1999). Furthermore, the percentage of years with runoff below the current drought runoff is likely to increase by about 30% across much of southern Africa by the 2050s (Arnell 2004).

Floods

Floods are already having very large impacts on cities and on smaller urban centres in many African countries. For instance, the floods in Mozambique in 2000, which included heavy floods in Maputo, killed at least 700 people, displaced 650,000 and affected 4.5 million; the floods in Algiers in 2001 killed approximately 900 people, and affected 45,000; heavy rains in East Africa in 2002 brought floods and mud-slides forcing tens of thousands to leave their homes in Rwanda, Kenya, Burundi, Tanzania and Uganda, and the very serious floods in Port Harcourt and in Addis Ababa in 2006 also caused mayhem. Furthermore, the Mombasa floods in October 2006 were particularly serious, affecting some 60,000 people; some studies have estimated that about 17% of Mombasa's area (4,600 hectares) could be submerged by the sea-level rise of 0.3 metres (Mahongo 2006), with a larger area rendered uninhabitable or unusable for agriculture because of water logging and salt stress (Awuor 2007).

Climate change impacts

Several studies have confirmed that Africa is 'highly vulnerable' to the impacts of climate change because of factors such as; widespread poverty, recurrent droughts, floods, inequitable land distribution, poor social and economic infrastructure, and the over-dependence on natural resources that are climate sensitive sectors such as, rain-fed agriculture, forestry and water resources (IPCC 2001: 489-491; Slingo *et al.* 2005; FAO 2003; Parry *et al.* 2004; Elasha *et al.* 2006; Schneider *et al.* 2006; Ben 2005; Orindi & Murray 2005). Large-scale events such as the ongoing drought in the Horn of Africa, the 1998 floods in East Africa and the 1997/8 and 2000 floods in Mozambique, illustrate ways in which many communities are already suffering from the less predictable and more extreme weather patterns.

It is well established that climate change impacts in most parts of arid and semi-arid Africa have increased the degree of inter-annual rainfall variability. It is therefore, not surprising that most of the continent is prone to extreme events such as droughts and floods with far reaching socio-economic devastations that include damage to infrastructure, loss of life, mass migration of people and animals, poor crop yields, food shortages, famine, malnutrition, and many other socio-economic miseries (Indeje 2000).



Rainfall variation has, to a large extent, disrupted the economies of most southern African countries that largely depend on agriculture. The region is highly vulnerable to the amounts and distribution of rainfall (Indeje 2000). Climate extremes often wipe out decades of national development investments and infrastructures, and often force local and national authorities in the region to redirect most of their scarce resources planned for other national development activities to disaster response and recovery including relief programmes. Climate change leading to changes in the space-time patterns is yet another threat to different parts of Africa, in particular south of the Sahara. It impacts on human populations, food security, physical infrastructures, natural resources and ecosystems, and eventually brings new risk levels that require new or modified coping strategies (IDRC/CCAA 2009).

The IPCC's Fourth Assessment Report (IPCC 2007) describes a trend of warming in Africa at a rate faster than the global average, increasing aridity. These changes exert multiple stresses on the biophysical as well as the social and institutional environments that underpin agricultural production. Some of the induced changes are expected to be abrupt, while others involve gradual shifts in temperature, vegetation cover and species distributions. Climate change is expected to, and in parts of Africa has already begun to, alter the dynamics of drought, rainfall and heat waves, and trigger secondary stresses such as the spread of pests, increased competition for resources, and attendant biodiversity losses (SEI 2008; WGCCD 2005; IDRC/CCAA 2009; IPCC 2001, 2003; CARE 2006; Mwandosya *et al.* 1998 cited in Agrawala 2003; Paavola 2003).

These impacts are widespread in all parts of Africa, although there are disparities between regions due to adaptive capacity differences. While other areas have relatively higher technology and economic power (e.g. South Africa) to support adaptation; there is no pronounced mechanism for adaptation in most southern African countries, such as Tanzania. Likewise, while the southern African region is poorly equipped in terms of adaptation strategies, there is evidence indicating that climate change is directly felt in terms of higher temperatures, changes in the timing and in the quality of rains, and in an increase in the frequency of climate hazards, for example, floods, droughts, cyclones, tropical storms and sea-level rise (CARE 2006; IPCC 2001; Orindi & Murray 2005).

Climate change has already changed the mean temperature and the rainfall leading to the increased variability of rainfall, prolonging the length of dry seasons annually and the severity of periodic droughts (IPCC 2001). This is greatly experienced in the interior part of the East African countries, such as central Tanzania and Northern Kenya, due to reduced rainfall. Coastal areas are prone to floods and are less exposed to droughts, while the interior areas are facing enormously dry spells and extended droughts. Mombasa has already experienced several floods since 1998; while central Tanzania and the northern part of Kenya have faced several drought incidences. Both crop and livestock rearing are vulnerable to these extreme events (Paavola 2003; Parry *et al.* 1999; Downing 2002; Mwandosya *et al.* 1998).

Climate change impacts on southern Africa are further aggravated by poverty. However, many of the strategies have been reactive, especially in addressing drought and flood impacts such as food aid and the evacuation of the affected poor people located in rural areas, which are largely dependent on agriculture for their livelihoods. Hence, adverse shifts in climate can cause devastating declines in human welfare especially in rural areas where transport and infrastructures are not well established (Majule 2009). Such shifts have been implicated in everything from famine to the slow economic

growth and to the heightened risk of civil conflict. For instance, in northwest Kenya, recurring droughts have led to increased competition for grazing resources, livestock losses and conflict (SEI 2008).

Inadequate rainfall, coupled with drought and reduced runoffs, have diminished river flows and decreased the availability of water for irrigation and electricity generation, thus affecting national economies such as Tanzania. Also, increasing temperature and rainfall patterns may in turn affect groundwater recharge and the water supply both in urban and rural communities (Paavola 2003; Wheeler et al. 2000; Porter & Semenov 2005; Challinor et al. 2007). Conversely, climate change affects freshwater quantity and quality (Kundzewicz et al. 2007). More dramatic impacts on water supplies are liable to be felt under the extremes of weather that could arise as a result of climate change, particularly drought and flooding (Wilbanks et al. 2007).

Impact of climate change on social systems

Available studies ascertain that the predicted changes in climate and climate impacts have direct and indirect impacts on human health (IPCC 2001; McMichael et al. 1996; Patz et al. 2002; Paavola 2003). Obviously, the associated impacts of climate change are predominantly negative, with the most severe impacts being seen in low-income countries, and vulnerable communities where the capacity to adapt is weakest (Haines et al. 2006; Confalonieri et al. 2007).

Accordingly, the projected increases in temperature and the changes in rainfall patterns will increase malnutrition emanating from food insecurity and famine; and diseases such as malaria, schistosomiasis, typhoid, trypanosomiasis, cholera and diarrhoea, already evident in Tanzania. In general, malnutrition and food shortages will increase morbidity and mortality related to infectious diseases (IPCC 2001; McMichael et al. 1996; Patz et al. 2002; Rogers & Randolph 2000). Many more diseases, however, are projected to occur in the future in the developing countries. The projected diseases include cardio-respiratory diseases due to higher concentrations of ground-level ozone (Confalonieri et al. 2007).

The potential impacts of climate change on populations in the interior and in the coastal regions will be determined by the future health status of the population; its capacity to cope with climate hazards and its ability to control infectious diseases, and to implement other public health measures (Confalonieri et al. 2007). For instance, coastal communities that rely on marine resources for food, in terms of both supply and maintenance of food quality (food safety), are highly vulnerable to climate-related impacts, in both health and economic terms (ibid).

The consequences are articulated by the fact that marine ecological processes, linked to temperature changes, also play a role in determining human health risks, such as, from cholera, and other enteric pathogens, shellfish and reef fish poisoning (Hunter 2003; Peperzak 2005; McLaughlin et al. 2006; Nicholls et al. 2005; Confalonieri et al. 2007). In addition, climate change has a range of adverse effects on some rural populations and regions, including increased food insecurity due to geographical shifts in optimum crop-growing conditions and yield changes in crops, reduced water resources for agriculture and human consumption, flood and storm damage, loss of cropping land through floods, droughts, a rise in sea level, and increased rates of climate-sensitive health outcomes (Confalonieri et al. 2007).



Water scarcity itself is associated with multiple adverse health outcomes, including diseases associated with water contaminated with faecal and other hazardous substances (including parasites), vector-borne diseases associated with water-storage systems, and malnutrition. This problem constitutes a serious constraint to sustainable development, particularly in savannah regions which cover a vast area across southern African countries (Rockström 2003; Confalonieri *et al.* 2007).

Climate change leading to reduced rainfall and freshwater resources capacity is one of the major sources of conflicts in Africa. The flooding of river basins is currently affecting water quality due to siltation and the destruction of the rich low river basins that support most livelihoods. In addition, increased frequency of flooding and drought also stress freshwater systems and pressurise water supply networks. Again, most energy for industrial and urban areas, in many locations in Africa, is derived mainly from hydropower. There has been unpredictable energy supply since the water resources generating electricity are highly dependent on, and sensitive to extreme climatic fluctuations such as droughts and floods. Droughts are known to be accompanied with low water levels in the major dams, while floods bring a lot of silt into the dams that can sometimes lead to the malfunctioning of, or damages to the turbines (IDRC/CCAA 2009; Kundzewicz *et al.* 2007).

In recent years there have been resurgences of malaria in the highlands of East Africa. Although many factors are probably involved in the malaria implications, such as poor drug-treatment implementation, drug resistance, land-use change, and various socio-demographic factors, including poverty; there is also a strong correlation with climate change (Pascual *et al.* 2006; Collier *et al.* 2008). This is attributed to fact that the temperature in the highlands of East Africa has risen by 0.5° C since 1980, much faster than the global average, thus correlating with a sharp increase in the mosquito populations (Collier *et al.* 2008).

Unless countered, both malaria and dengue are expected to spread substantially. Malaria already inflicts enormous costs on Africa, over and above its direct effects on health. Gallup and Sachs (2001 in Collier *et al.* 2008) argue that, controlling of other factors, the impact of intensive malaria means a reduction of income by two-thirds; while a 10 percent reduction in malaria is associated with 0.3 percent of higher growth. Hence the spread of malaria, and the concomitant increase in the difficulty of its control, may imply high, though currently unquantifiable, long-term costs (Collier *et al.* 2008).

Impact of climate change on natural systems

Historically, climate change has resulted in dramatic shifts in the geographical distributions of species and ecosystems. In order for species to adapt, the current rates of migration of species will have to be much higher than the rates during post-glacial periods (Malcolm *et al.* 2002). Species that have the capability to keep up with climate shifts may survive; others that cannot respond will likely suffer. For example, biome sensitivity assessments in Africa show that deciduous and semi-deciduous closed canopy forests may be very sensitive to small decreases in the amount of precipitation that plants receive during the growing season, illustrating that deciduous forests may be more sensitive than grasslands or savannas to reduced precipitation (Hély *et al.* 2006). Invasive species and other species with high fertility and dispersal capabilities have shown to be highly adaptive to variable climatic conditions (Malcolm *et al.* 2002). Southern Africa may be particularly vulnerable to exotic and invasive species colonisation due to its climate sensitive native fauna.



Migratory species that use southern Africa as breeding sites may also be vulnerable to changes in climate, mainly through altering migratory routes (and timings) of species that use both seasonal wetlands (e.g., migratory birds) and track seasonal changes in vegetation (e.g., herbivores), which may also increase conflicts with humans, particularly in areas where rainfall is low (Thirgood *et al.* 2004). Land-use patterns in Africa can also prevent animals from changing their migratory routes, for example, park boundary fences have been demonstrated to disrupt migratory journeys, leading, for example, to a population decline in wildebeest (Whyte & Joubert 1988).

Climate change also threatens some of the large protected areas (including ones that protect migratory species) that have been designated to conserve much of Africa's magnificent biodiversity. It is expected that vegetation will migrate or move in order to utilize suitable habitats requirements (i.e., water and nutrient availability). However, this may mean that in some locations the geographical range of suitable habitats will shift outside the protected area boundaries. In addition, weather extremes can also affect biodiversity in more complex ways. For example, African elephants (*Loxodonta africana*), breed year-round; dominant males mate in the wet season and subordinate males breed in the dry season. Subsequently, a change in the intensity or duration of the rainy versus drought seasons could change relative breeding rates and, hence, genetic structures in these populations (Poole 1989; Rubenstein 1992). Strategies for future designations of protected areas need to be developed that include projections of future climate change and corresponding changes in the geographic range of plant and animal species to ensure adequate protection.

Vast forest disappearance due to climate change-induced die-back and land use change would substantially affect species composition and global geochemical cycling, particularly the carbon cycle (Malcolm *et al.* 2002). Chidumayo (2005) showed that dry tropical trees suffer severe water stress at the beginning of the growing season and that a warmer climate may accelerate the depletion of deep-soil water that tree species depend on for survival. In sub-Saharan Africa, which includes parts of southern Africa, several ecosystems, particularly grass and shrub savannahs, are shown to be highly sensitive to the short-term availability of water due to climate variability (Vanacker *et al.* 2005).

Shrub and grassland vegetation types generally have root systems that are shallow and dense. These plants draw their moisture from water that is available in upper soil layers. Growth in these species depends highly upon the timing, intensity and duration of rainfall. Climate projections suggest that during the already dry months, less precipitation will occur likely reducing the resilience of these plants (Vanacker *et al.* 2005). Changes in plant composition will also have an impact on ecosystem resilience; less diverse systems can be more sensitive to precipitation fluctuations. For example, ecosystems that are comprised of uniform herbaceous cover, such as in savannah plant communities, show the highest sensitivity to precipitation fluctuations when compared with plant communities of a mix of herbaceous, shrub and tree species that support a higher diversity of species (Vanacker *et al.* 2005).

Climate change may also affect the range of species, which could have profound impacts on the population size of species. Among Tanzania's important and productive coastal ecosystems, mangroves are the most vulnerable to inundation, followed by sand and mudflats. Sea-level rise would also cause salt water intrusion in Tanzania's aquifers and deltas, affecting fresh water availability, especially in coastal areas (Orindi & Murray 2005).



METHODS AND TOOLS FOR ASSESSING CLIMATE CHANGE IMPACTS

Climate change impacts have been studied overtime, with much focus on biophysical and socio-economic aspects. Crop production and yield patterns have been of particular interest as they link to food security in rural communities. Since atmospheric concentrations of greenhouse gases continue to rise at rates that are both unprecedented and alarming, efforts have been made to understand the implications for crop production (Siegenthaler *et al.* 2005; Spahni *et al.* 2005; Anderson & Bows 2008). These efforts are primarily based on climate models, which use spatial grids with resolutions typically in the order of a hundred kilometres. Such simplification of the spatial heterogeneity of processes has direct implications for the assessment of the impacts of climate change at a local scale. Likewise, location-specific methods have also been developed, to account for the variety of climatic and non-climatic stresses induced by climate change and variability, often not observable at aggregated spatial scales. It is at this smaller field scale that crop models, for example, were originally designed to operate (Sinclair & Seligman 1996; van Ittersum *et al.* 2003), resulting in applications in decision support (Boote & Jones 1998) and in discussion support (Hansen 2005).

It is clear that regional prediction, using crop and climate models, cannot rely solely on methods developed as part of the longer standing tradition of crop simulation in the field scale (Moen *et al.* 1994; Faivre *et al.* 2004). Whilst the results of field-scale models can be directly compared with regional-scale yields (Yun 2003; Nain *et al.* 2004; Xiong *et al.* 2007), it can be argued that this requires the design or the selection of crop models that have a low input data requirement (Priya & Shibasaki, 2001; de Wit *et al.* 2005). An alternative is to take a field-scale crop model and make it applicable to the regional scale through one or more procedures, such as calibration (Chipanshi *et al.* 1999; Jagtap & Jones 2002), aggregation of inputs (Haskett *et al.* 1995), and aggregation of outputs from multiple sub-grid simulations. This latter method can use either simulations sampled by varying model inputs such as planting date and crop variety (Jagtap & Jones 2002; Irmak *et al.* 2005), or else simulations explicitly carried out at the sub-grid scale (Thornton *et al.* 1996).

Estimates of yields at the regional scale can also be made by designing a crop model that operates on that scale. Such a model may be empirical, with weather variables used within a statistical regression of output from a field-scale crop model or of observed yield data (Iglesias *et al.* 2000; Lobell *et al.* 2008). The use of regressions of field-scale crop models can introduce significant errors through the linearisation of the equations for crop yield and/or an inability to account for sub seasonal climate variability (Challinor *et al.* 2006). More generally, the validity of empirical methods under climate change is limited by the necessity of using data outside the range for which the models were fitted. Also, statistical models have no explanatory power to enable understanding as to why certain changes have occurred. This is one reason why process-based regional-scale (or large-area) methods have been developed.

CLIMATE CHANGE VULNERABILITY

This is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is considered as a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (FAO 2008). Climate variability and change have direct impacts that cause vulnerability to the natural and social systems through flooding, droughts,



changes in average temperatures (e.g. leading to thawing of permafrost), temperature extremes, and extreme weather events such as hurricanes and cyclones (Brenkert & Malone 2005). For example, dry land agro-ecosystems in southern Africa, that provide the resource base for some of the rapid growing populations today, is currently stressed by long-term dry spells and droughts. Hence, rainfall variability straining already poor soils makes these systems inherently vulnerable, and land degradation reduces their capacity to cope with disturbances (Barron *et al.* 2003; Mortimore 2005). These characteristics limit the productivity and make dry land agro-ecosystems both inherently dynamic and vulnerable. Eventually, one of the outcomes of the degradation process is a reduced capacity of the environments, subjected to it, to absorb disturbances, such as droughts and floods (Rockström 2003; Enfors & Gordon 2007). Despite a thorough description of vulnerability across scales and regions, it is important to note that all societies have inherent abilities to deal with certain variations in climate, yet adaptive capacities are unevenly distributed, both across countries and within societies.

These disparities exist because vulnerability depends critically on context, and on the factors that make a system vulnerable to a hazard, and depend on the nature of the system and the type of hazard in question. For example, the factors that make a rural community in semi-arid Africa vulnerable to drought cannot be identical to those that make areas of a wealthy industrialised nation vulnerable to flooding, wind storms and other extreme weather events (FAO 2007; Schneider *et al.* 2007). Generally, if climate change occurs faster than those affected can adapt, community vulnerability to the impacts of both climate variability and change increases enormously. It is also necessary to understand how physical, biological and economic systems are likely to respond (FAO 2007).

Isolation and income diversity might be important determinants of vulnerability to drought for rural communities in Africa, whereas the dominant factors mediating vulnerability to storms and floods in developed countries might be the quality of physical infrastructure, and the efficacy of land use planning. Nonetheless, there are certain factors that are likely to influence vulnerability to a wide variety of hazards in different geographical and socio-political contexts. These are developmental factors including poverty, health status, economic inequality and elements of governance (Brooks *et al.* 2005; Eriksen 2001; Majule 2009).

These differences in vulnerability are a function of a number of factors. Exposure is one key factor. For example, crops at low latitudes will have greater exposure to higher temperatures than crops at mid- and high latitudes. Thus, yields for grain crops, which are sensitive to heat, are more likely to decline at lower latitudes than at higher latitudes. Social systems in low-lying coastal areas will vary in their exposure and adaptive capacities, yet most will have increased vulnerability with greater warming and associated sea-level rises or storm surges and floods (Yamin *et al.* 2005; Schneider *et al.* 2007; FAO 2007).

A second key factor affecting vulnerability is the capacity of social systems to adapt to their environment, including coping with the threats it may pose, and taking advantage of beneficial changes. Other determinants of adaptive capacity include such factors as wealth, societal organisation and access to technology (Smit *et al.* 2001; Schneider *et al.* 2007; Yohe & Tol 2002). These attributes differentiate vulnerability to climate change across societies facing similar exposure. For example, Nicholls (2004), and Nicholls and Tol (2006), found that the level of development and the population growth are very important factors affecting vulnerability to sea-level rise and to floods.



Vulnerability associated with water resources is still complex because vulnerability is quite region-specific. In addition, the level of development and adaptation and social factors determining access to water are very important in determining the vulnerability in the water sector. Studies differ as to whether climate change will increase or decrease the number of people living in water-stressed areas (Parry *et al.* 1999; Arnell 2004; Hitz & Smith, 2004; Alcamo *et al.* 2007). Hundreds of millions of people are estimated to be affected by changes in water quantity and quality (Arnell 2004; Schneider *et al.* 2007) but uncertainties remain concerning the degree to which these risks might be labelled as 'key'. But in general terms, floods and droughts appear to have increased in some regions and are likely to become more severe in the future (Schneider *et al.* 2007).

Low-lying, densely populated coastal areas are very likely to face risks from sea-level rise, and more intense extreme events such as storms and floods (Schneider *et al.* 2007). The combination of land-use changes and climate change is very likely to substantially reduce biodiversity leading to excessive flood events in low land areas. In addition, extended warm periods and increased drought will increase water stress in forests and in grasslands and increase the frequency and intensity of wildfires, especially in the semi-arid areas of southern Africa (Cary 2002; Westerling *et al.* 2006). These effects may lead to large losses of accumulated carbon from the soil and the biosphere to the atmosphere, thereby amplifying global warming (Langmann & Heil 2004; Angert *et al.* 2005; Bellamy *et al.* 2005).

Communities in coastal, semi arid and arid areas, particularly in low income countries, are vulnerable to a range of health effects due to climate variability and long-term climate change, particularly extreme weather and climate events such as, floods and droughts. These vulnerabilities are largest in semi-arid and arid low-income countries, where precipitation and stream flow are concentrated over a few months, and where year-to-year variations are high.

The poor and marginalised have historically been most at risk, and are also most vulnerable to the impacts of climate change. Recent analyses in Africa, Asia and Latin America, for example, show that marginalised, primary resource-dependent livelihood groups are particularly vulnerable to climate change impacts if their natural resource base is severely stressed and degraded by overuse, or if their governance systems are in or near a state of failure and hence not capable of responding effectively (Mary & Majule 2009; Leary *et al.* 2006). Livelihood literatures in Ellis (2000), Ellis and Mdoe (2003); Ellis and Allison (2004); Scoones (1998); Challinor *et al.* (2007), suggest that low levels of income, with high proportions of income used for food consumption and dependence from risky agriculture, are factors that create vulnerability (Paavola 2004).

There are several studies concluding that the countries of the Greater Horn of Africa (GHA, among which East Africa is part of the region) are particularly vulnerable to droughts, which characterise the region with increasing economic impacts. This vulnerability is further exacerbated by factors such as widespread poverty and over-dependence on rain-fed agriculture (IDRC/CCAA 2009). It is also constraining the ability of individuals to use food effectively by altering the conditions for food safety and changing the disease pressure from vector, water, and food-borne diseases (Easterling 2007).

Due to disparities of economic capacity between women and men among southern African communities, it has been observed that vulnerability to climate risks exacerbates poverty and existing inequal-



ities (IPCC 1998, 2001; Hulm, 1996). Increased vulnerability is predicted for millions of smallholder farmers in the semi-arid areas where drought and excessive dry-spells threatens agricultural activities (Challinor *et al.* 2007; Easterling *et al.* 2007; Huq & Ayers 2007; Ziervogel *et al.* 2008; Nelson & Stathers 2009). Furthermore, the vulnerability is altered by the high economic dependency on climate sensitive sectors like agriculture, water resources, tourism and the hotel industry. Thus, better management of climate related risks is significant to disaster risk reduction, climate change adaptation, and sustaining socio-economic development (IDRC/CCAA 2009; IPCC 2001: 489-491, 2007).

In the southern Africa region, according to Challinor *et al.* (2007), rainfed agriculture (mainly maize) is the largest sector of the economy agricultural production that is under pressure from increasing demands for food triggered by rapid population pressure. A large percentage of the population is already vulnerable to a range of natural hazards with increasing climate variability and change expected to aggravate the situation further by causing more frequent and more intense droughts, floods and increases in temperatures (IDRC/CCAA 2009).

According to the IPCC (2007), the Africa region still stands out as the most vulnerable continent. Again, the vulnerability differs across regions depending on the capacity to cope and to adapt with the changing climate. The IPCC (2007) further confirms that the threat of climate change is real, and Africa together with the other developing countries is expected to be hardest hit due to the current high vulnerability and low coping capacity levels. The limited adaptive capacity to climate change among southern Africa countries, and Africa in general, has been noted as a key factor in the continent's high vulnerability to climate change (IDRC/CCAA 2009; Nelson & Stathers 2009).

The productivity of food crops, from year to year for example, is inherently sensitive to the variability in the climate. Producers in many parts of the world have the physical, agricultural, economic and social resources to moderate, or to adapt, to the impacts of climate variability on food production systems. However, in many parts of Africa this is not the case, making agricultural systems and other livelihood supporting systems particularly vulnerable (Haile 2005). This is partly because a large fraction of Africa's crop production depends directly on rainfall. For example, 89% of cereals in sub-Saharan Africa are rainfed, hence, in many parts of Africa, climate is already a key driver of food security (Cooper 2004; Gregory *et al.* 2005; Verdin *et al.* 2005).

CLIMATE CHANGE ADAPTATION

From an integrated point of view that takes into account impacts on both the natural and social systems, adaptation may be seen as those measures that enable the natural systems and the communities to cope with the adverse effects of climate variability and change. Despite the wide reflection provided by an integrated approach and by other literatures in defining adaptation; for the purpose of this review, the definition of adaptation to climate change, is adopted from the IPCC (2001), that regards the concept as an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change, or take advantage of new opportunities. Hence adaptation is considered to involve both building adaptive capacity thereby, increasing the ability of individuals, groups, or organisations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action



(Adger *et al.* 2005, 2007). It therefore, incorporates a wide range of measures that would increase the resilience of the environment and the communities to the possible adverse effects of climate variability and change. Thus, adaptation strategies are an integral part of sustainable development and should improve the society's ability to cope with changes in climatic conditions across time scales from the short term (e.g. seasonal to annual) to the long term, such as a decades to centuries (IDRC/CCAA, 2009).

The ongoing studies on climate change and associated impacts have identified various types of adaptations feasible in combating climate change impacts. These include anticipatory, autonomous and planned adaptation. Anticipatory or proactive adaptation takes place before impacts of climate change are observed. On the other hand, autonomous or spontaneous adaptation does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. The last category is the planned adaptation that occurs as the result of a deliberate policy decision based on an awareness that conditions have changed, or are about to change and that action is required to return to, to maintain, or to achieve a desired state (FAO 2008; Leary *et al.* 2006; Adger *et al.* 2007).

The primary aim of adaptation is to moderate the adverse effects of un-avoided climate change through a wide range of actions that are targeted at the vulnerable system of the community. The ultimate goal of adaptation is to develop flexible and resilient societies and economies that have the capacity to address both the challenges and the opportunities presented by changing climatic conditions (IDRC/CCAA 2009).

Currently, climate change impacts and responses are observed in physical and ecological systems. Adaptation to these impacts is increasingly being observed in both physical and ecological systems as well as in human adjustments to resource availability and risk at different spatial and societal scales (Adger *et al.* 2005). Nevertheless, there is increasing evidence from ecological studies that the resilience of socio-ecological systems coupled to climate change will depend on the rate and magnitude of climate change, and that there may be critical thresholds beyond which some systems may not be able to adapt to changing climate conditions without radically altering their functional state and system integrity (Adger *et al.* 2007).

Although several literatures have identified and classified the context and scale of adaptation, the general principle has been the emphasis that adaptations have to be an on-going process reflecting many factors or stresses, rather than discrete measures to address climate change specifically (Leary *et al.* 2006; Adger *et al.* 2007). According to Adger *et al.* (2005), both dimensions of adaptation can be continuously implemented in preparation for, or in response to impacts generated by a changing climate by the actions throughout the society, by individuals, groups and governments. These actions and dimensions can be motivated by the protection of the economic well-being, or the improvement of safety through market exchanges, and the extension of social networks or through the actions of individuals and organisations to meet their own individual or collective goals (Adger 2003; Adger *et al.* 2005).

Increased understanding of climate threats to agriculture in Africa, however, has not been met with a similarly improved understanding of how best to respond. Given the adaptability displayed by farmers



in the face of past climate variability in Adger *et al.*(2007), African farmers will likely continue to adapt as the climate changes, for example, by adopting new crops or varieties or by altering the timing of planting and other agronomic practices (Burke *et al.* 2009).

But if future climates move as quickly outside the range of past experience as they are expected to throughout the tropics (Battisti & Naylor, 2009), farmers may be unable to adapt rapidly enough without some help (Burke *et al.* 2009). Accordingly, there is a widely acknowledged need for significant investment in agricultural and ecological adaptation. However, these needs of rapid adaptation have been constrained by; little systematic assessment of how to prioritise the 'planned' adaptations, what form of adaptation should be taken, and on what crops and locations they should focus (Burke *et al.* 2009).

Despite these adaptation challenges, several countries in southern Africa have established several adaptation options, which are mainstreamed in the Initial National Communication of respective countries as shown in Table 1 below. Due to the heavy dependence on the agricultural sector, southern African countries priorities adaptation measures mainly in this sector.

Table 1: Future Climate Change, its expected effects on crops and the various adaptive strategies proposed by southern Africa Governments in the Initial National Communication to the UNFCCC

Country	Baseline Period	Predictions	Effects on Crops	Adaptive Measures	Sources
Botswana	1961-1990	<ul style="list-style-type: none"> • 10-20% rainfall decrease shown by most models • 10 % rainfall increase shown by few models • Shorter and less reliable rainy season 	<ul style="list-style-type: none"> • 30% decrease of maize and sorghum yield in the dry scenarios • Light increase in sorghum yield in the wet scenario • Shorter and less reliable rainy season 	<ul style="list-style-type: none"> • Develop capacity for drought early warning units • Import of cereals and relief package for rural people • Wider use of early maturing varieties • Adjusting to planting dates • Addressing major yield limiting factors 	<ul style="list-style-type: none"> • Government of Botswana (2001)



Lesotho	1961-1990	<ul style="list-style-type: none"> • Warming by 0.7, 1 and 2°C by 2030, 2050 and 2075 respectively • Lower rainfall in spring and summer, higher rainfall in winter and gradual warming 	<ul style="list-style-type: none"> • Marginal maize production increase in normal rainfall years, no clear effects on sorghum and dry bean • Extensive and improvement for maize (20%), sorghum (108-115%) and dry bean (350%) in dry season 	<ul style="list-style-type: none"> • Drought tolerant and fast maturing cultivars • Shift from maize mono-crop to crop diversification, irrigation and intensification • Rescheduling of planting dates and promotion of soil liming, organic fertilization and soil conservation activities • Abandonment of marginal land slopes, • Improved food activities and planting of trees for wind breakers 	<ul style="list-style-type: none"> • Government of Lesotho (2000)
Malawi	1961-1990	<ul style="list-style-type: none"> • 2-3°C temperature rise by 2100 • 3-50% increase or 2-40% decrease in monthly rainfall depending on model 	<ul style="list-style-type: none"> • Gradual decrease of maize yield from 2020 to 2100 showed by 3 out of 4 models • Marginal increase in maize yield shown by 1 model 	<ul style="list-style-type: none"> • Changes in cultivated land area, in line with projected climate change • Changes in crops types • Change in crop locations • Use of irrigation and fertilizers • Control of pests, weeds, parasites, and diseases • Soil drainage and soil erosion control • Development of farm infrastructures 	<ul style="list-style-type: none"> • Government of Malawi (2002)



South Africa		<ul style="list-style-type: none">• 1.3°C warming at the 2050 horizon• 5-10% decrease in annual rainfall	<ul style="list-style-type: none">• 10-20% decrease in maize production	<ul style="list-style-type: none">• Change in planting dates, row spacing, planting density and cultivars choice• Planting drought resistant crops such as sorghum and millet, or shifting crops from crops to livestock• Promoting practices such as planting dates and millet	



Zimbabwe		<ul style="list-style-type: none">• Warmer and drier climate by 2075	<ul style="list-style-type: none">• Low lying areas will cease to be suitable for maize production• Growing season 2-5% shorter than it is currently	<ul style="list-style-type: none">• Introduction of livestock and dairy production in areas where maize production becomes uneconomical;• Promotion of drought tolerant crops• Improvement of irrigation techniques and promotion of agricultural diversification• Adjustment of the timing of farming operations and changing planting density• Installation of medium to large dams throughout the country for the development of irrigation projects• And shifting from subsistence to cash crop economy to boost rural-income	<ul style="list-style-type: none">• Government of Zimbabwe (1998)
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Source: UNEP & ICRAF (2006): Climate change and variability: Impacts and adaptation strategies



THE ROLE OF HIGHER EDUCATION IN SUPPORTING ADAPTATION

The ultimate goal of higher education, throughout the world, has been to provide solutions to development challenges (Bloom *et al.* 2005). For instance, it is gratifying to note that African educators are taking a leading role in assessing what needs to be done in providing solutions to the challenges posed by climate change. In southern Africa, Higher Education is well placed to contribute to this process. The key contribution of higher education has been to create awareness through research and training, and it is this role that it should play in climate change impacts and adaptation potentials. The availability of multidisciplinary professionals in the region facilitates establishing synergy between development and education. Several networks and partnerships have been formed to concentrate on research and awareness creation among southern African countries. Despite past investments by African governments in Higher Education, the hope that Universities would provide solutions to Africa's problems is yet to be realised. There has been an enormous brain drain from Africa to other continents. It is estimated that 23,000 qualified academic professionals emigrate from Africa each year in search of better working conditions (BASIC 2006). Many of these are in agriculture and natural resources, areas that are of crucial economic importance for most African countries and relevant to climate change issues.

Shortfalls in the existing university curricula

In 2007, Biodiversity International commissioned a survey to evaluate how plant genetic resources and agro-biodiversity are being taught in universities in southern Africa (Muluvi *et al.* 2008 cited by Rudebjer *et al.* 2008). The countries surveyed included Zimbabwe, Malawi, Zambia and Uganda. The results showed that none of the surveyed universities offered comprehensive agro-biodiversity programmes at undergraduate or graduate level. This survey recommended an urgent need to incorporate agro-biodiversity in the tertiary agricultural education programmes.

The shortfalls in tertiary agricultural education have been further described by Temu *et al.* (2003) and Chakeredza *et al.* (2008) as: the poor standing of institutions to meet the desired curriculum coverage; the training is predominantly based on curricula adopted from countries that had colonies in Africa, the curricula were founded on an agricultural philosophy that aimed at the production of cash crops for consumption by the colonising countries; the teaching mode is not learner-centred; and there is very little integration of theoretical training with field level experience. While agricultural sector and land use are the chief economic sector in the region, in contrast, most of the universities are located in towns where there are no farming communities nearby to work with. In most cases neither the farming community nor the private sector is involved in the design and delivery of the agricultural curricula.

The need for climate change in the curricula

Increasingly, climate change is becoming a challenge to African development efforts because of its dependence on climate sensitive sectors for livelihoods. There is a need for graduating university students to be well versed with the challenges posed by climate change, if they are going to advise the communities they will be working with appropriately. They also need to understand the implications of climate change on economic development. Educating learners, currently at school about climate change, will help to shape and sustain future policy-making. Studies on climate change have so far been limited to adaptation and mitigation intervention strategies. The faculty and students should be able to contribute to the development of the body of knowledge as regards climate change. Students



should be aware of the various International Conventions and Protocols surrounding climate change. These include UN Framework convention on climate change (UNFCCC), Kyoto protocol, and a range of other informal partnerships and dialogues that provide both a framework that supports co-operation and a foundation on which to build further collective action. The challenge now is; how to develop good curricula, produce relevant learning resources and capacitate educators. This is where efforts should be put to ensure such needed knowledge is offered in the region

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CLIMATE CHANGE SCENARIO DEVELOPMENT IN SUB-SAHARAN AFRICA¹

2

CONTEXT

As the science of climate change settles on clear understandings around the global climate response to the increasing atmospheric greenhouse gas concentrations, so increasingly the attention turns to reducing uncertainty at the regional scale and advancing our confidence in the messages delivered to users of climate information. Likewise, as these users grapple with the realities of developing response strategies, tailored to their specific vulnerability and geographic location, so the paucity of clear regional information becomes a leading constraint in their decision-making process.

The demand for such regional information continues to grow rapidly, a demand reflected in the substantial expansion of a broad spectrum of activities. For example, the growth in workshops and conference sessions looking at the development and communication of regional climate information (reflected by the high profile 2009 World Climate Conference³ focusing on climate services), the emergence of new internet-based data portals purporting to provide the requisite information, and the development of national climate services⁴. Few of these activities integrate across the multiple lines of evidence to develop robust messages of regional change, and evidence of the shortcomings in current information availability can be seen in the continued heavy reliance placed on the native grid resolution data from Global Climate Models (GCMs) – a low skill attribute of GCMs – and often dangerously using only one or few GCMs.

These activities represent a partial isolation of the development of regional climate change scenarios from the larger societal context. Each facet of the broader context is a potential factor that both informs and limits the development of regional information. These factors fall largely into three areas: (1) issues of the uptake and adoption of climate products (including aspects of communication), (2) the formulation of information into user relevant tailored products, and (3) limitations in the science engaged in the knowledge generation activities.

1 This paper draws heavily on material currently in preparation for a science paper titled "Developing defensible messages of regional and local-scale climate change" by B.C. Hewitson, W. Gutowski, M. Tadross and R. Crane.

2 Bruce Hewitson is a Professor at the Environmental and Geographical Science Department and heads up the Climate System Analysis Group, University of Cape Town. Email: hewitson@csag.uct.ac.za.

3 See http://www.wmo.int/wcc3/page_en.php

4 As examples, see <http://www.ukcip.org.uk/> or <http://www.nature.com/news/2009/090219/full/news.2009.108.html>



Commonly the first expressed need for information from users is a request for numbers; for a data product that is taken as a stand-alone representation of the actual future, and which is then applied in a cascade of impact assessment and adaptation activities. Recognition is usually given to the question of uncertainty, but the acknowledgement of uncertainty is not a guarantee that this is effectively accommodated in subsequent applications of the data. In developing nations, where the experiential knowledge around the value-use of climate data is often limited, the weak incorporation of uncertainty represents an additional vulnerability to adaptation responses. It is clear that developing nations do have a growing capacity of competent theoretically trained scientists. However, in dealing with a climate system that is quasi-deterministic in behaviour, usually with poor observational baseline data, the experiential knowledge around climate projections and model output is critical to appropriate application – this only comes with time. Thus, in this regard, it is not only the scientific capacity for the knowledge generation that is fragile in Africa, perhaps even more limiting is the users' communities capacity to rightly use and understand the limits of regional climate scenario information.

Context is thus paramount; the generation of regional scenarios sits within an external context that needs to evolve and develop alongside the core science. The external factors are broad, cross-cutting, and relate to the overall development of multiple sectors of society. Examples of these external elements include:

- communication between science and society
- experiential skill and capacity of stakeholders to use climate information
- time imperatives of project deliverables and user demands driving research agenda
- funding agency agendas that leave key knowledge gaps unaddressed
- lack of critical mass in institutional capacity
- weak sustainability of research undermined through poor retention or diversion of capacity
- bureaucratic constraints on data access and management
- poor career opportunities not attracting new emerging scientists
- infrastructural limitations, especially bandwidth and computational resources

From the other end of the spectrum within the core science activities, other constraints further hinder the process. Such factors can be both purely scientific, or consequences arising from the external constraints. Examples include:

- poor availability (or access to) historical data
- weak understanding of some key regional climate processes and feedbacks
- inherent limitations in the models skill or analysis methodologies
- the high degree of climate variability in Africa making identification of the climate change signal problematic
- weak effort expended on integration of multiple lines of evidence
- inadequate methods for addressing uncertainty
- a historical limitation of generated regional climate projection data leading to a problematic over-reliance on GCM data for regional applications

This paper primarily explores the issues internal to the activities of generating regional information on climate change. It is not possible to completely cover all the external factors which are common to a broad range of disciplines and issues of societal development and for the most part lie beyond the scope of this paper.



APPROACHES TO REGIONAL CLIMATE INFORMATION

One relevant, yet simple question is 'Why regional climate change information?' Unlike more foundational curiosity-led research, the question of regional climate change is tightly coupled to issues of real world impacts, societal vulnerability, economic viability, national and local policy plans, and ultimately in real terms the investment and resource commitment to adaptation action and risk management. Thus information that is delivered by the science community has real-world implications of significant and immediate consequence, especially where major national and international commitments are made for adaptation. As a result, the development of regional change information needs to be carefully handled, contextualised and tailored to the knowledge and interpretative capacity of the intended recipient, and formulated to be relevant to a sector's climate exposure and the relevant attributes of vulnerability. There is thus no one simple regional message, but rather a broad spectrum of permutations built on a common underlying knowledge of the physical system responses.

The IPCC has often been seen as the primary entry point for obtaining regional climate change information. The IPCC has wrestled with the question of assessing regional information in Working Group 1 (WG1) of the 3rd (TAR Ch10) and 4th (AR4 Ch11) assessment reports, and in providing guidance for approaches to developing regional information (IPCC Data Distribution Centre). This objective can, however, only be achieved in terms of overarching messages within the IPCC material due to the impossibility to address the regional specific details within the constraints of the IPCC reports. Paradoxically, at the same time the activities of the IPCC Working Group II (WG2) are highly dependent on such regional information. At present alternative resources that offer a comprehensive assessment of regional details on climate change are only now emerging.



Inadequacies in any one of the foundations places constraints on the degree to which one can develop an integrated understanding of regional change. Moreover, there are significant inter-dependencies between each foundation block that present further limitations to achieving optimal findings. For example, limits on observational data undermine the evaluation of model skill, or limits on understanding the regional circulation dynamics, limits our capacity to rightly interpret the indicated process changes in the GCMs.

In some respects these core principles for developing robust regional messages of change have been articulated in the IPCC AR4 Ch11 executive summary, which notes:

'Regional climate change projections presented here are assessed, drawing on information from four potential sources: AOGCM simulations; downscaling of AOGCM⁵-simulated data using techniques to enhance regional detail; physical understanding of the processes governing regional responses; and recent historical climate change.'

This approach is predicated on two foundational concepts which encapsulate the process of deriving a regional change message. First, is that all sources of information have particular limitations and strengths as regards what can or cannot be represented, as all sources contain both noise and signal and needs interpretation. Such limitations on the representation of information are often poorly understood by users. Second, that information contained in a particular source has varying degrees of value and relevance to a given need. (Table 1).

Table 1: Two parallel and complementary conceptual frameworks for approaching the development of regional climate change analyses. On the left is the cascade from raw data to informed action, on the right is the progression of criteria on the quality of the derived understanding

<p>Quantitative data Climate models, historical observations, trends, downscaling, projections, event frequency, etc.</p> <p>↓</p> <p>Information Measures of vulnerability and risk, threshold exceedence, combinatory impacts, uncertainty and confidence, regional scale variations, etc.</p> <p>↓</p> <p>Knowledge Assessing options, understanding consequences, evaluating responses, informing decision making, etc.</p> <p>↓</p> <p>Action Policy development to balance competing priorities, strategic investments in adaptation and mitigation, new research avenues, coordination of response, etc.</p>	<p>Credible The data / information reflect known processes and understanding; that is, the data is recognisably representative of the real world.</p> <p>↓</p> <p>Defensible The distilled information can be explained in terms of physical, chemical and biological principles; i.e. there is a defensible physical basis for reasonableness of the interpreted information.</p> <p>↓</p> <p>Actionable The knowledge based on the distilled information, when used to inform decision making and policy development, is robust enough within a risk management framework such that the choice for action or inaction is the sensible and recommended response.</p>
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5 AOGCM = Atmosphere Ocean Global Climate Model



The first concept begins with the need to understand that data are not information; data are numerical representations of a process, and data reflect to varying degrees error, bias, stochastic variability, and some measure of the signal of the deterministic response to system forcing. The data, suitably analysed, can lead to the creation of information that expresses the *signal* (the attributes of interest) as clearly as possible in the context of *noise* (that is, variance in the data unrelated to the intended use). Moreover, data by virtue of its source (measurement or model) contains only some subset of information. For example, a GCM produces grid cell values. These values are not fully representative in terms of sub-grid cell scale processes and, for some parameters, may not even be a robust integration of the area covered by the grid cell. This is further dependent on the type of landscape represented by the grid cell. For example, rainfall (often needed in regional scale climate assessments) is a typical parameter for which the signal to noise ratio of the single grid cell is often low, and where users should be very cautious to not over-interpret the possible information content.

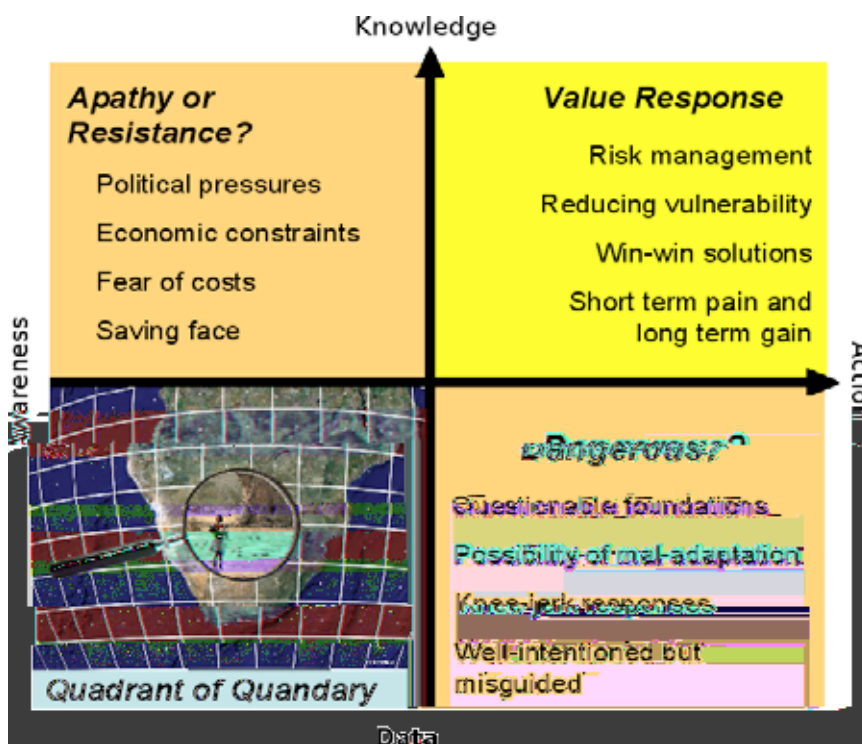
Following this is the recognition that information needs to be translated to knowledge; that is, the information may be distilled from the data, yet needs to be understood and considered in a wider context to provide knowledge about the implications of the information. An example would be GCM data providing information that indicates a poleward expansion of the Hadley Cell circulation. Based on our understanding of the climate system at the mid-latitude margins of the Hadley circulation, we could develop from this knowledge concerning changes in regional wind, or perhaps decreases in mid-latitude frontal activity, etc. Finally, it is the knowledge component that informs and enables an effective (and presumable wise) response in policy, adaptation, and risk management. Whilst we are here concerned with the information and the knowledge that can be generated about changes in the climate system, similar flows of data, information and knowledge of social or ecological systems would also be necessary before suitable actions could be determined.

Complementing this flow from data to action, are three levels of quality – three questions that can be asked of any given regional climate change product: First, is it credible? That is, does it look like planet earth and does it have the known physical attributes of the region in question. Credibility does not imply that it is correct, but it is a necessary pre-condition. Typically, answering this question requires activities such as GCM evaluation, although this is often not taken far enough. Assessing a GCM based on seasonal mean values may ignore critical sub-seasonal attributes that are of key importance to users' interests, but which may be poorly simulated by the model. For example, seasonal means in a GCM may be very realistic, yet the sub-seasonal frequency of rainfall events and intensity may be significantly wrong with critical implications for agriculture and water resources. Second is the question of whether the information is defensible; that is, does the regional expression of climate change have an interpretable physical basis that is reflected in the driving dynamics of the climate system? For example, an indicated change of regional drying needs to be placed in the context of the larger dynamics leading to this response; is the drying in this example consistent with the larger scale circulation, changes in atmospheric stability, tele-connection relationships, etc.? Last is the question of whether the regional projection is actionable. By this we mean, is it (1) significant enough in magnitude to warrant a response decision (even if the decision is to do nothing), (2) important enough in relation to other stressors/vulnerabilities of concern, and (3) has a narrow enough range of uncertainty that, within a risk management framework, would contribute significant additional knowledge to the decision making process.



Not all of these conceptual criteria will ever be perfectly met, but it is imperative that the assessment is made, and a conclusion drawn as to whether the result and outcome is 'good enough'. Figure 2 integrates these issues into a diagram representing the situation that users face. In the bottom left quadrant is what we term a 'Quadrant of quandary'. This is where users typically begin; there is an enhanced awareness of the challenge arising from climate change, and an availability of data.

Figure 2: A conceptual framework for considering the response pathways open to stakeholders, beginning with an awareness of the climate change problem and the availability of data (After Zermoglio, pers com)



The task is then to move from data to knowledge and from awareness to appropriate actions. Three pathways are open:

- One may move from data to knowledge, yet take no decision on appropriate responses (be it to take action or not). This is seen in one context in the international debate around the political response to climate change, where a range of factors may constrain or hold back a decision on responses.
- A decision may be taken for an action based on the raw numbers alone. This is a potentially dangerous route in that one may well engage in action that results in a negative outcome. Sectors (especially in developing nations) with low experiential or technical skills are vulnerable in this respect, with the danger that data will be over-interpreted and a response implemented without fully understanding the limitations of the data at the scale of intended application.
- The optimal path is to translate data to knowledge, and to build on this to move from awareness to appropriate actions, as shown in the upper right hand quadrant of Figure 1.



KEY ELEMENTS IN UNDERSTANDING REGIONAL CLIMATE CHANGE

Conventionally, climate is typically described as mean values of variables such as temperature and rainfall. However, in terms of societal impacts and relevance to different sectors and natural systems, there are a range of concepts that are central to correct interpretation of data and information, most especially as regards global change and its anthropogenic aspects. This section briefly introduces each of these and discusses their relevance for correctly understanding climate change issues.

Detection versus attribution

One of the first natural questions posed when talking about climate change is; 'What has changed?' Often the inference is automatically, but incorrectly, made that identified changes are attributable to anthropogenic climate change. On a global scale the detection of change is comparatively easy and the detection of the change in global mean temperature has been well established. Attribution, the distinction that one can ascribe the cause of the detected change, is considerably more difficult and the defensible attribution of much (but not all) of the identified global change to human factors is only a recent development (see IPCC AR4, 2007), and then only at the global scale.

At the regional scale detection is likewise comparatively easy. Attribution of identified *regional* change to anthropogenic greenhouse gas forced global change is, however, yet to be robustly demonstrated. While plausible, and even persuasive arguments as to how anthropogenic forcing may be causing a detected regional change, the attribution step to say that human activities and not natural variability caused the regional change is difficult. Typically such work involves complex modelling, evaluating the model as a credible proxy for the real world, and then simulating the climate system with and without greenhouse gas forcing to assess the degree to which regional change is attributable to human factors.

Prediction versus projection

Weather forecasts are a product familiar to most of society, and represent a prediction. That is, a prediction that seeks to state what will occur as a deterministic outcome of the system evolving from a given initial state. Most people readily recognise that a prediction has a degree of uncertainty, but nonetheless accept it as a statement of the best understanding of how the system will likely evolve in time.

By comparison the information on future climate change is not a prediction. It is not a statement of what the future will deterministically be; rather it is a statement of a possible (and arguably likely) future dependent on how key factors develop over time. Thus, one seeks to make projections of possible futures – scenarios of varying likelihood. There are a number of aspects that introduce uncertainty into such projections, not least of which are questions of future greenhouse gas emissions and a model's ability to correctly simulate the response to those emissions at the required scale. This distinction between prediction and projection may seem unnecessarily subtle, but it is absolutely critical to the right handling and the appropriate application of information about future climates. Even the IPCC does not make predictions, but explores possible scenarios that are consistent with the growth of greenhouse gas emissions.



regional climate system and livelihood strategies. An often ignored attribute of uncertainty, yet one particularly relevant at regional scales, is what may be termed 'boundary uncertainty': This refers to the situation where a geographic region of concern lies on the boundary of two regions showing strong, but opposite directions of change. In this case the change in the region is highly sensitive to the spatial position of the boundary.

BUILDING A REGIONAL CHANGE MESSAGE

Projections of the future climate are, as already discussed, not a prediction but an assessment of the plausible and likely futures. The skill of projections is strongly dependent on how far in the future one looks, the temporal and spatial scales in question, which variables, which models, which greenhouse gas emissions pathway, etc., and as discussed earlier, deriving the key regional messages requires assessing multiple information sources.

There are four levels of value in climate change messages, each progressively more difficult to attain:

- Whether or not it is possible to generate useful information for a given location / variable (it is not always possible to generate a useful message on the regional change).
- The likely direction of change (positive or negative, or equally importantly, no change).
- The attributes of indicated change (changes in the mean, the extremes, derivative parameters, etc.).
- The probable range of the magnitudes of projected change.

At its root, all regional change is driven by human modifications to their local environment (such as through land use changes) or changes in the circulation of the atmosphere and oceans, coupled to the complex inter-linkages of regional and global forcing and feedbacks. Substantial and valuable information can be drawn from understanding how such large scale processes are projected to change. These large scale attributes are the primary strength of GCMs which are most skilful with respect to circulation and large area averages of surface variables. By contrast, GCMs are least skilful at their native (coarse) grid cell resolution – typically around 250km by 250km for a single grid cell – and especially so for grid cell rainfall. Thus, while map representations of GCM projections suggest detailed regional information, such maps encourage a fine spatial interpretation that is not defensible. For example, maps such as found in the IPCC AR4 show detailed smooth fields of climate change for southern Africa, and while the broad scale features may be somewhat robust, they are not valid for interpretation at sub-national and local scales.

Moreover, it is critically important that climate projections be assessed from as many models as possible; one model alone is a dangerous basis for regional change messages. In each model, the regional change is a function of the model's internal processes and its representation of the regional climate system.

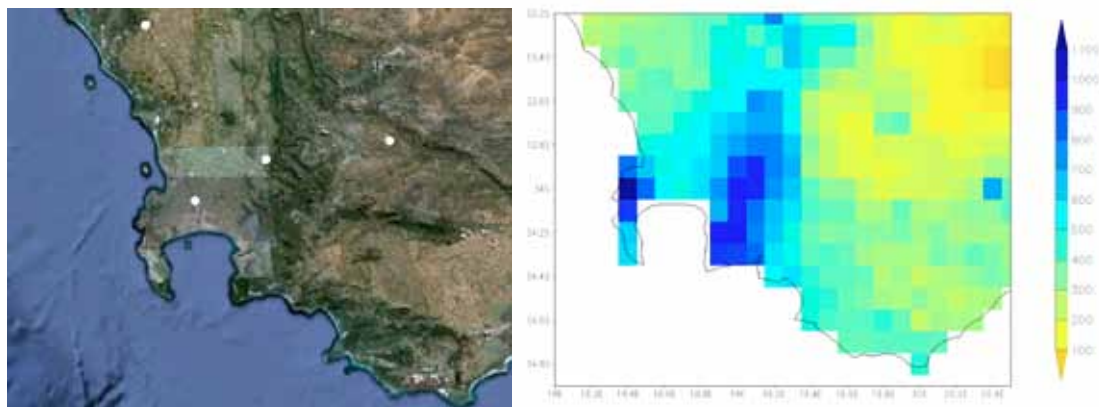


the 20th century. However, even then such skill does not imply accuracy at capturing the climate system sensitivity to projected future change. Likewise, agreement between models on the sign of the projected change (an approach such as is used in the IPCC AR4, Ch 11) also does not necessarily imply a basis for confidence (for example, GCMs may agree on a projected regional change, but this could be fundamentally wrong if the region is subject to strong orographic forcing that is not captured by the models). Consequently, it will always remain important to assess the spread of the results across models, and even if the models are all near perfect, there will still be spread due to the nonlinear internal variability, i.e., the unpredictable part of climatology.

A CASE STUDY OF REGIONAL RAINFALL CHANGE

In this section we use the above ideas to explore the change in rainfall for a region in south-western South Africa. The domain is characterised by an ocean margin, steep climate gradients, complex topography, and strong seasonality. The local climate is a result of the interaction of the local geophysical characteristics, the ocean modulating influences (especially coastal upwelling in the west) and the synoptic scale circulation characterised principally by the subtropical high pressure system and mid-latitude frontal systems. The dry summers are vulnerable to fire and drought with prevailing winds causing coastal upwelling of cold water, whereas the winters are cool and wet, with episodic heavy rainfall that at times leads to local flooding. The rainfall gradients are steep, varying by up to 1000mm/year over horizontal distances of <100km. In Figure 3 the domain, with the topography and land surface cover is shown on the left, and mean annual rainfall is shown on the right.

Figure 3: Domain of the case study. Topography and land cover shown on left (Google Earth) and the mean annual rainfall (mm) on the right, together indicating the complexity of the land surface and the strong climate gradients. Also shown are the selected station locations for the historical analysis of observed change



The GCM data are drawn from the CMIP3⁶ archive of GCM simulations which were assessed in the IPCC AR4. For this study we use GCM output based on the A2 SRES emissions scenario; a moderately high emission scenario characterised by a heterogeneous world with increasing global population and regionally oriented economic growth. The analysis utilises all nine models⁷ in the CMIP archive that

6 See http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php
 7 CGCM3.1(T47), CNRM-CM3, CSIRO-Mk3.5, GFDL-CM2.0, GISS-ER, IPSL-CM4, ECHO-G, ECHAM5/MPI-OM, MRI-CGCM2.3.2
 See http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php for further details.

have the necessary variables at a daily resolution. We use periods spanning the last 30 years of the 20th century (1971-2000) and the 20-year periods from 2046-2065 and 2081-2100 for the future climate.

To attain local scale resolution the GCM data are typically downscaled whereby the large scale from the GCMs is translated to the local user-relevant scales. Downscaling may be accomplished through statistical downscaling, Regional Climate Models (RCMs), or high resolution and variable resolution global models. All three downscaling approaches use the GCM large-scale forcing, and are thus dependent on the GCMs large-scale skill. Downscaling is in effect a scale translation technique to add spatial detail consistent with the large scale changes in the GCMs. Note, however, that this is much more than an interpolation of the GCM data to a higher spatial grid. The downscaling adds additional information, either through the development of transfer functions that relate the large scale forcing to an observed local response, or through a dynamical model that resolves local-scale processes and features. The different downscaling approaches have relative merits and shortcomings, but are, in principle, considered to be of comparable skill (See Ch11, IPCC AR4). At present the dynamical downscaling approach has not been implemented over many regions of the world to the extent that there is a robust spread of multi-model information; largely due to the high computational costs of a number of such integrations. This is likely to change in the near future as the CORDEX⁸ experiment begins to produce results. The case study here gives local-scale climate change projections based on statistical downscaling, using the method of Hewitson and Crane (2006). All 9 GCMs used here are statistically downscaled to a 25km grid over South Africa.

The historical data for the region is based on quality controlled station observation data (Lynch *et al.* 2002) as well as a 25km gridded version (Hewitson & Crane 2004). The station data is used to assess historical trends and change, and the gridded historical data is the basis for developing the statistical downscaling. These available sources of information are integrated into key messages that may legitimately be interpreted from the data. The primary focus is on the changes by the middle of the 21st century as this is most relevant to policy time frames (and other relevant socio-economic planning horizons), and where the choice of emissions scenario has limited impact. The late 21st century is also examined as representing the longer term implications of climate change.

A full exploration of each component of the analysis is precluded by the available scope of this paper, but a brief interpretive analysis is presented. The available strands of information are then brought together at the end in a cohesive message of climate change.

Historical changes in precipitation

For assessing historical change we use the network of stations in the region. Observation data are usually incomplete with spatial and temporal gaps and related problems. For this study we use the data that have at least a 90% complete record for the period from 1960-2006. We further select stations that reflect the different local climates; the northern and southern coastal plain of the region, the coastal mountains, and the interior plateau. For each station we analyse all sub-annual trends using a 60-day moving window. So, for example, we calculate the trend over the time period for the 60-day window centred on 1st January, then for the 60-day window centred on 2nd January, and so on, for the full annual cycle. The reason for this approach is that historical change is not constant through the annual cycle. The 60-day window is selected in this case to smooth some of the shorter time period variability, but

8 See http://wcrp.ipst.jussieu.fr/RCD_Projects/CORDEX/CORDEX.html

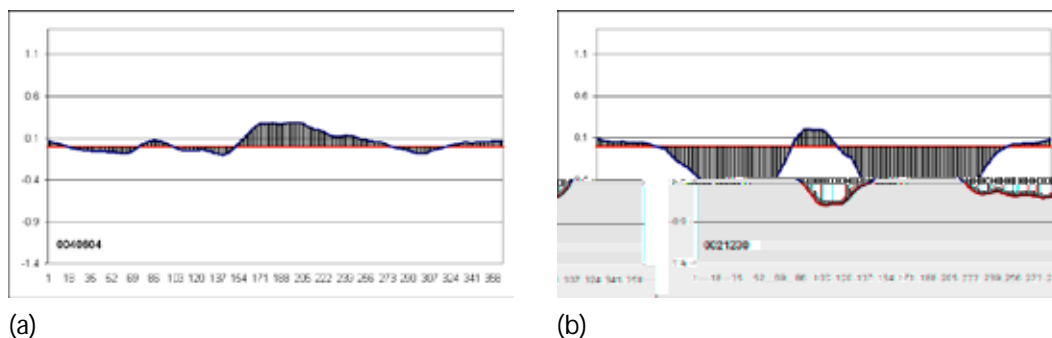


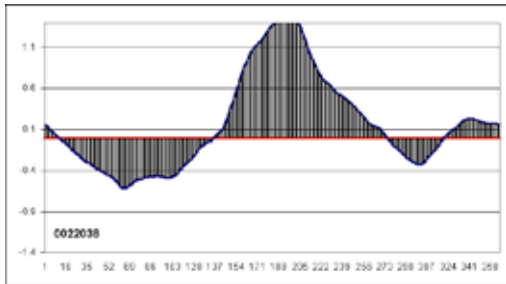
not to the point of losing seasonal boundary information. When the analysis is repeated using shorter time windows it leads to the same overarching conclusions, but as would be expected with some increase in variability of the magnitude of the trend through the course of the year. The analysis produces an annual trend curve as clearly shown in Figure 4, and there are strong and critically relevant sub-annual variations in the trends.

While there are marked differences across the region, there are also commonalities. A plausible interpretation is that the region is responding to the changes in the large scale circulation, modulated by local influences. Consequently, the north-west coastal plain (Fig 4a), which has no proximal topographic influences, shows minimal change with perhaps a hint of winter wetting. This location is at the northern reach of winter frontal influences. Further south (Fig 4b) on the coastal plain where it is more exposed to frontal activity and closer to topographical influences (it is sited between two mountains 50km away on either side), one sees again the suggestion of core winter wetting, but now with marked drying in the shoulder seasons. To the east against the windward shoulder of the main mountain belt (Fig 4c) the same pattern of trend is evident, but now with a much enhanced winter wetting. Inland of the mountains (Fig 4d), and somewhat removed from the primary influence of the frontal activity, the trends are again minimal.

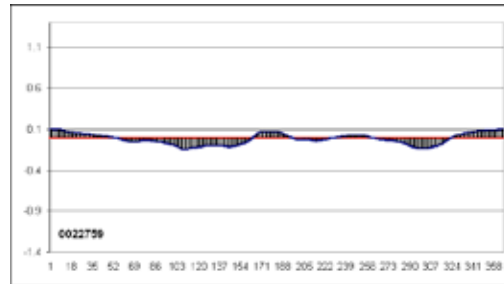
Taking the trends together, and recognising a warmer world with increased atmospheric water content (Santer *et al.* 2007) and a pole-ward expansion of the Hadley circulation (Hu & Fu 2007; Lu *et al.* 2007), the historical precipitation changes show a physically plausible response. Under this scenario the region would experience a decrease in frontal intensity and a shorter winter as the frontal systems move marginally southward, while the increased moisture content could lead to increased precipitation under topographically forced situations. As a result one would arguably see a decrease in the shoulder seasons while the core winter season would experience precipitation enhanced by both topography and increasing atmospheric moisture content.

Figure 4: Sub-annual variation in rainfall trends (mm/year) between 1960 and 2006 for 60-day windows centred on each day of the year, for (a) north-west coastal plain, (b) south-west coastal plain, (c) western margin of mountains, and (d) interior plateau. See Figure for locations





(c)



(d)

Simple extrapolation of the above scenarios would suggest increased drying for the region, with the core winter wetting continuing (at least in terms of total accumulated rainfall as opposed to extremes), but subject to further pole ward retreat of frontal systems at which point the drying would likely extend to the mountain regions. This brief exploration of the historical changes forms the first foundation of building a regional climate change message.

GCMs: projected regional circulation changes

With regard to GCM data, the World Climate Modelling Summit in 2008 noted that to use GCMs directly for regional studies:

"... means making their simulations good enough to guide hard decisions, ... the adaptations required to meet changing rainfall and extreme weather events on regional and local scales. Today's modelling efforts, though, are not up to that job" (Editorial in Nature, 2008⁹).

Consequently the primary value sought from GCMs is by assessing the large-scale process changes which guides interpretation of the regional native grid cell data. Figures 5 and 6 show the projected changes in sea level pressure and surface wind speed/direction as the median anomaly of the 9 GCMs – created by differencing each GCMs projected future climate from the GCM simulation of the present climate.

The primary large-scale circulation changes are:

- an increase in the intensity of the continental surface low pressure trough associated with an increased surface warming
- an extension of the Hadley circulation expressed at the surface as an increased surface pressure south and west of the continent.
- a regional strengthening of wind velocity, primarily along the west coast and especially in summer, related to the Atlantic high pressure and increased pressure gradient on the continental margins
- a decrease in the strength of the prevailing westerly winds south of the continent



Figure 5: Multi-model median sea level pressure anomaly (hPa) for (a) 2045-2064 and (b) 2081-2100 compared to 1971-2000, for four seasonal periods (DJF = December to February, MAM = March to May, JJA = June to August, SON = September to November)

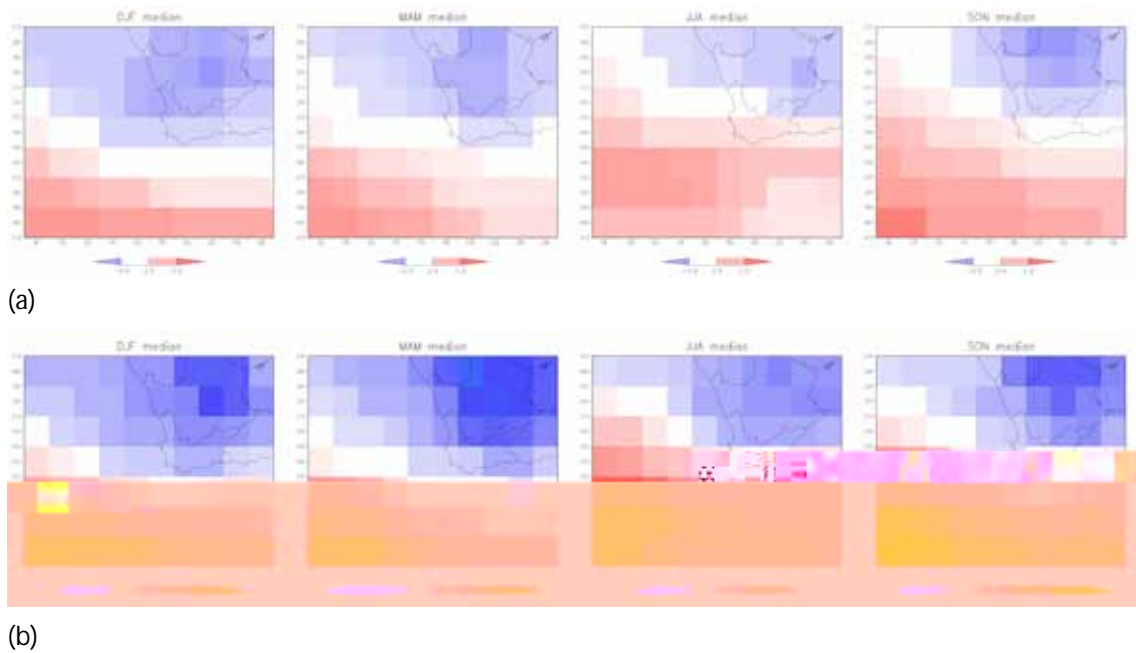
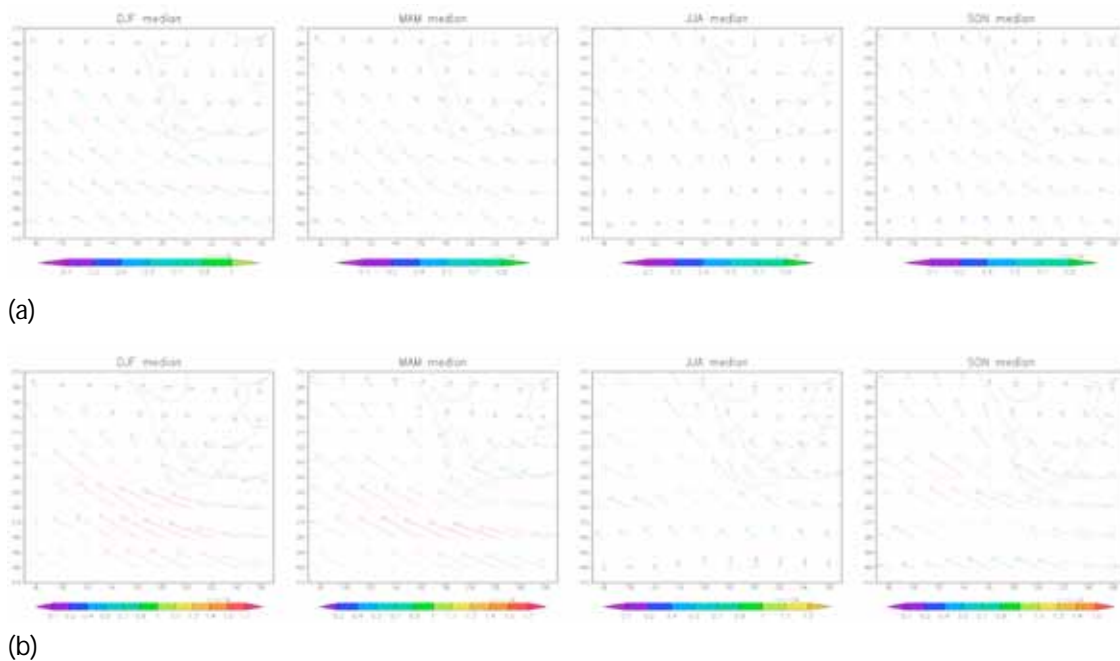


Figure 6: Multi-model median wind speed (m/s) and direction anomaly for (a) 2045-2064 and (b) 2081-2100 compared to 1971-2000, for four seasonal periods (DJF = December to February, MAM = March to May, JJA = June to August, SON = September to November). The length and color of the arrow indicates the speed anomaly





These circulation changes allow for inferring a number of primary consequences for the regional climate response, which include:

- Likely strengthening of upper air subsidence over the continent, with implication for stronger elevated inversions that can inhibit weak convection
- Stronger long-shore winds on the west coast leading to enhanced west-coast upwelling of cold water
- Weaker frontal systems due to pole ward contraction of the circumpolar flow, which would translate to a shorter core winter season and weaker penetration of fronts across the coastal mountains into the continent, leading to drier winter conditions.

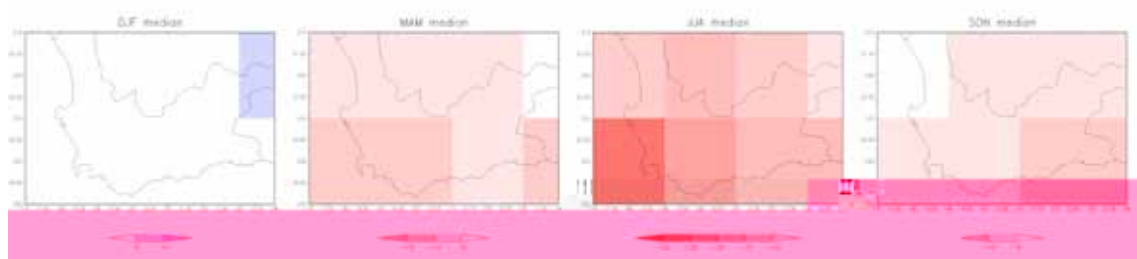
When considering the results across the model range (not shown) the message is not substantively altered, and the differences are mostly in terms of intensity. These results reflect a reasonably robust first-order response of the regional circulation to the global scale changes, and are the second foundational information stream.

GCM native grid cell projections

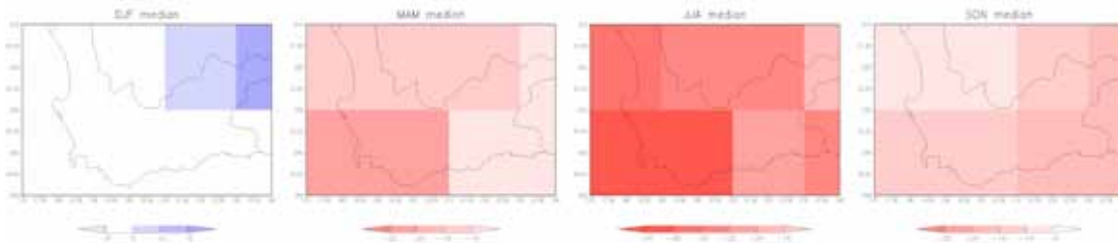
Figure 7 shows the GCM precipitation response. While caution is needed in interpreting the grid cell precipitation, the figure does suggest a strong drying trend across the region, with a hint that the north east of the region may experience a slight wetting in summer (when the larger domain is examined, the summer wetting is seen to extend and increase along the eastern continental margins). However, the GCMs are not even close to being able to capture the mountains and spatial complexity of the region, and as the rainfall distribution has a strong component of topographic enhancement, these results at best indicate that the change in large-scale dynamics are conducive to drying, and physically consistent with the changes in the circulation seen in figures 4 and 5.

Not presented here are the regional temperatures changes which show a general and robust message of warming across the region, with the greatest warming away from the coastal margin. Consequently, the joint response of the GCM native grid cell temperature and precipitation changes suggest a potential for decreased soil moisture as a result of the increased temperatures and the drying tendency for much of the region. This forms a third foundational information message alongside the earlier historical trend analysis.

Figure 7: Multi-model median rainfall anomaly (mm/ season) for (a) 2045-2064 and (b) 2081-2100 compared to 1970-2099, for four seasonal periods (DJF = December to February, MAM = March to May, JJA = June to August, SON = September to November)



(a)



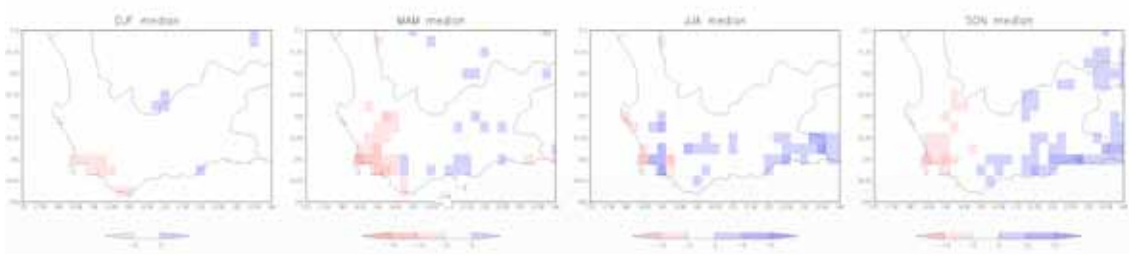
(b)

GCM Downscaled projections

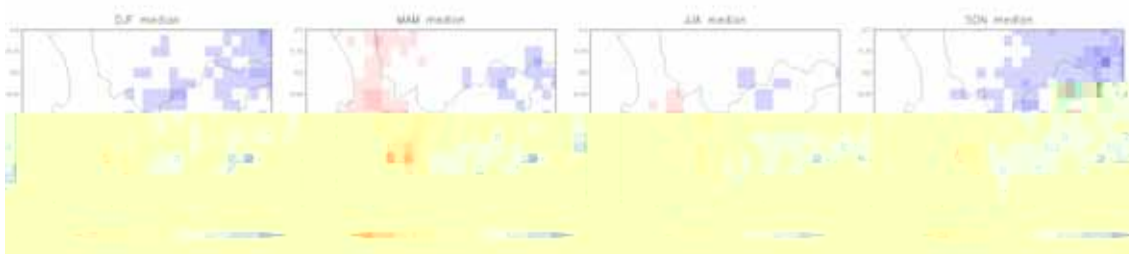
The downscaled data are generated as daily time series. From these a suite of relevant derivative attributes may also be derived such as dry spell duration, rain day frequency, etc. Since the downscaled data are derived from the large scale atmospheric fields, validation of the downscaling is warranted. Assessment of downscaling is usually accomplished by applying the downscaling to historical atmospheric circulation and comparing the results with actual observed high resolution observations. Hewitson and Crane (2006) undertake this for the method and region used here, and shows that the downscaled results have excellent agreement with the observed rainfall.

Figure 8 shows the downscaled multi-model median projected changes in total rainfall, and Figure 9 shows the same but for rain day frequency. In this case the downscaling represents the regional climate response at a high spatial resolution (0.25°) that is dynamically consistent with the large scale circulation and atmosphere state of the GCMs, but includes the effect of local modifying processes, especially topography. The colour scale is chosen such that grid cells whose projected change is considered to be small in terms of relevance are left blank (between +/-5mm/season for rainfall totals, and between +/-1 rain day / season for rain day frequency).

Figure 8: Downscaled multi-model median rainfall change (mm / season) for (a) 2045-2064 and (b) 2081-2100 compared to 1970-2099, for four seasonal periods (DJF = December to February, MAM = March to May, JJA = June to August, SON = September to November)



(a)



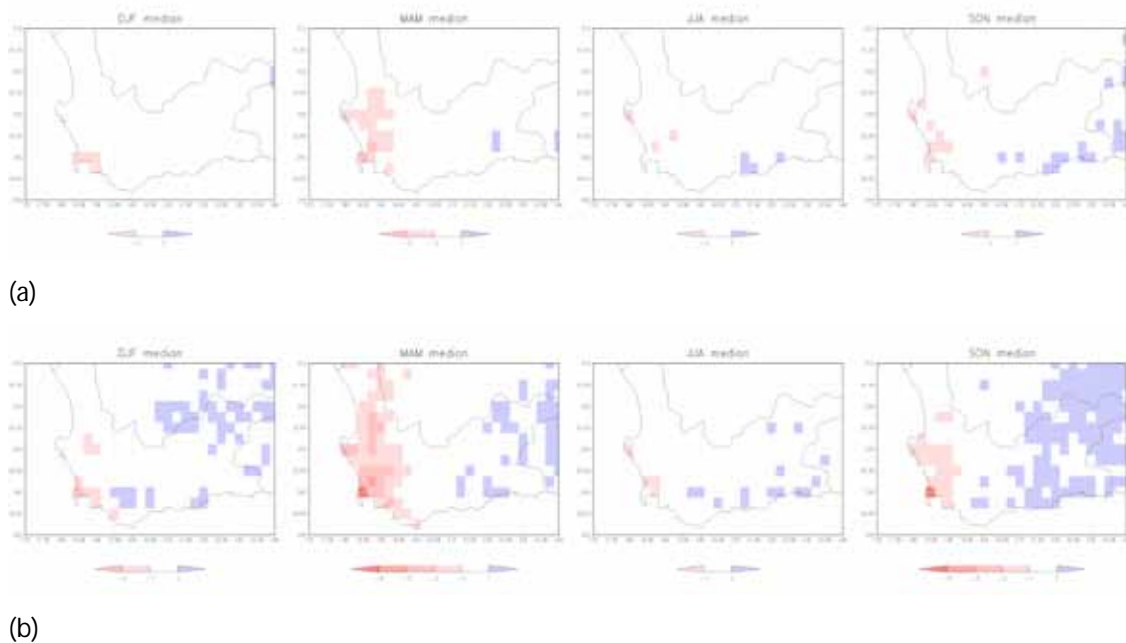
(b)



The overarching message of the downscaled results in figure 8 is not incompatible from that of the coarse resolution GCM native grid cell data presented earlier. However, the downscaled results show a more nuanced regional response with important spatial detail. Critically, in places there is an indicated reversal of projected change in rainfall compared to what one would interpret from the GCM native grid cell data. Where the GCM initially indicated general drying everywhere, the downscaled results show that there is some wetting in the future that is related especially to topographical forcing. Most important is the projected wetting in the mountains in the south west in the core winter season by mid-21st century, with a drying in the mountains during the autumn. This local region is very important to the water sources of the city of Cape Town. Interestingly, these projected changes strongly compliment the historical trends. Crucially, however, as the climate change signal becomes stronger toward the latter part of the 21st century (figure 8b) the mid-century wetting in the important water catchments areas is reversed, with significant drying over the entire western region. This likely reflects increasing dominance of the effects from a stronger high pressure system overriding any topographically forced rainfall enhanced by increasing atmospheric moisture.

The changes in rain day frequency (Fig 9) indicate changes commensurate with the total rainfall, with small reductions in the west of the region, and small increases in the east by mid-century, increasing in magnitude towards the end of the 21st century. These changes are in accord with the interpretations of the large scale circulation changes.

Figure 9: Downscaled multi-model median rain day frequency change (days / season) for (a) 2045-2064 and (b) 2081-2100 to 1970-2099, for four seasonal periods (DJF = December to February, MAM = March to May, JJA = June to August, SON = September to November)



One key to understanding the differences between the downscaled and native GCM results lies with recognising the role of the escarpment and topographical forcing on rainfall. The GCMs are not able



to represent the strong role played by the steep topographical gradients, especially on the south and east coasts where they are central to the formation of orographic-triggered rainfall. Coupled with increased moisture content in the atmosphere as well as greater onshore flow in the southern margins, it is reasonable to anticipate increased precipitation response in these regions. This information forms the fourth and last information stream considered here.

Drawing conclusions and managing uncertainty

By linking the GCM grid cell response, downscaling results, and the indications of large scale circulation change, and considering the relevant strengths and weaknesses of each data form, some consistent messages can be identified. Table 2 summarises the different information sources and the plausible messages that may be arrived at.

Many sector specific conclusions may be drawn from this analysis, but the overall robust message is one of general regional drying in the west and consequent reduced moisture availability, excepting perhaps in the core winter season within the mountains in the near term, and with moderate wetting in the east of the region. The drying in the extreme south-west is especially relevant for society with the city of Cape Town (population ~4 million) located there, and is a consistent message although with a notable spread in magnitude across the model solutions. Coupled with a regional increase in temperatures this will increase pressure on societal activities and ecosystems that are vulnerable to water availability. Moreover, as the region is already significantly vulnerable to fire, the increased southerly wind strength, coupled with the drying in the west suggest a marked increase in future fire potential.

The scope of this paper precludes a detailed examination of uncertainty associated with the results. What is presented is best taken as a case study of the 'central tendency' message of change; that is, the direction of change most dominantly indicated by the different information sources when taken together. In a fuller analysis one would also examine in greater detail the spread of the multi-model GCM data and related downscaled products (recognising that even then the full real-world range of possible futures is likely to be under-estimated). Likewise, the trend analysis presented would be further assessed in light of error estimates. For an application in a specific adaptation context one would thus dig deeper into the data engaging with issues that include, among others:

- further sifting of signal from noise,
- exploring the large scale circulation dynamics in greater detail to further understand the controls on the projected regional change,
- examine the higher time resolution data for information on extremes and the histogram of events, especially in relation to sector-specific thresholds of vulnerability,
- look for contradictions in messages, and seek to understand their foundations and implications and
- assess the regions linkage to global tele-connection processes (such as ENSO), and how this may modulate the conclusions reached.

In effect, to better assess the uncertainty means to apply in greater detail the principles outlined here. The advent of a rapid growth in research activities catalysed by the forthcoming AR5, along with the increasing efforts to bridge the science-society divide, would suggest that substantial progress can be made in addressing adaptation questions, if a robust regional message is appropriately generated.

Table 2: Summary of the messages drawn from each information source examined

Information source	Message	Discussion
Historical trends	Core winter wetting dominantly in the mountains. Shoulder season drying. Marginal indications of a possible wetter summer.	The region is spatially inhomogeneous in trend magnitude, although the dominant trends can be seen to greater or lesser degrees across the region.
GCM changes in circulation / processes	Increased subsidence due to a stronger mid-latitude high pressure inducing drying. Deeper thermal surface trough over the continent increasing west coast pressure gradient and possibly summer convection in the east. Pole ward shift in mid-latitude low decreasing frontal intensity. Increased long shore west coast wind promoting stronger upwelling, colder coastal waters, and consequent drying on the west coast.	The models are in good agreement on these large scale circulation changes, albeit with a range of differing magnitudes of change. . The change further is physically consistent with the anticipated first order response of the climate system.
GCM grid cell changes	General drying over the region. A weak suggestion of possible summer wetting in the north east.	The models are in strong agreement on the drying message for the region, but it is clear that the spatial detail related to local scale topography is absent.
Local scale downscaled changes	A general drying in the west with modest wetting to the east, modulated by the topography. Core winter wetting in the important water catchments in the core winter season. Small decreases in rainfall frequency in the west and small increases in the east. Changes in dry spell duration commensurate with the above changes.	The downscaled projected changes across all models are robust in spatial pattern although vary in magnitude, and the projected changes in some regions are too small to be of consequence. . Of importance is the drying in regions of non-irrigated agriculture in the west, and while core winter wetting in the key catchments is indicated for the near term, later in the century this reverses.. Taken with an increase in temperatures, the indication is for problematic increases in water stress.



NEW OPPORTUNITIES FOR AFRICA

The landscape of activities in Africa is broad and rapidly evolving. It is not possible to comprehensively review these due their broad and diverse nature, and new initiatives are rapidly appearing making any survey soon out dated. However, five categories are highlighted here, indicative of the emerging trends:

New online resources to provide an engagement forum and integrate across communities

With the growth of bandwidth in Africa and the electronic networking of virtual communities, it is logical to evolve this to leverage the intellectual capacity across diverse communities. An early initiator of this approach is the weAdapt¹⁰ platform. This has been live online for a number of years and is evolving into a valuable resource for cross sector engagement and for accessing knowledge resources. The approach draws strongly on community contribution and is thus not a top-down delivered resource that is constrained by the ideas of the developers, but evolves with the input of the community it serves. With the current technological directions of society, and with innovative enrichment of new technology such as semantic searching, this approach is a logical direction to adopt, and is likely to become an approach that represents a key foundation in future knowledge platforms.

New regional climate information portals

Drawing a stark distinction between information portals and data portals, there is a significant growth in this sector to serve relevant information to users. Data portals are prolific on the internet, and represent a mix of good, as well as dangerous products. Dangerous products are defined here as when data is served without complete qualification of the skill or the applicability to regional questions, and raises the potential for mal-application in user contexts. This raises a need for accreditation, but it is difficult to see how, and who, would provide an accreditation or quality assessment of portals. Consequently it is currently a case of *caveat emptor*, let the user beware!

As regards information portals¹¹, these seek to distil data into information products that separate value messages from noise and error in data. Key elements are the provision of qualified information tailored to the general user needs, but with a facility allowing users to query the data themselves in new ways. The developers of any portal cannot anticipate all possible user needs, and thus flexibility for the user to interrogate the underlying data becomes important. Ideally a regional climate change information portal would provide access to information on all foundations as expressed in Figure 1. However, not all portals are likely to be able to do this, and again it becomes a user responsibility to engage with the distillation of multiple lines of evidence in building a tailored regional message of change.

New development of regional climate data

There is currently a strong push to address the paucity of model and downscaled climate data for Africa. The CORDEX¹² programme seeks to make a major advancement in this respect. CORDEX was implemented by the World Climate Research Program (WCRP), and brings together multiple regional climate modelling groups and statistical downscalers to address the development of regional climate projections within a standardised experiment framework, and so to allow for comparison and for the development of probabilistic products. This activity stands to change the state of play in Africa.

¹⁰ See <http://www.weAdapt.org>

¹¹ One example of an attempt to realize a comprehensive data portal on these principles was <http://data.csag.uct.ac.za/>.

This portal is currently under re-development based on lessons learned in the pilot phase, and will be re-released at the end of 2010.

¹² Coordinated Regional Downscaling Experiment. See http://copes.ipsl.jussieu.fr/RCD_CORDEX.html



Complementing the production of the regional data is an activity to undertake regional analyses targeted at regional user needs. Within the next two years it is likely that the products available through this activity will leapfrog that which is available in many other continents.

Commercial climate services

It is worth noting that there is a rapid growth of commercial climate opportunities¹³. These go beyond the traditional consultancy agencies and seek to explicitly focus on the integrated suite of climate change knowledge needs. These activities are likely to proliferate in future. Two roles can be envisaged; a more traditional consultancy role that brings to bear integrated knowledge to meet targeted user needs, and resources to build capacity through stakeholder sector training and 'training the trainers' to



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ADAPTATION, AGRICULTURE AND FOOD SECURITY

1

ABSTRACT

The Southern African Development Community (SADC) Region is one of the most vulnerable regions to Climate Change in Africa because of its economic status and high dependence of its economy and peoples' livelihoods on rainfed agriculture. Agricultural productivity of major food crops (e.g. maize, potatoes) in the Region is estimated to decrease by 20-30% and approximately 16-22% of the wild relatives of these crops will become extinct by 2055 consequent to climate change. The Region has so far accumulated and developed adequate knowledge and technologies through research to make vast improvements to the sustainability and productivity of agriculture systems – improvements that can compensate for the negative impacts of climate change today, and at the same time build resilience to more distant changes in the climate. Higher education institutions in agriculture and natural resources of the Region have an important role in delivering this knowledge to the present and future leaders and to members of society through the provision of locally relevant training based on local circumstances, experiences and contexts with regards to climate change. The institutions must generate new knowledge through research in order to adequately prepare the societies to the new challenges that climate change will pose in future.

INTRODUCTION AND BACKGROUND

Despite strong political will and the implementation of a number of programmes aimed at improving the quality of life of the people of the Southern African Development Community (SADC) Region, poverty remains one of the greatest challenges in the region (SADC secretariat 2008). The situation is exacerbated by the impacts of climate change, which is slowly shrinking livelihood opportunities, threatening biodiversity and food security, and up-scaling disasters such as droughts and floods. In the SADC Region, climate change is seen as a threat to economic development as it affects agriculture, natural resources and infrastructure which are the back bone of the economies of the Member States. In addition, a large proportion of the Region's population depends directly on agriculture and natural ecosystems for their livelihoods.

Climate change is associated with mean higher average temperatures, changing rainfall patterns and rising sea levels; and there will be more and more intense, extreme events such as droughts, floods and cyclones (IPCC 2007). Although there is a lot of uncertainty about the location and the magnitude of these changes, there is no doubt that they pose a major threat to agricultural systems in the Region. There are some critical challenges that agriculture will face as the climate changes.

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Water availability is at the top of the list. Water is the defining link between the climate and agriculture (Moorhead 2009). Even without climate change, competing demands combined with mismanagement of water resource in the region means that water availability has become an urgent issue facing farmers and other users. Thus, climate change will exacerbate an already critical situation. Farmers in the SADC Region, especially smallholder farmers, depend directly on the rain for their food production and their livelihoods; and any changes to rainfall patterns present a major risk.

Studies of the impacts of climate change on some major crops, e.g. maize and potatoes, conducted by scientists at the International Centre for Tropical Agriculture (CIAT) and the International Potato Centre (CIP), showed an aggregate decline of crop yields in the range of 20 – 30% by the year 2055 in sub-Saharan Africa (Moorhead 2009). On the geographical distribution of wild species related to three major food crops: cowpea, peanut and potato, scientists from Bioversity International, CIAT and IRRRI estimated that 16–22% of the wild relatives of the three crops could become extinct by 2055, and that the distribution of the remainder could be reduced by more than half (Moorhead 2009). The impacts on peanut wild relatives are predicted to be especially severe – about half of the 51 peanut-related species studied could also become extinct, and the distribution of those remaining could decline by more than 90%. There are also predictions of the outbreaks of potato late blight and ascochyta blight of chickpea diseases with climate change (Moorhead 2009). When the climate becomes favourable, some will become prevalent in areas where they were previously unknown. In areas where they have not occurred before, the danger is that there is usually low immunity to a disease as well as poor knowledge of pest or disease management. The consequences of their attack on crops can be devastating.

With regard to the vulnerability of the Region, scientists at ILRI found that SADC Member States were among the most vulnerable countries in the sub-Saharan Africa because of their current socio-economic status, i.e. high level of poverty, HIV and AIDS prevalence, high dependence of economies and livelihoods on rainfed agriculture and others (Kandji *et al.* 2006). Within the agricultural sector, the study showed that smallholder agriculture systems are the most vulnerable compared to other systems because of the limited capacities of the smallholder farmers to avert challenges posed by climate change.

The SADC Member States do recognise that since climate is changing, agricultural systems in the region must also change if the Region is to avoid a catastrophe. This is manifested by the development of national climate change initiatives, such as the National Adaptation Programmes of Action (NAPA) by Member States, as vehicles for implementing climate change adaptation and other related strategies. In some of these initiatives, it is explicitly stated that farming, fishing and forest communities need to adapt their livelihood systems. The changes that are needed are many and diverse. The adaptation strategies will happen at the local level, tailored to local circumstances and ecosystems, and chosen and managed by the communities themselves. The strategies should have immediate benefits for the communities, as well as long-term benefits. These changes must be based on sound science, and enabled by effective policy at all levels. The changes should be built not only on the wealth of knowledge that already exists, but also on the new directions that research must now take to meet this enormous challenge. Higher education institutions worldwide are strategically positioned to provide leadership in this new endeavour (Marjanovic 2010) and SADC higher education institutions are no exception.



Higher education institutions in agriculture and natural resources in the Region have a profound role in creating the capacities and the knowledge base needed to develop pathways to adapt the agricultural systems and livelihoods to current and future vulnerability consequent to climate change. These institutions have an important responsibility given the precarious position of SADC, as one of the most vulnerable regions to climate change. This responsibility pivots around educating and preparing present and future leaders and members of society with the ideas as well as the social, technical and managerial capabilities to respond adequately to the challenges posed by climate change. The higher education institutions must also conduct locally relevant research and educate leaders and communities, not only about the risks, but also about the strategies for adaptation and mitigation.

The purpose of the paper therefore, is to describe the trends in higher education teaching, research and collaboration in integrating or mainstreaming climate change concerns into agriculture and food security-related disciplines in the SADC Region.

Existing adaptation and mitigation knowledge

The SADC Region has so far accumulated adequate knowledge through research to make vast improvements to the sustainability and productivity of agricultural and other natural resource-based management systems – improvements that can compensate for the negative impacts of climate change, at least in the short term, and at the same time build resilience to more distant changes in the climate. There is no reason or excuse for the Region not to put this knowledge into action with the available knowledge in the following areas:

Crops for the uncertain future

The Consultative Group on International Agricultural Research (CGIAR) institutions have been working in partnerships with national agricultural research systems and universities in the Region to develop crop varieties that are drought, heat, salt and flood tolerant. Such crops include drought tolerant maize varieties – over 50 varieties have already been developed and some are being grown in the region; drought tolerant rice – New Rice for Africa (NERICA); flood tolerant rice; drought tolerant beans and cassava (Moorhead 2009). These varieties are likely to withstand the pressures exerted by climate change on changes in rainfall patterns in the immediate future. However, due to uncertainties of the distant future climates, plant breeding programmes must ensure that new varieties have the genetic diversity that climate uncertainty, and other variables such as changing pests and diseases, demand.

Sustainable soil management

Even without climate change, deteriorating soils are one of the main challenges to future agriculture. For example, in recent years some 320 million hectares, or 25%, of the already fragile African drylands have been degraded to an extent known as ‘desertification’. This is largely a result of unsustainable practices such as over-grazing, over-cultivation and deforestation, which mines soils of their nutrients without adequate replenishment. Reducing vulnerability of farming systems in the face of climate change demands a turn-around in soil management. There is substantial information about sustainable soil management, but there is now a need for a concerted effort to overcome the obstacles that have prevented more widespread uptake of these technologies. Soil organic matter is the critical factor in sustainable soil management. Increasing organic matter content improves soil fertility, nutrient supply, soil structure, water-holding capacity, and a host of other vital soil functions. Ways to do this include



adding compost, crop residues, animal manure, chipped wood, agroforestry, and growing cover crops such as legumes. All these technologies are available and known by farmers in the Region, but their adoption is still low.

Managing changing pests and diseases

Anticipating pest and disease outbreaks, and integrated pest and disease management (IPDM) where outbreaks occur, are the fundamentals behind managing changing pests and diseases into the future. For instance, CIAT in collaboration with some national agricultural research systems and universities in the Region are developing computer models to predict the movements of some important crop pests and diseases in the region, e.g. potato late blight (Moorhead 2009). Participatory learning is implicit in IPDM, so that farmers understand the relationships between crops, pests and diseases, and climate. With this knowledge they can adapt their own systems and build resilience.

Livestock systems for the future

As the climate changes, there will inevitably be impacts on livestock and livestock-based systems. At the same time, as the regional demand for draught power, manure, meat, milk and other animal products increases, animal numbers are growing rapidly, with accompanying impacts on ecosystems such as rangelands and pasturelands, and on demand for water. The solution is to manage growth of the livestock sector sustainably through adaptive strategies that simultaneously address the climate challenge to livestock-based systems, and the livestock pressure challenge to the environment. These adaptive strategies will include diverse options from which livestock keepers can select. Examples include using livestock species and breeds best suited to future climate, and adapting stock composition. Managing feed supplies will be critical, and will depend on a range of approaches, from developing alternative feeds that are not dependent on crops, to planting appropriate species under rangeland rehabilitation programmes.

Managing fisheries and aquaculture

Fishing and aquaculture provide food and livelihoods for many millions of resource-poor people in SADC, and may become even more important to regional food security as the climate changes and other sources of food become less reliable. Both are vulnerable, however, to a range of environmental pressures including climate change. Aquaculture, on the contrary, is growing in many parts of the Region and offers some good opportunities to adapt to climate change. Farming fish provides an easily managed and predictable source of food. By focusing on herbivorous species, aquaculture can provide food with a low carbon footprint. Fish are highly efficient at converting grain to protein – cattle require around 7 kg of grain to produce 1 kg gain in live weight but herbivorous fish, such as tilapia or carp, need less than 2 kg. And ironically, it requires less water to grow fish than meat, as the water is mostly recycled and not consumed. Climate change could open up new opportunities for aquaculture as the sea encroaches on coastal lands, as more dams and impoundments are constructed in river basins to buffer changing rainfall patterns, and as urban waste demands more innovative disposal pathways.

Agriculture and mitigation

According to the 4th Intergovernmental Panel on Climate Change (IPCC) Assessment report (IPCC 2007), agriculture globally contributes about 14% of annual greenhouse gas emissions, and forestry another 17%. Irrigated rice systems produce significant amounts of methane, while nitrous oxide is a



by-product of soil management systems that add nitrogen fertilizers. Burning of vegetation – trees and crop residues, for example, is a very direct path to raising atmospheric carbon dioxide levels. Livestock systems also contribute; animals produce methane, while manure is another source of nitrous oxide. Yet all of these practices can be changed, with the right support and incentives.

The management of soils and trees to capitalise on their carbon storage potential is the main bonus that agriculture has to offer to the world's mitigation efforts. There are different ways to boost the carbon content of different agricultural systems. Zero-tillage farming, mulching and cover cropping are all low-tech ways to improve the carbon content of cultivated soils. Careful fertilizer management, balancing use of organic manures and inorganic fertilizers, also enhances carbon sequestration. Where soils are low in carbon, such as the degraded soils of over-grazed rangelands, there is great potential for carbon sequestration through extensive planting programmes. Agroforestry has multiple benefits besides its carbon-capturing role – selected tree species provide animal fodder, fruits, timber and medicines, for example, as well as contributing to soil health. Mangrove conservation similarly contributes to coastal protection, sustainable ecosystems and livelihoods at the same time as mitigating climate change. Indeed, the win-win nature of many of these practices should hasten their adoption. At the same time, the value of carbon storage within these systems for global society should be demonstrated by incentives to natural resource managers, to tip the balance firmly in favour of such practices.

Linking these activities to carbon markets is a way to do this, but it is no simple task. One of the challenges in the SADC Region is the accuracy of measuring greenhouse gas emissions and carbon content of soils and vegetation in order to verify changes due to changed practices, and so determine payments. Advances are being made, and low-cost solutions sought. The next stage is to develop a framework that allows the inclusion of small-scale carbon sequestration projects in global carbon markets.

TEACHING AND LEARNING

The vast knowledge accumulated so far in the SADC Region with regards to climate change science, adaptation and mitigation technologies in agriculture and food security have great potential to build the resilience of millions of people to weather variability and uncertainty today, and to future climate change. If successfully adopted and integrated in the farming systems, this will bring huge benefits to poor and vulnerable communities in the short term and into the future. But as dangerous climate change threatens, it will not be enough. There is a need to stay ahead of climate change – and to do that we need to go beyond current knowledge, and push agricultural science to new frontiers. Higher education institutions in the Region have an important role to fulfil in delivering this knowledge to the present and future leaders and members of society through the provision of locally relevant training, based on local circumstances, experiences and contexts about climate change in the Region. The institutions must also generate new knowledge through research in order to adequately prepare the societies to the new challenges that climate change will pose in future.

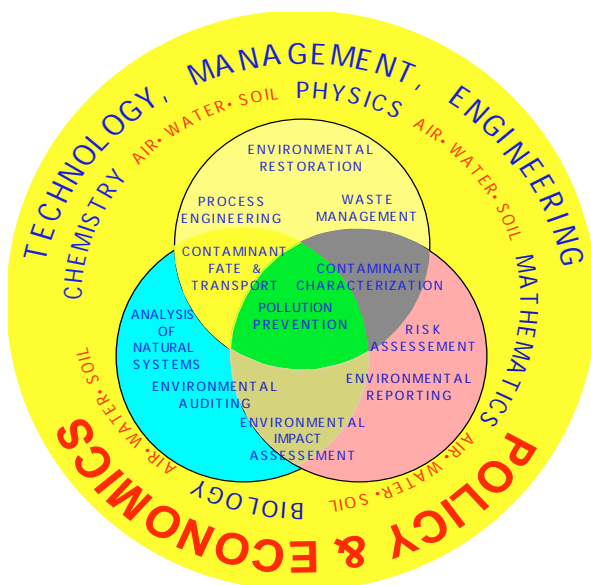
However, Chakeredza *et al.* (2009) observed that most higher education institutions in agriculture and natural resources in sub-Saharan Africa are less-prepared to take up this new challenge of climate change in their education systems. The curricula content, teaching materials and methods and delivery approaches are not adequately responsive to the modern climate, which Barnett (2003) referred to as one of 'super complexity'. The training is predominantly based on curricula adopted from countries



that had colonies in the region; the learning materials are generally not adequately contextualised in the local environment, and teaching modes are not learner-centred. It is not surprising therefore that most of the higher education institutions in the Region have so far done very little in the integration of climate change issues into their education programmes. There is a need, therefore, to rethink and to transform the higher education systems in the Region in order to remain relevant and become competitive and responsive to the challenges and needs of the modern society.

Marjanovic (2010), at a meeting in Belgrade, Serbia, demonstrated that climate change science was not a new science in higher education institutions worldwide. His model (Figure 1) showed different science based disciplines on which climate change science was based. Various disciplinary courses and programmes presented in the model are already being offered in different universities, at different spatial and temporal levels in the SADC Region. Hence, climate change science is also not a new science in itself in the Region. However, what is missing in the education system is the link of these individual disciplines to provide a full understanding of the complexity of the climate change problem. Without complete understanding of the problem, the adaptation and mitigation strategies to avert the impacts of climate change on agriculture and food security in the Region will be poorly designed and will lack robustness.

Figure 1. What really is climate change science? (Source: Marjanovic 2010)



Traditionally the education system has approached problem solving from disciplinary perspectives; where a complex problem is sliced into disciplinary devices and solutions are generated in isolation for each component of the problem. Due to the dynamism and complexity of the climate change problem, these traditional approaches are no longer valid in generating solutions for climate change. By the time the partial solution for a particular component is generated, the climate change problem would have already changed shape and dimension. Systems thinking that integrates these different disciplines to understand how humans affect the patterns and cycles that operate in nature, and their manifestations to the society at large, is missing in our education system.



Another missing link in the region's education curricula is the inadequate foundation of climate change science. Our education curricula lack the ability to develop critical thinking skills in our students enabling them to take the data and information that is generated from science to understand the implications of that data, and then to apply it to solving the prevailing societal problems currently facing the region. As the students graduate, they are unable to realistically provide leadership in generating solutions to societal problems, including climate change. The curricula, therefore, need to be redirected to include

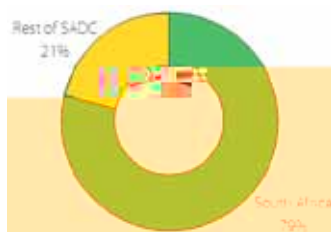


will not sufficiently generate new knowledge based on local circumstances and experiences as required by a modern approach to tackling climate change.

International funding is usually also project-driven with the result that researcher salaries, laboratory and equipment costs are not funded. Donor funding – even if it is well meant and properly used – does not help to build an indigenous scientific infrastructure and capacity. In the long term, governments in the region have to find the funds to build, to sustain and to grow their own scientific institutions and capacities, if they wish to overcome existing dependencies and more directly steer their own scientific efforts to adequately respond to climate change challenges in the region. Therefore, the generation of new climate change related knowledge relevant to the current and future climate change scenarios remains a challenge in the region.

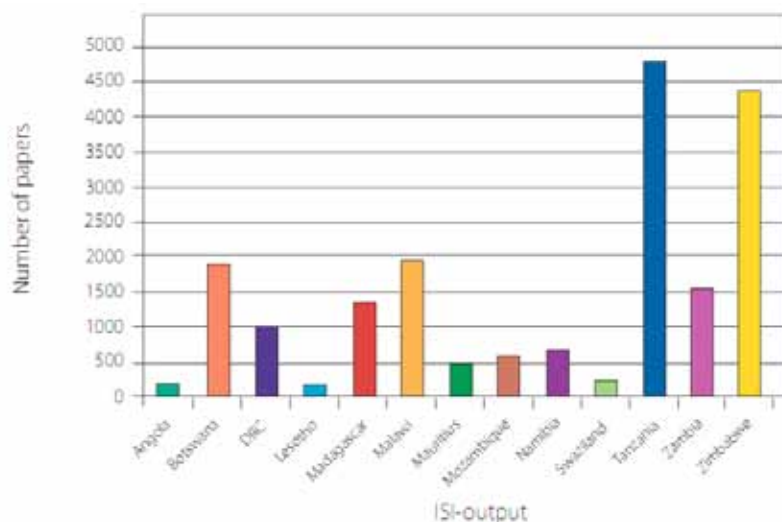
In terms of research productivity in the universities in the region, Mouton *et al.* (2008), noted that South Africa is the most prolific and productive producer of scientific output in the region. In fact it dominated scientific production by producing on average 80% of all output for the period between 1990 to 2007 and being about four times more productive than the average for the region (119 papers per million of the population compared to the average of 29 papers per million of the population) see Figures 2 and 3.

Figure 2: Research outputs in SADC region



(Source: Mouton et al. 2008)

Figure 3: Research output per country – excluding South Africa: 1990 – 2007



(Source: Mouton et al. 2008)





within the university in implementing a climate change teaching or research programme; or within and across countries in the Region or outside the Region. This also includes collaboration with the national and international research centres and organisations. Another aspect of collaboration is with the users of the products of higher education institutions and/or potential funders of the academic and research programmes. These include the farming communities; the government, including bilateral and multilateral donor institutions; the private firms, companies and non-governmental organisations.

A study conducted by Kruss and Petersen (2008), provided strong evidence for collaboration of higher education institutions in most fields of scientific research in the SADC Region. The major areas of collaboration were on writing of funding proposals, conceptualisation and/or planning of research, execution of research and the publication of research results (writing reports and articles). However, intra-regional collaboration amongst countries in the SADC region was evidently less than extra-regional collaboration. Collaboration was mostly with countries in the northern hemisphere; where such collaboration was driven by well-established networks based on mutual interest or by the availability of funding from donor agencies in the north. Scientists and scholars from South Africa were found to be involved in fewer joint activities across the whole spectrum of the research process, than their counterparts in the other SADC countries. This observation was an indication that scientists in the other SADC countries co-operate more internationally because of their greater reliance on overseas funding.

Within the countries in the region, Kruss and Petersen (2008), found strong collaboration between local universities and with public agricultural research institutions, although there are not many public research institutions in each country. Collaboration on a moderate scale exists with a wide range of public sector and development partners – national government, regional government, community organisations and local non-governmental organisations (NGOs) – potentially important for universities' roles in support of local development.

With the prevailing challenges of climate change, the current community engagements and collaborations are not sufficient to address the complexity of the climate change problem. New forms of engagements and collaborations are required if we are to win the battle against climate change. The first area of collaboration will be in the design and implementation of climate change programmes among academic staff of different disciplines across science faculties within the university and with other local or regional universities. Through collaboration, best human and physical resources, including teaching materials, would be brought together to implement a strong climate change academic programme, responsive to the local needs of the region. This would rationalise the engagement and efficient use of limited personnel and physical resources available in the region, while getting the best results of climate change training programmes at higher education institutions in the region. For this to succeed, a strong political will of the Member States of the SADC Region would be required to provide a catalyst for such an initiative.

In terms of conduct of climate change research, the forms of community engagement and collaboration will be many and diverse. These would include the actual process of conducting research, from problem identification and definition all the way to delivery of the research results and outputs. The stakeholders have to be fully engaged at each stage of the research to enhance ownership and acceptance of the research results.

The delivery of research outputs are effectively done through collaboration and partnerships. For instance, methodology outputs of the research (such as databases, diagnostic toolkits and evaluation frameworks) are well delivered through multi-level research partnerships that range from the international/regional science community to national agricultural research systems (NARS) and universities, and public sector service delivery organisations. Developmental outputs such as adaptation options need different types of partnership, and these may include researchers, government development agencies, NGOs and producer associations, private sector investors and service providers, and other organisations involved in implementing activities on the ground. Policy outputs may be delivered through coalitions of policy partners and decision-makers, researchers, regional information networks, pro-poor civil society organisations, and development donors. It should be noted therefore, that depending on the output of the research, the nature and type of collaboration and partnership that will be required will be different. There is no such a 'one for all' type of approach if we are to be successful.

CONCLUSIONS

Climate change threatens agriculture and food security, yet it also brings an opportunity – one which the Region cannot afford to miss. The products of agricultural research have great potential for much wider adoption than has been achieved so far – and their adoption will build the resilience of millions of people to the current weather variability and uncertainty and to future climate change. Some will also contribute to the mitigation of climate change. Drought- heat- salt- and food-tolerant crop varieties, new ways to irrigate crops and better ways to manage soils are just some of the technologies that hold great promise to help farmers today, and into the future. Livestock keepers can choose adapted breeds, and alternative feeds that do not depend on crops, among many other options, to reduce their vulnerability. There are many innovations to improve the sustainability of fisheries and aquaculture systems for food security in the region.

Bringing the products of more than three decades of research into use, will be a tremendous challenge. The higher education institutions in the Region have an enormous role to play to make this a reality. The institutions need to first change and transform themselves in order to respond adequately to the challenges and opportunities offered by climate change. The curricula content, delivery methodologies, administrative procedures and institutional settings of the higher education institutions must change and be directed towards teaching to change the mindsets of students. Climate change, being a complex problem, requires captivating critical thinking, which the higher education institutions must instil in their students, in order to unveil the climate change problem. The current education system does not adequately provide such critical systems thinking.

The higher education institutions must also take leadership in generating new knowledge through 'critical' research that will respond to the anticipated impacts of future climate change on agriculture and food security. The institutions must move away from traditional approaches to research and include 'systems analysis' that provides a complete understanding of the climate change problem and generates appropriate and relevant solutions to a climate change problem. Partial solutions are no longer adequate and valid as climate change is a dynamic phenomenon.



Finally, efficient and effective collaboration and partnerships are required in planning and in the delivery of academic and research programmes on climate change if the higher education institutions in SADC region are to play a meaningful role in combating and adapting agriculture systems to climate change. Different facets of climate change require different expertise from different disciplines and these disciplines are spatially located in the region. Harnessing such expertise from different institutions requires a transparent system supported by strong political will from the governments in the region.

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CLIMATE CHANGE, WATER AVAILABILITY AND SUPPLY

1

ABSTRACT

The increase of anthropogenic emissions of greenhouse gases has caused the global mean temperature to increase above the pre-industrial levels. This warming will affect precipitation and evaporation, both of which determine the availability of surface and groundwater resources. There is considerable uncertainty regarding the magnitude and the direction of change of precipitation over the various parts of southern Africa. The major problem for water resources management in southern Africa is the high inter-annual variability of precipitation. There are no accurate predictions on the magnitude of the change of this inter-annual variability. Studies carried out in southern Africa have shown that the region has hydrological responses that are highly sensitive to changes in precipitation and evaporation. A 10% change in both precipitation and evaporation has the potential of changing runoff by 50%. Thus decreases of precipitation, due to climate change, will decrease the available water resources. The growth of human population and improvement in lifestyles, and the expansion of agriculture and urban areas will increase the water demand. Thus climate change will be an added stress on water resources.

An integrated water resources management approach which considers factors affecting water supply, water demand, and the socio-economic aspects, provides a framework for developing adaptation measures for climate change effects on water resources. Since there are considerable uncertainties regarding climate change effects on water resources, adaptation measures should be developed so that there are benefits with or without climate change. Possible adaptation measures are: the expansion of water supply to improve the water supply to the current and to the future populations, and the introduction of measures for managing water demand. The improvement of the human capacity and the institutional framework are necessary adaptation measures. This will result in the effective and efficient management of water, which in turn will provide benefits with or without climate change.

Teaching about climate change and water resources is done at universities either through the extension of existing courses or the introduction of new stand-alone courses. The lack of expertise in the field of climate change is a major constraint when introducing this issue in university courses. South African universities dominate the research being done on climate change and water resources in southern Africa. It has the highest number of scientists involved in this research that is funded by the national government through funds from, e.g. the Water Research Commission. There is a great need to expand research on climate change and water resources to other countries within southern Africa. This research will improve the understanding of the sensitivity of water resources for the various existing climatological and physiographic conditions to climate change, and provide a basis for developing appropriate adaptation measures.

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INTRODUCTION

Observational temperature records reveal that the global mean temperature has increased by 1.4° – 4.3° C above the pre-industrial 1750 values (McMullen & Jaboor 2009). The rate of increase of the global mean temperature was 0.13° C per decade during the 1956 to 2005 period. The 1995 to 2006 period is considered to have been the warmest period since 1850 (IPCC 2007). The increase in temperature is attributed to emissions of greenhouse gases. The increase of the global temperature affects precipitation (P) and the evaporative demand (E) both of which determine the availability of water as shown in Equation (1) below:

$$P = Q - E \pm S$$

where Q = runoff, S = change of both surface and subsurface water storages.

Precipitation and the evaporative demand set the broad limits to the amount of water available as runoff or river flows, and the replenishment of surface and subsurface storages.

Simulations of climate for the emission scenarios B1, A1B and A2 (IPCC 2000) that were done using global circulation models show that the global mean temperature for the 2011 to 2030 period will increase by 0.64° C to 0.69° C relative to the 1980 to 1999 period (Meehl *et al.* 2007). This will increase the atmospheric moisture holding capacity and therefore result in increased precipitation at the global level. Changes in precipitation due to climate change will vary globally. Models predict that relative to the 1980 to 1999 period, precipitation will increase by the end of the 21st century in the high latitude regions, e.g. Europe 9%; North Asia 15%; North America 15 - 21%; and East Asia 9%. (Christensen *et al.* 2007). Table 1 provides the predicted changes in temperature and precipitation by the end of the 21st century over southern Africa. The southern Africa region considered extends from latitudes 12° S to 35° S and longitudes 10° E to 52° E.

Table 1: Predicted changes of the average minimum, medium and maximum annual temperatures and precipitation for the A1B scenario by the end of the 21st century relative to the 1980 to 1999 period for the southern Africa region (Christensen *et al.* 2007)

Season	Temperature (°C)			Precipitation (%)		
	Min	Median	Max	Min	Median	Max
DJF	1.8	3.1	4.7	-6%	0%	10%
MAM	1.7	3.1	4.7	-25%	0%	12%
JJA	1.9	3.4	4.8	-43%	-23%	-3%
SON	2.1	3.7	5.0	-43%	-13%	3%
Annual	1.9	3.4	4.8	-12%	-4%	6%

Note: DJF = December, January and February; MAM = March, April and May; JJA = June, July and August; SON = September, October and November.

It is of interest to note that most of the predicted precipitation changes over southern Africa (Table 1) occur during the winter period (JJA) and the dry season (SON). Very little rainfall occurs during the JJA and SON seasons in southern Africa except for the Western Cape Province of South Africa that receives winter rainfall. Furthermore, the predicted change of annual precipitation (-4%) is rather insignificant in view of the high inter-annual variability.



Hydrological effects

The prediction of climate change effects on water availability for a specific river basin is problematic because global circulation models (GCMs) have coarse spatial resolutions, ranging from about 150 km by 150 km (23,700 km²) to about 440 km by 550 km (24,200 km²) (Randall *et al.* 2007). However, planning and management of water resources is often done for river basins that are usually less than 10,000 km². Furthermore, different GCMs give different precipitation predictions for the same river basin (Andersson *et al.* 2006; Murray-Hudson 2006). Even the same GCMs will give different precipitation predictions for different initial starting conditions during simulations (New 2002). Consequently, there are considerable uncertainties in establishing the hydrological effects of climate change. There have been very few studies examining the hydrological effects of climate change in Africa upon which to base generalisations about the future availability of water resources (Boko *et al.* 2007).

The goal of water resources management is to overcome water supply problems arising from climate variability and from the variation in space of the available water. Outputs of GCMs give indications of changes in average precipitation values, but not the change in variability. Most parts of southern Africa, particularly south of the Zambezi River, are semi-arid to arid receiving less than 800 mm/year of rainfall except for the highland areas and the eastern coastal part. Sub-humid conditions occur along the northern parts of Angola and Zambia, and throughout the Democratic Republic of Congo. The annual rainfall for most parts of southern Africa has high inter-annual variability with the coefficient of variation being 25% to 40% in the semi-arid part and over 100% in the arid part (Schulze 1997; Mendelsohn *et al.* 2002). Under these conditions rainfall in any year can be as low as 60% of the average value, and as high as 140% of the annual average value. The adaptation to high variability of rainfall is a necessary part of life in southern Africa. Thus, the major concern regarding climate change effects is whether climate variability will be influenced by climate change, and not by the changes in the average values (Jensen 2010). Unfortunately global climate models do not provide adequate information about possible future changes in rainfall variability, which can be used for predicting the effects on water resources.

The proportion of rainfall that forms runoff (runoff coefficient) decreases with decreasing rainfall, and the runoff coefficient is generally less than 20% for most parts of southern Africa except for the humid and mountainous areas. Changes in precipitation due to climate change will be amplified in the changes of runoff. Rainfall-runoff modelling done on three catchments in Zimbabwe showed that a 15-20% decline in rainfall and 10% increase in potential evaporation resulted in a 50% decrease in runoff (Mazvimavi 1998a). New (2002), found that a 10% decrease in precipitation and 10% increase in evaporation caused a 14% decrease in average annual runoff of a humid catchment (mean annual precipitation = 2300 mm/year) and a 32% decrease for a semi-arid catchment (mean annual precipitation = 410 mm/year) in the Western Cape region of South Africa. De Wit and Stankiewicz (2006) concluded that a 10% decrease in precipitation in regions receiving 500 mm/year will reduce surface water by 50%, while this was 17% for areas receiving 1000 mm/year. It has been predicted that by 2050 runoff will decrease by 10 - 30% in southern Africa for the A1B scenario (Kundzewicz *et al.* 2007; Bates *et al.* 2008). The predicted hydrological effects of climate change for the period up to 2030 have been found to depend on the global circulation model used for predicting rainfall changes. Average flows of the Okavango River decreased or increased depending on the global circulation model used to predict future precipitation (Murray-Hudson 2006; Andersson *et al.* 2007).

Most of the southern African countries depend on reservoirs (dams) for water supply to urban areas and for irrigation. Climate change has the potential to affect water supply from these reservoirs. According to Mazvimavi (1998a), an assessment of the effect of climate change on three reservoirs in Zimbabwe showed that the design yield declined by 34 - 43% (Table 2). Inflows and evaporation were estimations based on the rainfall and temperature changes predicted by the Canadian Climate Centre global circulation model for the 2CO₂ scenario. In order for the same reservoirs to satisfy the demand for which they were designed, the storage capacities would have to be increased by about 40%, which increases construction costs of dams. New (2002) made similar conclusions for reservoirs used for water supply to the Cape Town Metropolitan area.

Table 2: Effects of the decline in rainfall and the increase in evaporation due to climate change on the yield of three reservoirs in Zimbabwe: Gwayi, Zivagwe, Odzi

	Gwayi	Zivagwe	Odzi
Area (km ²)	38,500	1,550	2,450
Mean annual rainfall (mm/year)	633	714	819
Potential evaporation (mm/year)	1,930	1,800	1,690
Mean annual runoff (mm/year)	21	82	158
Reservoir capacity (10 ⁶ m ³)	691	264	385
Baseline yield (10 ⁶ m ³)	256	69	242
% Change of average annual rainfall	-15	-20	-16
% Change of average annual evaporation	8	13	9
% Change of average annual runoff	-47	-50	-50
% Change in the reservoir yield	-34	-41	-43

Southern Africa countries are already experiencing varying degrees of water stress; however, climate change has the potential to modify the severity of water stress. The per capita amount of renewable water resources available per year is one of the indicators for water stress (Raskin et al. 1995; Mazvimavi 1998b; Arnell 2004). The per capita available water resources for each of the countries was estimated using the FAO estimates, (<http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>) and the projected population for the 2010 to 2050 period, done by the United Nations, Department of Economic and Social Affairs, Population Division (<http://esa.un.org/UNPP/>) for the medium variant population growth rates. For the year 2010 South Africa had 900 m³/capita/year of renewable water resources and falls within the high stress category (500 – 1000 m³/capita/year), while Lesotho, Malawi and Zimbabwe are in the moderate stress category (1000 – 1700 m³/capita/year) see Figure 1 and Table 3. Tanzania will fall within the moderate water stress category by 2020 without climate change. By the year 2050, Malawi, South Africa, Tanzania and Zimbabwe will be in the high stress category even without climate change. The renewable water available in 2010 for semi-arid to arid Botswana and Namibia was estimated as being 6188m³/capita/year and 8011m³/capita/year respectively. These apparently high values for countries that experience extreme difficulties in accessing water include water resources existing in the Okavango River and Cunene River that occur along their boundaries or in regions far removed from the major water demand areas.



The effects of climate change on the available renewable water resources per capita was investigated by Arnell (2004), who compared simulated runoff taking into account the predicted climate change and the future population projected as based on assumptions made for each of the emission scenarios. Climate change was predicted to cause an increase in the number of people affected by water stress in southern Africa, while regions such as north America and Eurasia, that are likely to experience an increase in precipitation, will have decreasing numbers of people affected by water stress (Table 4).

Table 4: The number of people in millions in southern Africa affected by water stress without climate change. Climate change projections were done using the HadCM3 model of the Hadley Centre (Arnell 2004)

Year	Emission Scenario	Without Climate Change	With Climate Change
1995		3.1	
2025	A2	37.6	43-47
	B2	32.9	26-61
2055	A2	60.8	86-108
	B2	126.7	105-141

Changes of the variability of precipitation due to climate change will be amplified by runoff. The southern Africa region already has a highly variable runoff, for example the annual runoff in South Africa has a coefficient of variation of 40 - 100% on the eastern part, and 100 - 160% on the western part. Most rivers in Botswana, Namibia and Zimbabwe have the coefficient of variation being greater than 100%. Frequent water shortages occur in this region due to the high variability of runoff, and any increase in this variability will worsen an already existing problem. The magnitude of the likely change in the variability of runoff is not known since global circulation models do not give an indication of the change in rainfall variability.

Most of the rural population in the semi-arid and arid parts of southern Africa depend on groundwater for water supply. The expansion of the coverage of population with improved access to potable water, which is in line with the Millennium Development Goals, will greatly depend on the use of groundwater. There is very little knowledge about climate change effects on groundwater (Kundzewicz *et al.* 2007; Xu & Braune 2010). Any decrease in precipitation together with an increase in evaporation will reduce the amount of water available for recharging aquifers. The predicted decrease in runoff will result in an increased number of people depending on groundwater therefore depleting the available resource. Climate change is also predicted to cause an increase in the intensity of precipitation leading to flooding. Groundwater aquifers, occurring along ephemeral rivers such as the Kuisieb River in Namibia (Morin *et al.* 2009), are mostly recharged by flood flows, and therefore any changes in the frequencies of floods will affect recharge to these aquifers. Medium to large floods were found to be the most significant in recharging alluvial aquifers along the Kuisieb River (Morin *et al.* 2009). The predicted rise in sea levels will lead to saline water intrusion in coastal aquifers.



ADAPTATION TO CLIMATE CHANGE

The goal of water resources management has always been to develop measures for adapting to the mismatch between the availability of water and its demand. Climate change has the potential to affect both the availability of water and its demand. The development of measures for adapting to climate change has to take into account climatic and non-climatic factors that will affect both the availability of water resources and their demand. Measures for adapting to climate change also have to consider the institutional and the technical capacity required for their implementation by water management agencies. Water resources management occurs at various levels: from the household, farm, and provincial sector, to the multi-sectoral and the national levels. Climate change adaptation measures should be implemented at all these levels. Due to various factors affecting water resources management and the levels at which this is done, an integrated approach that takes all these factors into consideration, needs to be adopted in the development and implementation of adaptation measures. Such an approach should consider issues affecting water availability (supply), demand, as well as the institutional and the technical capacity for water resources management. Integrated water resources management (IWRM) provides such a framework that has been accepted globally as being appropriate with or without climate change (van Beek *et al.* 2002; Kundzewicz *et al.* 2007).

This paper has highlighted uncertainties regarding the effects of climate change on water resources. While most models predict that southern Africa will experience a decline in the mean values of precipitation and runoff, there is, however, a distinct possibility that some of the river basins could experience increases in both precipitation and runoff. Adaptation measures should therefore take into account such uncertainty. The major challenge for water resources management in southern Africa, with or without climate change, is the spatial and temporal variation of water resources. The development and the implementation of measures to overcome problems due to this variability provides benefits with or without climate change, and thus there will not be any regrets despite the uncertainties regarding climate change effects (Schulze *et al.* 2001; van Beek *et al.* 2002).

Institutional and technical capacity

One of the major constraints for water resources management in southern Africa is the lack of information about the available water resources. Large parts of this region are not covered by hydrological monitoring systems. In fact the number of hydrological monitoring stations has declined since the 1980s. Most of the countries in southern Africa have no readily accessible or efficient database on water availability and demand. A reactive approach is often adopted in managing water resources since the availability and demand for water are not accurately known. Without adequate data, it is not possible to isolate effects of climate change from those of other factors such as land use change. The availability of accurate data about the various aspects of water resources will go a long way in overcoming the challenges arising from climate variability and climate change (Conway *et al.* 2008). National water resources management agencies, at various levels in southern Africa, have a limited capacity to manage extreme events such as floods and droughts and to forecast and monitor these events under the current climate. Low levels of funding the personnel and for monitoring equipment, inhibits the development of the capacity to respond to current water resources management challenges that may arise in future due to climate change. The development of the capacity to plan, to monitor, and to develop appropriate responses to extreme events will provide immense benefits for the current climate and for the future when such events may be more frequent due to climate change.

Water supply

Most parts of southern Africa have relatively undeveloped surface water and groundwater resources, while the majority of the population lack access to improved water supply, and inadequate water constrains industrial and agricultural growth as well as energy production. Table 5 shows that 40% of the population in the region has no access to potable water. The development of water resources will enable these countries to achieve goals that have already been agreed upon (Millennium Development Goals), and will also cushion them against climate change effects. Expansion of access to potable water could be achieved by building additional storage works such as dams. A major challenge in the planning of these works is that the design of water infrastructure has historically been based on the assumption that historical hydrological observations are representative of future conditions, but climate change invalidates this assumption of stationarity. Water storage works, with a lifespan of 20 to 50 years, have to incorporate the potential effects of climate change in their design. However, southern African countries have not yet adopted guidelines on how the design of water supply projects should incorporate the uncertainty arising from climate change. The SADC Water Policy recommends that adequate water be allocated for environmental uses along rivers (SADC 2006), and this has to be taken into account when developing additional storage works to overcome the effects of climate change.

Table 5: Coverage of improved water supply for countries in southern Africa in 2008

Country	Total Population (X1000)	Proportion of Urban Population (%)	Proportion of Rural Population (%)	Proportion of Urban Population Served with Improved Water (%)	Proportion of Rural Population Served with Improved Water (%)	Proportion of Total Population Served with Improved Water (%)
Angola	18,021	57	43	60	38	50
Botswana	1,921	60	40	99	90	95
Democratic Republic of the Congo	64,257	34	66	80	28	46
Lesotho	2,049	25	75	97	81	85
Madagascar	19,111	29	71	71	29	41
Mozambique	22,383	37	63	77	29	47
Mauritius	1,280	42	58	100	99	99
Malawi	14,846	19	81	95	77	80
Namibia	2,130	37	63	99	88	92
Swaziland	1,168	25	75	92	61	69
United Republic of Tanzania	42,484	25	75	80	45	54
South Africa	49,668	61	39	99	78	91
Zambia	12,620	35	65	87	46	60
Zimbabwe	12,463	37	63	99	72	82
Total	264,400	39	61	85	46	61

Source: WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation (<http://www.wssinfo.org>).



There is a potential for cushioning against climate change effects by increasing groundwater abstraction. A major constraint for this adaptation measure is the limited knowledge about the existing groundwater resources in southern Africa (Xu & Braune 2010). Groundwater is rarely included in the inventory of national water resources due to the lack of systematic monitoring of groundwater resources at national levels. For those groundwater bodies that have been identified very little is known regarding their yields, recharge rates and the threats to them from contamination. The mechanism and rates of recharge of basement aquifers that are widespread in southern Africa are not accurately understood. Thus the sustainable levels of utilisation of these resources are not known. Expansion of the groundwater exploration will improve the knowledge about the potential use of groundwater under the current and the future climate.

Inter-basin water transfer can improve water supply for regions that in future will have inadequate water. The southern Africa region has 15 major trans-boundary rivers and some of these basins have the potential for inter-basin water transfer. The experience of the Lesotho Highlands Water Scheme demonstrates the potential for improving water supply through inter-basin water transfer (Heyns 2003). The development of inter-basin water transfer from the Zambezi River has the potential to increase water supply to Botswana, Namibia, South Africa and Zimbabwe. Similarly the proposed transfer of water from the Okavango River to the high demand centres in central Namibia can, according to Heyns (2003), minimise the adverse effects of climate change. SADC is facilitating the formation of river basin organisations to improve water resources management. These river basin organisations will facilitate the joint development of water resources on shared river basins.

Studies carried out in southern Africa have shown that rainwater harvesting can contribute towards improving water supply and is a possible measure for adapting to climate change (Mukheibir & Sparks 2005; Mwenge Kahinda 2010). Sturm *et al.* (2009) found that roof harvesting technologies provided benefits comparable to private water taps in the northern part of Namibia. Rainwater harvesting and conservation tillage have also been shown to increase crop yields, even during seasons with below average rainfall (Munodawafa & Zhou 2008; Mupangwa *et al.* 2008; Makurira 2010; Mkoga *et al.* 2010). Rainwater harvesting enables households to overcome problems due to low rainfall under the current climate, and to reduce their vulnerability to inadequate water supply arising from climate change.

Water reclamation can increase water supply as has been demonstrated by the City of Windhoek where reclaimed water accounts for 35% of the water consumed in this city (du Pisani 2006). This has enabled Windhoek City to defer development of alternative water sources such as the transfer of water from the Okavango River (Heyns 2003). The desalination of sea water can increase water supply particularly to coastal areas where the transfer of freshwater is not feasible (Mukheibir & Sparks 2005). Desalination of sea water has improved water supply to some coastal settlements in Namibia and in South Africa. Similarly, desalination of groundwater has improved water supply to some villages in Botswana.

Water demand management

Water demand management aims to control water consumption using both non-structural and structural measures. Controlling demand enables society to increase the benefits arising from a unit volume of water under the current and the future climate. The SADC Regional Water Policy considers water demand management as an integral element of integrated water resources management (SADC



2006). Several initiatives, for implementing water demand management, have been undertaken in the SADC region (Gumbo 2004). Non-structural measures for water demand management include education and awareness raising, water allocation, and water pricing. There is a need to educate and increase the awareness of citizens about the value and the limitations of existing water resources and the need for conserving these resources. Citizens need to be aware of benefits derived from conserving water resources. Water allocations systems have tended to favour farmers without considering whether an individual farmer, allocated a water right, used the water efficiently. Modifications to the water allocation system, to consider the efficiency and the effectiveness of water usage, will reduce the water demand particularly for agricultural purposes. The pricing of water has not always reflected the cost of providing water. There have been cases of wasteful use of water due to inappropriate pricing or the non-existence of metering and billing of water users. The adoption of the rising block tariff resulted in considerable water savings in Cape Town (Mukheibir & Sparks 2005).

Structural measures for managing water demand include retrofitting of water appliances to make them more efficient, also for leakage detection and repair, and for the upgrading of water distribution systems including irrigation infrastructures. During the early 2000s, the level of unaccounted water or losses within the distribution system was 52% for Mutare in Zimbabwe, 65% for Maputo, 58% for Lusaka, 20% for Bulawayo and 18% for Windhoek (Gumbo 2004). Reduction of these losses through leakage detection and repair and pressure management will reduce water demand considerably and increase the coverage of the current water supply systems. Water saved by reducing losses to less than 10% can be made available to the unserved communities. Irrigation accounts for about 70% of the water use in southern Africa, but this sector has very low water use efficiencies. The upgrading of irrigation infrastructure will reduce water losses and free up water for other sectors.

TEACHING AND LEARNING

A survey administered through an emailed questionnaire was conducted in universities, in southern Africa, to determine the approaches that are being used to teach climate change issues related to water. Three approaches have been identified: (1) The inclusion of climate change in existing modules or courses, (2) The introduction of stand-alone modules dealing with climate change, and (3) short training courses. The following modules address climate change issues related to water:

- Agro Climatology
- Agricultural Geography
- Climatology
- Ecosystems and Ecology
- Environmental Systems
- Environmental Management
- Hydrology
- Water Resources Policy, Laws & Institutions
- Integrated Water Resources Management
- Water Resources Planning
- Land and Water Resources Management

The inclusion of climate change issues in existing modules have the advantage of enabling students to relate climate change issues to water resources and to other elements of the environment. The



responses received during the survey revealed that at some universities the inclusion of climate change in the curriculum depended on the interest of the respective lecturers. A disadvantage of this approach is that climate change issues may not be adequately covered.

Stand-alone modules on climate change have been introduced in a few universities. It was reported that this was part of the review of teaching programmes. This approach ensures that climate change issues are adequately dealt with. There is, however, the potential that the relationship between climate change and other environmental elements is not adequately considered in stand-alone modules.

Universities are facing several challenges in teaching about climate change. The major problem reported was the lack of expertise in this subject. Most of the teaching staff was trained before climate change became a recognised problem that needed to be dealt with university teaching. In addition the teaching of climate change issues is, in some cases, perceived to be the responsibility of meteorologists and climatologists. Climate change issues cut across disciplines and some of the lecturers are not comfortable dealing with issues beyond their own disciplines. The perception that climate change is a global problem that is not necessarily related to local issues has also contributed towards the lack of its inclusion in teaching programmes.

Different global circulation models give different, and in some cases, inconsistent predictions about changes of precipitation. This uncertainty creates a problem for teaching, as the lecturers cannot provide the exact effects of climate change. Most lecturers are used to providing guidance on the correct answers to problems, but there are no unique solutions for climate change effects. The lack of solid evidence about the effects of climate change creates problems when relating these effects to everyday experiences. Recent allegations of scientists exaggerating about climate change effects have created a problem for teaching as some students and lecturers have become sceptical about climate change.

Teaching of water resources management has traditionally been based on the assumption of stationarity which climate change invalidates. There are no generally agreed upon guidelines on how climate change should be incorporated in water resources planning in the short to medium term. This raises a challenge in teaching climate change issues related to water resources management.

There are very few studies which have examined climate change effects on water resources in southern Africa. An internet search on climate change and water resources reveals the lack of such studies in some of the southern African countries. Most of the effects of climate change on water resources that are cited are based on very few studies carried out on catchments which are not representative of southern Africa and the methodologies used for some of these studies are questionable. Therefore, the lack of studies on climate change and water resources in southern Africa means that there are few case studies which can be used for teaching.

The questionnaire survey revealed that most of the teaching is being done in specific disciplines such as climatology, geography and environmental science, hydrology, agriculture, engineering, natural resources management. Multidisciplinary teaching is done in postgraduate programmes dealing with multidisciplinary issues, e.g. environmental planning and management, water resources management.

The regional MSc in Integrated Water Resources Management has adopted this approach. The following universities are participating in this programme: the University of Botswana, University of Dar es Salaam, University of Kwazulu-Natal, University of Malawi, University of the Western Cape, Polytechnic of Namibia, and the University of Zimbabwe. This programme allows for student exchange among these universities. Students register at either the University of Zimbabwe or University of Dar es Salaam where they do the core modules. After completing the core-modules, the students can select one of the specialisations offered by any one of the participating universities.

Specialised training in climate change is done mainly through postgraduate research or short training courses. Students registered for postgraduate research on climate change tend to deal with climate science, hydrology, agriculture, water resources management, and rainwater harvesting. Short one to two week training courses are also offered by some of the universities, e.g. a two week winter school at the University of Cape Town, and similar courses at the University of Kwazulu-Natal, and the University of the Western Cape.

RESEARCH KNOWLEDGE PRODUCTION

There are two approaches which can be used to identify not only the type of research being carried out, but also the productivities of universities regarding the number of publications that have been submitted. The first approach involves administering a questionnaire to researchers in the respective universities. The second approach involves the use of online databases (e.g. Scopus, Jstor, ISI Web of Knowledge, EBSCOhost, Sabinet). Both approaches were used in the preparation of this paper. A questionnaire was administered by email to contacts in university departments dealing with climate and water issues. Most of the respondents provide neither the list of publications done by their respective institutions nor the number of papers submitted. Some respondents did provide the list of the research projects done by their respective institutions.

The online database used is the Scopus database (www.scopus.com), which has the largest abstract and citation database of papers published in a considerable number of peer review journals. Scopus captures information from about 16,500 peer reviewed journals and about 5,000 international publishers. The author is aware that this database does not capture all the peer reviewed papers, but it has been assumed the papers included will give a representative indication of the papers published by universities in southern Africa. The search for papers was done using the key words 'climate change', 'water', and 'name of a university'. The search engine, Google Scholar, was used for the identification of papers and reports not published in peer reviewed journals.

See Table 6 for a break down on the research on climate change issues related to water done by universities in southern Africa dealing with water, climate variability, ecological aspects, agriculture, rainfall, and social aspects.



Table 6: Areas covered by papers published on climate change issues related to water by universities in southern Africa

Issues Covered in the Papers Published	Percentage of the Papers Published
Agriculture	11
Climate Variability	23
Ecology	20
Rainfall	7
Water	37
Social issues, e.g. population migration	3
Total	100

Source: papers appearing on www.scopus.com

The dominance of water issues is not surprising because the possible decline in the available water resources as a result of climate change is a major concern in southern Africa. Large parts of southern Africa frequently experience droughts and floods due to climate variability, and understanding the nature of climate variability is a topical issue for research. Some of the research has focussed on explaining causes of climate variability, e.g. global tele-connections, El Nino, and sea surface temperatures.

Research on precipitation has focused on researching the existence of any evidence for climate change in historical records, in rainfall patterns arising from climate change, and in changes in the onset of the rainy season. Agriculture related research has covered climate change impacts on crops particularly maize, and other cash crops, e.g. cotton and sugar cane.

South African universities dominate the research on climate change and water resources, and contributed 90% of the articles published in peer review papers reflected on the Scopus database (Table 7).

Table 7: Contribution of universities in southern Africa in the publication of papers on climate change and water resources

Name of University	Percentage of Papers Published
Midlands State University	1
Rhodes University	5
Stellenbosch University	10
University of Botswana	5
University of Cape Town	42
University of Johannesburg	3
University of Kwazulu-Natal	4
University of Pretoria	10
University of the North West	1
University of Witwatersrand	6
University of Zimbabwe	4
University of Zululand	8
Total	100

Source: papers reflected in the Scopus database (www.scopus.com)



According to a study cited by Manase (2009), 50% of the climate researchers in southern Africa in 2005 were from South Africa. The University of Cape Town contributed 42% of the peer reviewed papers. This university has a very active research group (Climate Systems Analysis Group, www.csag.uct.ac.za) that is focusing on global and regional climate modelling, climate variability, and the downscaling of global circulation models. The University of Kwazulu-Natal focuses on hydrological issues related to climate change, and climate change effects on crop production. Universities outside South Africa are also investigating climate change effects on crop production, and examining conservation tillage as an adaptation to climate change.

Generally there is low productivity in terms of peer reviewed research outputs. The Scopus database recorded only 77 papers published by 18% of the 66 public universities in southern Africa. Thus the majority of the universities are not publishing papers on climate change and water issues despite this being a topical issue in the region. Universities in southern Africa are not adequately assisting societies to understand the climate change issues relevant to their region, and how to develop adaptation measures. Under these circumstances national policies on climate change are therefore based on information coming from international sources. The author serves as an Editor of the special issue of the *Physics and Chemistry of the Earth Journal*, published annually, focusing on water resources management issues in southern Africa. It has been observed over the last 4 years that the number of papers submitted for publication in this journal has been declining (Mazvimavi & Nhapi 2008). The low productivity with regards to the publications of papers on climate change and water resources partly explain why very few universities have developed specialised modules on climate change.

Grey literature covering climate change and water resources mainly comprises national reports done as part of the UNFCCC reports on the national assessment of climate change impacts, the adaptation strategies, and the vulnerability of selected sectors, especially agriculture to climate change.

COMMUNITY ENGAGEMENT

Scientists in southern Africa primarily undertake community engagement research projects at a national level. These research projects, related to climate change and water resources, are aimed at increasing the understanding of climate change impacts and the development of adaptation strategies. The obligation for individual countries to report on climate change, as part of the UNFCCC, has been critical in the engagement of southern African scientists at a national level. Engagement with universities is much more active in South Africa where the Water Research Commission has not only prioritised research on climate change but has also provided the necessary funding. Other countries do not have a research funding agency dedicated to the water sector.

There is a low level of engagement with local communities. This is not surprising since there is considerable uncertainty regarding the nature of climate change impacts at specific locations at the local level. The Small-holder System Innovations in Integrated Water Resources Management (SSI) research project carried out by 1) Sokoine University of Agriculture, Tanzania, 2) Stockholm University, 3) School of Bioresources Engineering & Environmental Hydrology, University of Kwazulu-Natal, 4) International Water Management Institute, and 5) UNESCO-IHE engaged farmers at the sites at which research was done. The farmers undertook activities such as monitoring and carrying out trials of selected rain water harvesting technologies. A similar approach was used by the recently completed Challenge



Programme on Water for Food research project (CP) whose goal it was to improve rural livelihoods through managing risk, mitigating drought, and by improving water productivity in the Limpopo Basin. The participating institutions were the:

- University of Zimbabwe),
- University of Eduardo Mondlane,
- National University of Science and Technology,
- University of Kwazulu-Natal (South Africa), and
- International Water Management Institute (South Africa).

The lack of funding is a major limitation for scientists in southern Africa wanting to engage among themselves on issues relating to climate change and water resources. The African Climate Change Fellowship Program did, as of November 2008, facilitate exchange visits through teaching, doctoral and post-doctoral fellowships (Manase 2009). Limited funding for staff exchange is, however, provided by Waternet: a regional network of universities in southern Africa aimed at developing capacity for integrated water resources management through research and training.

Community engagement with partners in the North is mainly done through joint research projects funded by international agencies. Some of the agencies that have facilitated collaboration between the north and south are: the International Development Research Centre of Canada, START (<http://start.org/>), and the European Union.

CONCLUSION

There is a high degree of confidence in the predicted increase in temperature due to anthropogenic emissions of greenhouse gases. The increase in global temperature will result in increased precipitation at the global level, but with variable effects in different parts of the world. Most models suggest that precipitation will decrease in southern Africa, but there is uncertainty regarding how these changes will occur at specific locations. The low signal to noise ratio, due to considerable climate variability in southern Africa, raises doubts as to whether predicted changes in mean values will have significant effects. Global climate models do not give an accurate prediction about changes in precipitation variability which is of major concern in southern Africa where rainfall in a year may be as low as 60% of the average value, or as high as 140% of the average value.

Changes in precipitation will be amplified in the conversion of precipitation to runoff. Most studies have managed to demonstrate the sensitivity of hydrological responses to climate change, but not the specific impacts for a particular river basin. The effects of climate change on groundwater are largely unknown in southern Africa.

Measures for adapting to climate change effects on water resources should be developed within an integrated water resources management framework. Climate change will have effects on water availability, water demand, and the quality of water, and therefore, an integrated approach is most appropriate. The southern Africa region already faces considerable water resources management challenges such as; low levels of access to improved water supply, frequent water shortages due to climate variability, and inadequate information about the spatial and temporal variations of water resources. Measures for managing these challenges will reduce the vulnerability to climate change





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KNOWLEDGE QUESTIONS ASSOCIATED WITH THE PUBLIC HEALTH AND CLIMATE CHANGE RELATION: SOME IMPLICATIONS FOR UNIVERSITIES IN SOUTHERN AFRICA

1

ABSTRACT

This paper, commissioned by SARUA to assist universities in southern Africa in deliberating the potential implications of climate change for university education, research and community engagement in southern Africa, is introduced with a consideration of the nature of the relationship that exists between climate change and public health. It surveys some of the literature on public health and climate change but not to provide *the* definitive analysis of the issue, as this has already been done by different authors who are specialists in the field of climate change and public health; see for example the paper, in a southern African context, by Dube and Chimbari (2009). What is of interest here, especially to the universities, is the *kind of knowledge questions and types of analysis* that are being debated and engaged with by researcher's i.e. different types of knowledge questions and associated knowledge-related issues and how they are engaged and analysed. These knowledge questions reveal the need for a mainstreaming approach to environmental and sustainability issues. The paper makes reference to some of the lessons learned in the Mainstreaming Environment and Sustainability in African (MESA) Universities Programme² initiated in 2004 by the United Nations Environment Programme in partnership with the African Association of Universities, the SADC Regional Environmental Education Programme and UNESCO. But most substantively, the paper raises questions about the epistemological consequences of engaging with complex issues such as climate change and public health in universities from a research, teaching and community engagement perspective. It also notes a neglect of public health and climate change related knowledge production and engagement in southern Africa.

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2 See www.unep.org/training for more information on the MESA Universities Programme.



INTRODUCTION

The 2007 IPCC report identifies three themes: health, water and food security as being of most significance to climate change discussions in a southern African context (Dube & Chimbari 2009), also refer to this volume of SARUA. Climate change impacts on the above three areas are seen to be a threat to sustainable development in the region, and can reverse important development gains. As such they require urgent attention from governments, universities, the regional and the international community, and also the citizens in the region. While it is relatively easy to identify these as critical issues, it is more complex to fully understand the *nature of the issues, and what they mean for universities*. The statement below introduces the discussion in this paper and reveals some of the dynamics of the issue of climate change and public health:

The potential consequences of climate change extend to the health of the public, with the warming of the planet projected to have both positive and negative consequences that will vary temporally and spatially. Climate change will not act to introduce new causes of morbidity and mortality, but to change the distributions of factors that affect the occurrence of morbidity and mortality. The time frames over which health consequences of climate change are anticipated to be manifest are sufficiently slow because a multitude of measures to come into play that may modulate the occurrence of these effects. (Samet 2009: 1)

This statement introduces a number of important dynamics because a full discussion on climate change and public health, notably 1) what the exact nature of the public health-climate change relation might be; 2) what the impacts of the public health-climate change relation might be; 3) when they may be expected; and 4) what might be done about it. Educational institutions, particularly universities and institutions of higher learning have a role to play in all of the above dimensions of engaging with the question of public health and climate change in a southern African context, not only to help society to understand the exact nature of the public health-climate change relation and potential impacts, but also to support societies to prepare for, and to develop the competence necessary for implementing adaptive measures that could 'modulate' the effects of climate change on public health. I discuss these aspects in greater detail below.

THE NATURE OF THE PUBLIC HEALTH-CLIMATE CHANGE RELATION

Much has already been said about climate change not only globally, but also in relation to the African continent. Since 2006 climate change has become a major public issue. It has also been described as a major development issue (UNDP 2010), while some authors (Giddens 2009; Toulmin 2009) describe it as one of *the most significant* development issues of our time, because not only is climate change an environment and development issue, it is also an issue tied closely to the geopolitics of energy, the resource flows and the control of international resources. The public nature of the issue has increased apace prior to, and since the release of the results of the International Panel on Climate Change's 4th Assessment Report (IPCC 2007) which definitively stated that climate change has anthropogenic causes, with unknown and unpredictable effects.



Discourses surrounding climate change, and the scientific evidence associated with climate change all point to a few important dynamics that are of interest to southern African universities:

- Climate change has different impacts in different geographical spaces. Refined sub-regional assessments are required to fully grasp the implications of climate change. It is noted in various places and by various authors that Africa currently lacks the scope of scientific expertise to provide the fine scaled analyses necessary to fully understand the full impacts of climate change at sub-regional scales (UNEP 2006; Toulmin 2009; Byass 2009). Byass (2009:173) for example states that 'Despite a growing awareness of Africans' vulnerability to climate change, there is relatively little empirical evidence about the effects of climate on population health in Africa'.
- Climate change will adversely affect those communities and societies that are already vulnerable to extreme weather conditions and unpredictable risk. Southern Africa, already heavily impacted by poverty, HIV/AIDS and other associated conditions such as unemployment, increased vulnerability etc. has been identified as one of the regions most at risk from the impacts of climate change (UNEP 2006; IPCC 2007). As stated by Eriksen et al. (2008: 5) 'Africa as a whole is considered to be among the most vulnerable regions to climate change due in part to a lack of financial, institutional and technological capacity; efforts are being made to find substantively reasonable and effective 'entry points' for reducing vulnerability to climate change in Africa.
- Climate change makes global interconnectedness more evident. Dealing with climate change is a global social justice issue, it affects economies and development policies, and it requires fundamental changes in production systems, energy supply and human behaviour. It is also highly politicised and is a complex 'meta' issue affecting all aspects of human endeavour.
- Climate change issues, while requiring specific attention from scientists, policy makers and the public, cannot easily be disconnected from other conditions, histories and contextual factors that shape society, economies, ecologies and geo-politics. As Ho man (2007: 7) states 'Global warming needs a response that isn't only at the level of managing an environmental problem to ensure the planet is just about liveable on in the years to come – it needs one that addresses the essential unfreedom, suffering and misery within the present global system'.

Located within this broader framework of understanding climate change, is a gradual realisation of **the complex relationship that exists between climate change and public health**. The main contours of the discussion on *climate change and public health* in Africa is as follows:

- Despite increased media coverage about Africa's vulnerability to climate change, detailed scientific evidence of public health related impacts remains scanty (Dube & Chimbari 2009; Byass 2009; Eriksen et al. 2008; Conway 2009; Toulmin 2009).
- Existing scientific work primarily looks at the effects of climate on specific diseases, without making clear connections to overall changes in population health. For example information that indicates that sub-Saharan Africa has conditions that are conducive for disease transmitting vectors and pathogens indicates that schistosomiasis is primarily a problem of Africa; Soil transmitted helminths (STH) follows the same distribution pattern, and Africa leads the world with respect to malaria suitable areas, see Figure 1 below (Dube & Chimbari 2009).

Figure 1: Global distribution of schistosomiasis (a); soil transmitted helminth infections (b); and malaria (c)



- Climate change impacts on human health in Africa will be both **direct**, i.e. through temperature extremes, insufficient rainfall, physical impacts of floods but also **indirect** through impacts on climate sensitive diseases, natural systems, agriculture, human infrastructure and the economy in general (Dube & Chimbari 2009).
- Major issues associated with public health and climate change are seen to be related to the interaction between HIV and rain-fed food production capacity; impact of drought on child nutrition; disease impact of floods; changing patterns of malaria transmission; and the impact of natural disasters. It is acknowledged by Ramin and McMichael (2009) that there is as yet not enough scientific evidence for these projected scenarios. The problems of 'not enough evidence' are also debated by scientists, philosophers and sociologists such as Glazebrook (2010), Giddens (2009) and Beck (2009) who indicate that *uncertainty* is, in fact, a characterising feature of the sciences (particularly climate sciences) and that to wait for significant accurate evidence before acting on best available knowledge may be waiting too long, with potentially dire consequences. They propose engagement with best available knowledge, a risk epistemology and reflexive justice practices (Fraser 2008) such as implementing the precautionary principle instead, noting that this may be a more ethical and a more practical way forward for a context such as Africa, where achieving the perfect state of 'enough scientific evidence' before acting may simply not be possible. Waiting for such a state may therefore also be irresponsible.
- Estimates are that the highest regional burden of climate change is likely to be borne by sub-Saharan Africa, with 34% of the global disability adjusted life years (DALY) attributable to climate change (Costello *et al.* 2009). Since sub-Saharan Africa only contains 11% of the world's population, this reflects a three-fold population-based risk for adverse effects of climate change compared with the global population (*ibid*). This provides further insight into why climate change is a social justice problem. Giddens (2009) and Hoffman (2007) and other authors comment on the complex geo-political relations that exist in, and for, the resolution of climate change issues, noting that how this social justice issue is addressed (or is not) is likely to define global geo-politics over the next few decades.
- Climate change research related to food security also indicates the highest potential impacts in sub-Saharan Africa, but much of this research does not consider the public health impacts of increased food insecurity (Havensvik 2007; Byass 2009; UNEP, 2006).
- Some researchers point to the relationship between water- and food-borne diseases and climate change, noting that warming is likely to increase the incidence of such diseases. Food-borne diseases such as *Salmonella* and *Camylobacter* are likely to increase with warming temperatures,



and warming temperatures may also cause increases in the prevalence and geographic range of the *Vibrio* bacteria in shellfish (Weber 2010). *Vibrio cholera* infection is an important cause of death in developing countries, and it is likely to rise sharply with global climate change (Greer *et al.* 2008). All of these are likely to impact more in developing countries, where health risk management and health services are less able to support increased resilience and adaptation measures (Weber 2010).

- The spread of malaria is widely documented as a potential public health risk related to climate change. Detailed climatic analyses indicate that patterns of malaria transmission in Africa may well change as a result of climate changes (Transfer *et al.* 2003), but current assessments of this issue indicate that there is a need to extend climate modelling into vector dynamics modelling to produce more accurate perspectives on this issue (Pascual *et al.* 2006, cited in Byass 2009).
- The dominance of malaria in the literature linking climate change to health in Africa may lead to a supposition that this is the major issue, but other effects which remain largely under-researched and undocumented may have greater impact as time passes (Byass 2009).
- Climate change impacts on human health in Africa are closely associated with **other health related issues**. The current poor health status of Africa (UNDP 2010); the prevalence of climate sensitive diseases (see figure 1 above), combined with the widespread diseases of the poor (as classified by the World Health Organisation 2008), and the growth of non-communicable diseases, clearly shows that the health sector in Africa will be highly vulnerable to the added stress of climate change. Dube and Chimbari (2009: 16) argue therefore, that **adaptation to climate change in Africa needs to give greater priority to health**.

HOW PUBLIC HEALTH AND CLIMATE CHANGE ARE BEING ANALYSED

With this as background, I now briefly consider some of the ways in which the public health and climate change relation is being analysed across the available body of literature³, with specific reference to southern African perspectives - where these are available⁴. This provides insight into the **different types of knowledge questions that arise at the interface of public health and climate change, with the associated methodological and analytical responses**. Researchers engaging this question are approaching it from a variety of vantage points, each providing either further insight or different angles on the question of how climate change affects public health.

Analysing public health and climate change from a scientific evidence perspective

Given a paucity of data and sophisticated studies linking climate change and public health impacts, most research into the effects of climate change on public health follows a process of making retrospective connections between meteorological data and health outcomes (Byass 2009). Byass (2009: 175) notes that 'population groups cannot be randomised to different kinds of natural climate change, and hence drawing causal inferences between observed climatic variations and disease patterns is difficult to achieve with certainty'. He goes on to recommend scientific studies that are located where longitudinal population surveillance studies are already in place, as 'it is usually too late to collect health outcome data once a particular climate phenomenon has been observed'. He recommends routine collection of meteorological data in such sites, and regular geo-referencing of population health data in national

3 Note that this analysis is not definitive, it is more indicative in nature, to provide insight into the nature of the knowledge question provided by the climate change-public health relation. Byass (2009) also notes that there is very little literature that analyses this relationship, indicating that it is an under-researched area of public health, particularly in an African context.

4 Only one substantive synthesis study on climate change and public health in southern Africa was found during the literature review (Dube & Chimbari 2009). Most other studies were of a broader nature, and tended most often to consider East and Southern Africa together, or to consider the question of public health on a broader continental level (see for example the studies by Eriksen *et al.* 2008; UNEP 2006; Conway *et al.* 2009).

and in regional studies. This importantly draws attention to the need for **cross-disciplinary research** involving meteorology and health.

Analysing public health and climate change through the lenses of predictive modelling

Climate science is an area of scientific endeavour that appears to be particularly closely associated with predictive modelling, due to its close links to climatology. Conway (2009), commenting on the status of climate science in Africa, notes, however, that 'despite considerable progress in African meteorological science, we are still not confident about the major climate trends at either the continental level or for individual countries ... Part of the problem is that the Global Climate Models (GCMs) used to simulate the regional patterns of climate change are relatively crude' (p.6). He goes on to explain that such predictive modelling processes work 'to a horizontal spatial resolution of several hundred kilometres'. Consequently they do not take full account of local topographic, vegetation or land use diversity of the landscape all of which have implications for the way in which public health risks are constituted and assessed. He recommends strategies for 'downscaling' through adapting the GCM to specific regions using smaller resolution climate models, of which he cites the PRECIS model as being an example. He argues further that such models are valuable tools for understanding local climate dynamics and may therefore also be more useful for predictions and modelling of climate change and public health relations. Such models also have their problems, and alternative approaches such as 'empirical downscaling' can also be used, but the use of such models is hampered by the paucity of accurate longitudinal data. In the final analysis therefore it is both inadequate technology and inadequacy on the ground systems for research that hamper accurate and substantive predictive modelling of climate change – public health relations.

Despite this, Conway (2009) notes that some level of certainty does exist, namely that large scale predictions of warming and drying are evident for Africa, even though the local climate information is not easy to produce or to find. **Substantive improvements in modelling capacity** are therefore necessary if more accurate understandings of the climate change-public health relation are to be developed with useful information for local climatic condition based policy and practice responses. This has other implications, particularly for epistemology and pedagogy. Predictive modelling introduces a futures oriented science into universities and new ways of thinking about knowledge, i.e. where past experience and data is used to predict and stage risk, for risk management and reduction. Such an epistemology cannot function if the dominant pedagogy is 'transfer pedagogy' working of existing bodies of knowledge. Thus more open-ended ways of thinking about knowledge and the work that it does in society are needed. Anticipatory learning becomes a critical new form of pedagogy, based on a risk epistemology, rather than a certainty epistemology. Consequently, the nature of science begins to change, as does the process of learning.

Analysing public health and climate change within a framework of 'multiple stressors' and vulnerability assessments

Researchers are increasingly realising that climate change and public health cannot be analysed as discrete items, even though the kind of predictive scientific work, and scientific overlay (of health sciences and climate sciences) described above, is necessary to get a more accurate picture of the relation that does exist between public health and climate change. Scientists are seeking to analyse and document *wider relations that exist* between climate change, public health and other stressors (e.g.



poverty). As argued by Eriksen et al. (2008: 9) 'People do not experience climate change in an isolated or discrete manner. Many other changes are occurring simultaneously, creating multiple sources of human insecurity. The spread of infectious diseases (e.g. malaria, tuberculosis and HIV/AIDS) is occurring alongside trade liberalisation, water reforms, political or social conflict'. What such scientists are raising, is *responsive capacity*, and the interrelated nature of complex issues such as climate change and public health. They argue that 'it is necessary to consider how processes interact to influence exposure to climate change and the capacity to cope with or adapt to climate variability and long term changes' (ibid). They talk about researching and understanding 'cascading stressors and cumulative effects' and systems perspectives which involve understanding processes such as 'path dependency', 'the spiral of poverty'; or 'chronic vulnerability' (ibid). Researchers such as Parham and Michael (2010) are developing process based mathematical modelling techniques to assess aspects of vulnerability related to climate change and public health (in this case vulnerability to malaria transmission).

The underlying argument with this kind of analysis is that unless there is a holistic understanding of the complex relationships that exist between issues such as climate change, public health and other factors that exacerbate vulnerability to the effects of these issues, a **comprehensive adaptation framework** will not be possible. Such a framework, they argue needs to be 'anticipatory and rapid, empowering and enabling individuals, communities and regions to cope with and adapt to the risks associated with climate change' (p.20). They suggest three measures with which to address climate change issues: measures to target the risks posed by climate change to poverty; measures to strengthen the capacity to cope and adapt to climate stress; and measures that address the causes of vulnerability such as poor health facilities (amongst others). They suggest measures such as the following to address public health and climate change (see Table 1):

Table 1: Some measures to address public health and climate change risks and issues (adapted from Eriksen et al. 2009)

Measures targeting the risk posed by climate change.	Measures enhancing the capacity to cope and adapt.	Measures addressing the causes of vulnerability.
Plan for climate variability for water supply and sanitation.	Strengthen school feeding during drought. Restoration of infrastructure after floods. Reduce cost of health services. Promote links between indigenous / formal knowledge to respond to health risks. Support implementation of practices that can address some of the risks (eg. Use of mosquito nets, boiling water for drinking etc.).	Improve health infrastructure and capacity to deal with shocks and climate change related illnesses. Enhance local education at community level to provide relevant anticipatory measures to avoid risks. Enhance water supply and sanitation services.

Analysing public health and climate change from critical political studies and philosophical perspectives

Another type of study that is evident in the public health – climate change research arena is a range of studies focussing on the geo-politics, social justice and philosophical aspects of public health related issues that arise from climate change (Giddens 2009; Glazebrook 2010; Irwin 2010; Toulmin 2009; Maibach *et al.* 2010; Worth 2009). Such studies point to the manner in which climate change impacts most on those who have been least responsible for the causes. As Irwin (2010: 6) states 'When we talk about the human responsibility for climate change, we are entering the realm of the philosophical'. Principally these discussions are focussed on ethics, responsibility, social justice and geo-politics. They raise fundamental questions about the state of the current world order, the manner in which justice is administered, and how humanity is to deal with a global issue within a justice system that is located within a nation state framework.

Ultimately these discussions ask questions about responsibility for the devastation; and for the loss of human lives; and for the increase of public health risks, mostly in developing countries. In a recent article entitled 'Power Politics' Jennifer Worth (2009: 3), writes that climate injustice involves 'a triple injustice': Firstly, climate change affects the poorest first and the worst. Secondly, those that are most affected did not cause climate change, and are powerless to stop it. Thirdly, the polluters are not paying. Worth further reports that there appears to be little real political emphasis on resolving the problems, noting the differences in expenditure on bailing out the banks, and supporting poor people to cope with climate change risks. Worth's (2009) paper points to a failure of the Westphalian state system and its associated interstate mechanisms (such as the UN and the World Bank) to adequately address climate injustices, and points out the problem of *incommensurability*, which is also raised by Sunita Narain (2009: 11), an environmental scientist and activist who notes: 'There is a fundamental difference between the rich and poor's response to climate change. The environmental movements of the rich world emerged after periods of wealth creation and during their period of waste generation. So they argued for containment of the waste, but did not have the ability to argue for the reinvention of the paradigm of waste generation itself ...' It is ironic that, despite the science telling us that drastic reductions are needed, no country is talking about limiting its people's consumption.

Yet efficiency is meaningless without sufficiency.' Anthony Giddens (2009) too, in his latest book on *'The politics of climate change'* raises similar issues noting that all governments face deep dilemmas in reconciling climate change and energy policy with sustaining popular support, especially in times of economic difficulty. This relegates the social justice issues associated with climate change and public health consequences to issues of 'ethical concern' to be addressed *if global ethical principles* prevail. He points to the very real risk of this not happening in current conditions, and with it a re-structuring of the geo-politics of the planet.

In a similar vein, Nancy Fraser (2008), a social justice theorist, argues that global problems such as climate change are fundamentally changing concepts of justice, which hitherto have been framed primarily by the Westphalian state system, and what Benhabib (2006: 2) refers to as the 'positive law' of the nation state. She argues that claims of redistributive justice bounded within state-level justice systems are no longer adequate for dealing with the complex nature of social justice issues such as climate change.



Consequently, the Westphalian justice system is now in dispute as social movements across the globe coalesce in their critiques of transborder injustices. Fraser (2008: 2) argues that such justice claims are also increasingly 'mapped in competing geographical scales ... for example, when claims on behalf of 'the global poor' are pitted against the claims of citizens of bounded polities'. Her argument is that 'the challenges posed in the present epoch are truly radical' (2008: 2), thus radically new conceptions of justice are required, since without this what will be left is a 'spectre of *incommensurability*' (2008: 3). Fraser proposes a way forward out of this impasse with the idea of *reflexive justice*. She (2008: 73) states that:

The idea of reflexive justice is well suited to the present context of abnormal discourse. In this context, disputes about the 'what', the 'who', and the 'how' are unlikely to be settled soon. Thus, it makes sense to regard these three nodes of abnormality as persistent features of justice discourse for the foreseeable future. On the other hand, given the magnitude of first-order injustice in today's world, the worst conceivable response would be to treat ongoing meta-disputes as a license for paralysis. Thus, it is imperative not to allow discursive abnormalities to defer or dissipate efforts to remedy justice.

She proposes that reflexive justice should *at the same time*, entertain and strengthen urgent claims on behalf of the disadvantaged, '... while also parsing the meta-disagreements that are interlaced with them. Because these two levels are inextricably entangled in abnormal times, reflexive justice theorising cannot ignore either one of them' (ibid: 73). This has implications for the way in which universities engage with the social justice aspects of climate change and public health i.e. through facilitating global discourse, assessment and analysis, while addressing issues and risks practically at local level.

Analysing public health and climate change from an educational and media studies vantage point

Given the potentially life threatening implications of the public health – climate change relation, it is not surprising that a range of educational studies are also emerging to probe the issue. Some contributions in this genre of research point to 'practical strategies for educating people' see for example Filho *et al.* (2010). Other contributions are more substantive in pointing to ways in which education can strengthen climate change responses. For example, Gonzalez-Gaudio (2010) critically analyses major contemporary approaches to climate change education and communication and notes that providing information and orienting people to new technologies is not enough. He argues that the media is responsible for reproducing what he calls 'facile interpretations' of the damages caused by climate change, presenting a 'case - by - case facade of containable calamities' (cited in Irwin 2010: 15). His critique is for more critically engaged approaches that address the underlying causes of climate change namely, the pollution production of the consumer classes. Only through addressing these issues, he argues, will public health issues in developing countries eventually be addressed. His argument is therefore towards socially critical approaches to climate change and public health education.

Lotz-Sisitka (2009) in arguing for social justice orientations to climate change education, argues further for educational approaches that strengthen agency for change, and that develop people's reflexive capabilities (i.e. abilities to make choices, to discover and to develop alternatives and new practices), and practices of reflexive justice (after Fraser 2008). In another paper by Lotz-Sisitka and Le Grange (2010), an argument is made for broadening the epistemology of teaching, from one of certainty, to



one which embraces the possibility for risk negotiation as a reflexive social change process. UNESCO (2009), in a policy dialogue paper on climate change education, argues that climate change education is about supporting transformative cultural changes⁵. These approaches to education differ from 'getting the message across' to approaches that seek to strengthen participation in creating solutions to issues and risks, while also engaging critically with the causes and consequences of issues. Such approaches to education have implications for the way in which universities engage with communities and how university knowledge of issues (e.g. public health risks associated with climate change) are communicated to and with people. O'Donoghue (2007) has argued for example that in cholera education, it is not enough to tell people what to do, it is more important that people develop the practical agency and understanding necessary to take actions to prevent the spread of cholera. His research points out too that educators are often guilty of sharing simplistic messages on such issues with communities, which is tantamount to *mis-educating*.

Meta reviews or studies on climate change and public health

Another type of study being undertaken is what is often referred to as a 'meta review' or a synthesis study in which researchers seek to relate various other studies to each other to gain a 'composite picture' of the status quo. Such studies are often dependent on available research and as Byass (2009) points out in his study that very few studies exist on the climate change and public health in Africa. Through an admittedly inadequate process of identifying such studies (through keyword search on the PubMed database) he was only able to trace some 31 citations (0.002%), pointing to the scant nature of the scientific evidence, and therefore also the substantive insights that can be gleaned from this type of study. In a southern African context, perhaps the most substantive study available on climate change and public health of this nature is the synthesis of available research on the issue produced by Dube and Chimbari (2009). They note in their synthesis that 'much more work on climate change is done through networks than single institutions'. They identified 36 networks in a southern African context that are working on this issue, almost all of which have indicated the need to undertake substantive institutional mapping and more meta level research to provide a vantage point on the 'bigger picture' of issue and response in a southern African context.

They also note that despite the considerable number of networks focussing on climate change, few focus on climate change and public health, indicating that this is an **under-researched, and under-developed area** of climate change knowledge development and practice in southern Africa. They also note that most of the studies (with some exceptions in South Africa and Tanzania) have been done with support from northern institutions. From their review, they also note a bias in studies towards malaria-related studies, and the tendency to ignore or under-focus on other issues. They also note that 'much more work on climate change and public health has been done in East Africa than in southern Africa' (p.38), and that there are very few institutions in southern Africa that specialise in climate change and public health. Most institutions focus more broadly on cross cutting issues of adaptation, mostly within a water and agricultural focus. They also point out that the National Adaptation Programmes for Action for Low Income Countries has not prioritised health. Out of the seven NAPAs produced in southern Africa, only three presented projects on health. Such meta studies are useful for disclosing the gaps, and indicating the status of research in a particular area such as climate change and public health.

5 This policy dialogue on climate change education for UNESCO was authored by Lotz-Sisitka.



KNOWLEDGE QUESTIONS ASSOCIATED WITH CLIMATE CHANGE AND PUBLIC HEALTH ISSUES IN SOUTHERN AFRICAN UNIVERSITIES

The evidence presented above shows a range of different analytical orientations and knowledge questions relevant to the question of climate change and public health. This evidence indicates that it is impossible to delineate the issue within the traditional disciplinary boundaries that characterise most universities. The issue needs to be dealt with in Faculties of Medicine and Health Sciences; but it equally needs to be dealt with in Politics Departments, Education Faculties; Environmental Science Departments and Sociology, Philosophy and Politics Departments. In fact, the issue *cannot be analysed without cross-disciplinary or transdisciplinary approaches*. The discussion above has also pointed out that the issue is not only an issue of knowledge production, but also of how knowledge is applied in the world, i.e. how we work with knowledge of climate change and public health in education, and also in community outreach or community engagement activities. Most significantly, the discussion above points out that if the knowledge question is to move beyond Aristotle's *episteme* (i.e. producing knowledge about the issue) there will be a need for engaging the issues in or through multi-disciplinary or transdisciplinary research, teaching and community engagement strategies in universities. The Mainstreaming Environment and Sustainability in African Universities Programme (UNEP 2008) has shown that addressing environment and sustainability issues such as the one that is the subject of this paper requires a *mainstreaming approach* to ensure that knowledge questions such as the one focussing on climate change and public health, are adequately addressed. Mainstreaming as used here does not mean 'pushing a focus a does not nstransd impoe adeq10s(ansd impoe adeq10s(ansd impoe a6 Tw Th one fy bounfullT(no)1)8 a6sue within ()Tj0.08bounalytical ort se



society, or whether universities ought to 'get engaged' in more substantive ways in resolving the issues affecting their societies. This issue was also debated in the MESA programme, and is being engaged through various practical initiatives that are changing teaching, research and pedagogical practices in the universities involved in this network. The MESA network engages with university professors and lecturers, from a range of disciplines, to consider how environment and sustainability issues can and ought to be addressed in universities (UNEP 2008). Lessons from this network indicate that such issues require engagement across the university disciplinary framework (as already indicated in this discussion), but that they also require engagement across all university functions – teaching, research and community engagement. Most significantly, however, the MESA programme is pointing towards the need to engage differently with knowledge in universities, and to question whether the experiment-based epistemological models established under modernity and the rise of colonial university in Africa are, in fact the most useful epistemological models for universities in Africa today.

As pointed out by MESA professors UNEP (2008), Scott and Gough (2007), Wals (2007), Lotz-Sisitka and Le Grange (2010) and others, learning our way towards a new sustainable development paradigm cannot be done in the same old ways that led to the problems that we are currently trying to address. New epistemological frameworks need to be deliberated, particularly the implications of how to deal with uncertainty and risk as epistemologies in universities. As mentioned above, this has implications for pedagogy and the way in which community engagement is considered, particularly if community engagement is not just about transferring messages to communities, but rather about working with communities to engage their agency for change, resilience and adaptation in the face of complex risks that affect their quality of life, well being and ability to cope with adversity and increased vulnerability.

CONCLUSION

In this paper I have highlighted the nature of the climate change public health relation, and how it is eventually being understood through various forms of analysis. This shows that different types of knowledge questions are emerging, and a range of disciplines and types of studies are necessary to develop a fuller understanding of this issue, all of which has implications for both the knowledge production project, and the teaching project in universities. However, at the centre of the analysis is a deeper question: a question of how knowledge is viewed and approached in universities. I have drawn attention to the need for a questioning of epistemologies based on assumptions of attaining certainty. In his discussion on knowledge Aristotle raises the possibility that knowledge is also a matter of *phronesis*, which is a form of knowledge that relates to humans' ability to form moral judgements and to make correct decisions. As Anderson and Bo Kaspersen (2000: 498) indicate, 'This type of decision making has consequences for the surrounding environment. It is instrumental in either promoting or hindering the emergence of the good life ... *Phronesis* is dependent on the situation: it involves the ability to determine which conditions apply in a given situation and then acting in accordance with them.'

Given the nature of the public health-climate change relation, such an epistemology may become more and more necessary in our societies, particularly if we are to 1) understand the issues we are dealing with at a level where actions are both feasible and possible, and 2) if re-examine justice, as proposed by Fraser (2008), is to be enacted while we wait for global geo-politics to re-organise itself. The additional challenge brought to us by issues such as the climate change – public health relation, as also noted by



Beck (1992, 1999, 2007), in his work on a global risk society, is that such praxis oriented epistemological frames also have to engage with questions of uncertainty and risk. This challenges universities to engage with the meaning(s) of dealing with epistemologies of uncertainty or risk. *How do we teach students about the uncertainties of climate change and public health relations in a southern African context?* If knowledge of such issues is complex and uncertain, what are the consequences for pedagogical practices in universities, and what are the consequences for the type of research that is or can be done? Is research to be increasingly predictive, model and scenario oriented? If so, what does this suggest for university pedagogy and how we work with knowledge questions in our institutions of learning? And is community engagement to continue as primarily a *response to* current conditions, or can community engagement be oriented towards *predictive adaptation practices* that can be preventative of risk, or at the very least moderate or reduce risk of climate change related public health risks? What are the consequences for community engagement epistemologies and practices? These are the questions that this paper leaves with universities, and their Vice Chancellors, participating in the SARUA dialogue on climate change and development in southern Africa.

And finally, it is worth being reminded of the issues raised by Byass (2009) in his commentary on the status of climate change and public health research in Africa when he notes explicitly that 'cross disciplinary work (between climatology and health in this instance) is not common in Africa *and needs to be actively promoted*' (my emphasis, p.175). Byass (2009) argues further that there is a compelling case (located in projected impacts of climate change on public health in Africa) that such research should be promoted, upscaled and extended in African universities in much larger quantities than heretofore, (p.175). The neglect of the public health –climate change relation, in much of the climate change and public health research (respectively) in southern Africa, is also a serious issue that needs to be confronted, as noted by Dube and Chimbari in their meta-analysis. An added challenge is that the issue is complex and it requires in-depth engagement from within and across a range of disciplinary frameworks. It also requires a transformation in teaching epistemologies, away from transfer oriented epistemologies of certainty, to more complex teaching epistemologies that recognise uncertainty and risk. It also requires a re-orientation of community engagement, from models of re-active responsiveness to existing community need and interests, to more pro-active, preventative engagement with potential future risks and development of competences for adaptive management and risk prevention.

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CLIMATE CHANGE CURRICULUM: IN SEARCH OF CREATIVE DESIGN

1

ABSTRACT

A synthesis is provided of some of the trends and responses to integrating climate change concerns into the curriculum, and in the research and collaborative activities of universities - both on campus and in partnership with other stakeholders in society. In the first part of the paper, some of the key themes are probed that have emerged in the wider climate change discourse. The paper then examines two approaches for assessing the implications of climate change, adaptation in particular, for the higher education sector, with specific reference to its mission of teaching, research and collaboration in South Africa and for Africa. These approaches are probed using t 8g.L(ollakey issi c r)10(ef)13(er)10(changnakely a)83()65(de



anticipatory, reactive, private, and public and planned adaptation. Adaptation thus, can be for the shorter term – where efforts are coupled to disaster risk reduction; it can also be planned and aligned to longer-term risk reduction, for example, enhanced and more effective town, service and infrastructural planning; and coupled to ongoing development such as enhanced livelihoods; or it can be geared to future technical adaptations that may be required, such as technological investments – improved irrigation, crop production, links made to elements of a ‘green’ economy, etc.

In addition to these considerations, adaptation options, it is argued, will also be shaped and/or constrained by the development trajectory one ‘signs’ up to. Arguments against the fostering of the silo effect in activity areas, whereby attention is devoted to either adaptation and/or mitigation, are therefore being heard. The quest in some circles is for options that can bring co-benefits to both efforts, e.g., adaptation and mitigation. Here notions of a ‘green economy’ perspective are considered, with a focus on sustainable resource utilisation and resource flows – ecological goods and services (Spencer *et al.* 2010). Efforts to sustainably ensure food, water and energy security are, being propelled with a view to growing the economy without over stressing resources, for example, reducing resource consumption through improved management of resources and through renewable and alternative technologies. Many of these ideas have implications for curriculum development particularly for those disciplines concerned with politics, development, technology including engineering, etc.

In spite of the areas of mitigation, adaptation and co-benefits that can assist in shaping and driving curriculum development for climate change, there are also some broader paradigmatic issues and questions around climate change assessments, that are emerging very strongly in the studies of the science of climate change. Most recently the IAC (Inter Academy Council) reviewed the processes of the IPCC (Intergovernmental Panel on Climate Change) and noted, that issues of assigning certainty in climate change science required more careful consideration, amongst a range of other concerns (e.g., the use of gray literature etc.).

Several ‘human dimension themes’, including the role and influence of values-based assessments, strongly coupled to social sciences endeavours such as values, behaviour and human security, are increasingly feeding into climate assessments. Studies of the practice of doing ‘science’ is also increasing, including considerations of what knowledge is deemed appropriate and how such knowledge(s) intersect the climate change discourse, as also seen in much of Demeritt’s work that calls for more reflexive understandings of science as social practice (Demeritt 2006; O’ Brien 2010). Finding out about – the ‘what counts as scientific knowledge’ and ‘how it comes to count’ and more critically ‘who makes it count’ and ‘who is enabled to or mandated to speak truth to power’ are questions as important as being able to set the limits for acceptable climate risk (Collins 1983:267. cited in Demeritt 2006: 458). As Demeritt (2006) argues, notions of ‘sound science’ that rests on simplistic correspondence between the theory of truth and a crude understanding of empirical data leaves ‘... little room for any trace of the experimental contingency, expert interpretation, or active intervention, manipulation, and creation of scientific phenomena that science studies has shown to be central to scientific knowledge and practice’ (Demeritt 2006: 455).

In spite of the huge contributions to climate change science something ‘extra’ seems to be missing. As Jasano (2010) more recently notes, while assessments such as those of the IPCC have helped



to establish climate change as a global phenomenon, they have in the process possibly detached knowledge from meaning. Climate facts, she argues, also require acknowledgement of the 'embedded experience' that can be found in the communal, political, spatial and temporal. Thus, what is that 'extra' that appears to be missing and how much more do we need to know before we can act?

'What is included in the science/what is excluded or currently not fully considered? Whose knowledge is included?' These dimensions of reflecting on issues are all considerations that require consideration and that will have impacts on curriculum design. As noted by Peschl (2007), some of the 'deeper' issues include reflections of epistemology, ways of knowing and 'blind spots' in our current ways of knowing. Failure to include this deeper reflection, as a central frame of reference, may mean that one ends up 'fiddling' and 'tinkering' with curriculum for climate change that is not anchored by the type of science needed to assist in adapting to the complex reality often being observed in the world 'out there'.

Background to climate change education developments globally

Global examples and initiatives

Several institutions and groups are already very active in climate change research and teaching that is arguably part of wider sustainability science efforts. Innovative ways of educating for climate change can already be found in some institutions such as; several institutions in Australia – e.g. Australian National University, ANU (a Masters programme in climate change); Arizona State University – School of Sustainability; The Earth Institute, Columbia University (USA) has a Master of Science in Sustainability Management and a Masters in Climate and Society. Several activities are linked to themes of sustainability (<http://sustsci.aaas.org>). The Forum: Science and Innovation for Sustainable Development has also been developed for Africa, for example, UNEP; the Centre for Sustainability, Zurich (www.unep.org/training or www.sustainability.ethz.ch) and the Youth Encounter on Sustainability Course (YES) (Vogel 2009). In South Africa, at Stellenbosch University, several Masters Courses are presented on Sustainability including transdisciplinarity perspectives, for example, Sustainable Development Planning; Community Development Practice and Management.

Courses on offer in such curriculum choices include a wide array of disciplines - for example at ANU and elsewhere, efforts include themes that cover:

- Government, markets and global change;
- Climate change, vulnerability and adaptation;
- Sustainability and ecological economics;
- Ethics, issues and consequences of science and
- ANU, Study@ANU, 2011, see web for further details, and also COPERNICUS; ARIES and the International Journal for Higher Education.

Of interest here, and an important issue that is expanded on below, is the degree to which the breadth and depth of a theme such as sustainability is interrogated and offered in such curricula with respect to climate change adaptation as also noted in Sherren's (2008) assessment of universities in Australia and Canada. The notion of 'sustainability science', as used in *this* paper, is one that calls for a reflexive process to engage in science for enhanced understanding of the complexity of tightly coupled human-ecological 'systems'. Such science is currently informed from relevant, place-based assessments and is a science that usually includes inputs from various sources of knowledge such as,



science practitioner experience and traditional knowledge. Here blue-sky research is usually deemed as useful and usable scientific knowledge - also see Burns and Weaver's book on *Exploring Sustainability Science – a Southern African Perspective* for other chapters on such themes. What arguably still appears to be missing is that learning process that enables one to go beyond the cognitive or intellectual domain into the 'very centre of one's being' – the domain of wisdom (Peschl 2007). With this as background to broader sustainability issues the attention now turns to focus in on adaptation to climate change

Background to climate change education developments in Africa and South Africa

While there are a number of research and capacity building efforts on climate change adaptation such as; Climate Change Adaptation in Africa, CCAA; International Institute for Environment and Development, IIED; and various humanitarian organisations e.g. Oxfam and Save the Children – many of whom already collaborate with various institutions in Africa, in the southern African region and in South Africa, very few of these have been directed at really enhancing existing, 'in-house' institutional capacities to build sustained adaptation skills through research, training and outreach. START (Global Change System for Analysis, Research and Training, Washington), for example, has over the years funded and supported the development of post-graduates in Africa to obtain degrees in global environmental change, including climate change, and has usually chosen not to actively engage in shaping curricula in local institutions in the continent, preferring to play more of a facilitating function as indicated in the recent paper of START, presented at an educational meeting in Dar Es Salaam, Tanzania, June 2010 and the formation of the African Climate Research and Education network ACRE, www.start.org.

In the SADC region, a range of specific, existing climate change adaptation education activities also already exist, for example, in South Africa, activities including the DiMP/Disaster Mitigation



be required for teaching and curriculum design, including elements of economics, psychology, law etc. and how other domains of knowledge such as practitioner knowledge can be included. Integrating such modules into existing post-graduate courses, is critical, but remains as yet, an untapped avenue particularly when elevating such courses into the 'mainstream' of graduate study options (see Sherren's 2008 assessment where similar issues were raised for selected universities in Australia and Canada). Longer course offerings, several with the themes of climate and society are, however, being generated at the post-graduate level, but these currently tend to be wider in focus and scope than the single climate change focus on adaptation (e.g. The Sustainability Institute, Stellenbosch).

The opportunity to think creatively about climate change curriculum design is being stimulated through various national developments. Nationally, in South Africa, much attention is being geared towards capacity and skills development in global environmental change including climate change. The National Ten-Year Plan: Innovation Towards a Knowledge-based Economy (Department of Science and Technology, DST 2009a, 2009b), identifies global change with a focus on climate change as one of the 'Grand Challenges' that face the nation (Table 1). Several other developments, including those linked more broadly to sustainable development (DPLG, Department of Provincial and Local Government 2008), show that South Africa is taking the development of skills of the next generation to deal with multiple changes, very seriously. In spite of some good examples of progress, there are gaps in both the institutional design and 'creative thinking' around what these developments may mean for education in climate change.

The Global Change Research Plan of South Africa (Table 1) identifies four major cross-cutting knowledge challenges and 18 research themes (www.dst.gov.za). A systems science approach permeates the challenge areas with the efforts on adaptation and innovation also clearly pro led.

Table 1: Examples of key focal research themes of the Global Change Challenge (after DST 2009a, 2009b)

A Understanding a changing planet	B Reducing the Human Footprint	C Adapting the way we live	D Innovation for sustainability
1. Observation and monitoring	1. Waste minimisation methods and technologies	1. Preparing for rapid change and extreme events	1. Dynamics of transition at different scales – mechanisms of innovation and learning
2. Dynamics of the oceans around southern Africa	2. Conserving biodiversity and ecosystem services	2. Planning for sustainable urban development in a South African context	2. Resilience and capability
3. Dynamics of the complex internal earth systems	3. Institutional integration to manage ecosystems and ecosystem services	3. Water security for South Africa	3. Options for greening the developmental state
4. Linking the land, air and sea	4. Doing more with less	4. Food and fibre security for South Africa	4. Technological innovation for sustainable social-ecological systems
5. Improving model predictions at different scales			5. Social learning for sustainability, adaptation, innovation and resilience.



The DST has also recently given some thought to finding effective ways to mobilise the SARVA (South African Risk and Vulnerability Atlas) that is linked to the challenges by providing a user-based data platform for global change research. One of the aims of the Atlas is to enable users to 'map the way to a resilient future':

The current shifts and changes being noted locally and internationally (both economically and in climate change), thus provide exciting opportunities for the coupling of both research and teaching on some key issues that arise for Africa, not least climate change. Africa is one of the continents that are considered most vulnerable to climate change, based on exposure to projected changes, combined with a low adaptive capacity (IPCC 2007). Ensuring that policy-makers and practitioners in Africa are adequately equipped to understand some of the technical science needed to adapt, but also creating a space where their knowledge can also inform what is needed to be taught and learnt to ensure effective adaptation is also required. Climate change also provides opportunities for action in both research-driven and socially responsive institutions. As the next section argues, however, while the Grand Challenges present a useful typology of areas for action (teaching, research and advocacy), the deeper discussion arguably required for real sustainable curriculum design is that which is more difficult, frustrating and time consuming but arguably is the most rewarding discussion to be having (Peschl 2007). Such discussion involves thinking that goes beyond current individual, disciplinary boundaries and includes considerations of modes of knowledge production and deeper interrogations of such knowledge.

Returning to the 'centre' – ideas on a more sustainable, 'deep' curriculum design

As briefly shown above, there is a huge array and a variety of activities that are beginning to shape and cluster themselves around the issue of climate change in the world, the wider SADC region and in South Africa. For some, the temptation to merely 'clip together' course offerings aligned to those as outlined in the columns A-D in Table 1 may be the easiest option. Such action would arguably make the life of an academic less stressful and would also free up valuable time for the 'publish and perish' publication derby that increasingly seems to consume so much academic time (see for example the Mail and Guardian article, September 24 - 30, 2010).⁵ It is, however, the reflection on some of the 'deeper' issues that emerge around Table 1, and the wider climate change arena that can really excite, and revive academic and students' passions, particularly when one begins to think creatively and more deeply about curriculum development.

Some of the following themes, each of which is a research arena on their own and requiring much deeper reflection than this paper permits, can be used as lenses through which one can begin to creatively explore and engage around the curriculum:

- ┆ Sustainability science
- ┆ Resilience thinking
- ┆ Transdisciplinarity
- ┆ Integral theory and education
- ┆ Leadership development
- ┆ Co-production of knowledge
- ┆ Communities of practice.

⁵ Do University Rankings Matter? Getting Ahead, Mail and Guardian, 24-30 September, 2010.



It is indeed difficult to imagine having a really useful academic debate and discussion about curriculum development and climate change without some deeper reflection on such themes and those linked to such issues raised earlier in the paper (e.g. references to the work by Demeritt and others). Space does not permit a full exposition of all these themes. Rather some elements from each, that resonate with possible reference to climate change adaptation are highlighted and will be teased out for further discussion here.

As indicated at the outset of this paper, *sustainability science*⁶, for example, recognises complexity as a phenomenon that exists as a result of the interaction of various systems components. Some of the key ingredients for 'sustainability thinking' include flexibility in design, co-developing and deploying knowledge that is appropriate to context (Cundill *et al.* 2005). In a similar way, *resilience theory* challenges the use of only top-down, command and control ways of responding to environmental concerns and tries to advocate for greater flexibility in the design of complex socio-ecological systems that can remain robust and persist after shocks and stresses have been experienced (Burns & Weaver 2008).

Van Breda (2008) and Nowotny *et al.* (2003), suggests that *transdisciplinarity* is also critical to reflect on when considering the academic enterprise. *Transdisciplinarity* requires one to think about the interaction between the disciplines, both 'across' the different disciplines but critically also 'beyond' the disciplines (Nicolescu 2002) and with various foci on organising around provocative questions such as: Where is the place of people in our knowledge? Nowotny (n. d.). As Nowotny (n. d.) further notes; we need to be asking probing questions such as what are the implications of our knowledge constructions, and the implications of formulating problems in particular ways that then feed into the curriculum? Such probing approaches may well mean surrendering personal and collective biases that can congeal around disciplines, resulting in endless debates about the 'sanctity' of certain revered domains of knowledge and where they are located in academic institutions - 'Knowledge is transgressive and transdisciplinarity and does not respect institutional boundaries'. There are therefore potentially acute challenges to using such approaches, particularly in more inflexible institutions of learning.

One arena that also merits further discussion, and that may be helpful in fostering deeper debates on curriculum design for climate change, is that which is offered in *integral theory approaches* (Wilber 2000, 2001). Using four quadrants, known individually as subjective, inter-subjective, objective and inter-objective (also referred to as 'I', 'We', 'It', and 'Its' or the terrains of 'experience', 'behaviour', 'culture' and 'systems') Integral Theory provides a way of making sense of diverse perspectives (Inglis 2009), (Figures. 1 & 2). Some are beginning to explore the types of education (here interpreted in its wider sense) that may be required for an integrated understanding of what it may take to, adapt to climate change. The field is rich in approaches that can be drawn in to better inform curriculum thinking (see for example the *Journal of Integral Theory and Practice* and the *Integral Leadership Review* and Esbjorn-Hagens *et al.* 2010's edited book entitled *Integral Education – New Directions for Higher Learning*). Here some examples of reflections, from Esbjorn-Hagen's (2010) recent work, are explored. The ontological status of climate change and notions of ontological pluralism are investigated using integral theory (Figures. 1 & 2). Such an approach clearly provides useful entry points for deeper debates about what may be required, and what may be of relevance for a climate change adaptation curriculum.

6 Sustainability science is not the same as sustainable development. For a useful introduction see chapters from Burns and Weaver, 2008.



In his thought-provoking paper Esbjorn-Hagens (2010), presents a sample of methods, building from an integral perspective, of what may be considered for addressing climate change (Figures. 1 & 2). Such framings begin to call for a much deeper reflection on what may begin to be considered for effective discussion on curriculum design. He also provides reasons why it is advantageous to both philosophically and pragmatically relate climate change as an ontological plurality for example, including, empowering effective leadership to enable people to work with many variables and scales associated with climate change; leadership also needs to be able to talk with and involve many stakeholders; we need to be able to engage and include various faith dimensions and cultural constructions of nature.

Figure 1: Twenty-five major dimensions of climate change (Esbjorn-Hagens 2010: 5)



Figure 2: Sample causes of climate change (Esbjorn-Hagens 2010: 8)





O'Brien (2009; 2010) and O'Brien and Hochachka (2010) have more recently, also begun to seriously consider issues of climate change adaptation using integral approaches. They argue that by framing climate change from an objective and systems perspective one tends to down play the importance of subjective, 'interior dimensions' of climate change, often also essential for adaptation. Focusing solely on adaptation technologies and systemic changes, that may be required to adapt, can mean that the need to design shared interventions that resonate *with* people in ways that are understood, may be lost. They argue that in spite of the incredible contributions made to climate change by positivist disciplines (e.g. systems understanding) it is now also time for the social sciences, through integrating approaches, to make their contributions in meaningful and synergistic ways (O'Brien & Hochachka 2010).

To conclude this section of the paper attention finally turns to, what many adopting some of the approaches outlined above include in the tools and methods required to begin to shape dialogues to inform discussions on curriculum design. These are hinged to notions of open dialogue, sharing and learning – here the work of Scharmer and the Theory 'U' (theory of U) process is being tried (www.presencing.com), particularly in *climate leadership* contexts (e.g. InWent and Wits University project), and various other *co-production modes of knowledge*. The focus in most of these cases is on; really listening to others, sharing perceptions, suspending judgments and views on a problem and then co-designing prototypes for climate change – adaptation and/or mitigation (Peschl 2007). Linked to such approaches is the practice of including perceptions of the 'other', including those often not central to scientific, expert-based scientific knowledge using participatory approaches and communities of practice. These efforts, once again, raise the issue of what knowledge is necessary to adapt to climate change (e.g. local and traditional knowledge) and how such knowledge is shared and negotiated? (see Nowotny and others such as Jasano on such themes).

Modes of knowledge production thus also require interrogation for example how the knowledge is being produced – Mode 1 and Mode 2 knowledge production (Nowotny; Scott & Gibbons 2003). Much has been written on these areas of investigation including, but not limited to, climate change (Lemos & Morehouse 2005; Vogel *et al.* 2007 – climate change; see also Jansen in Kraak 2000 – engineering). Science allied to the environmental disciplines including agriculture, health and engineering have in some institutions and cases developed and expanded over the past few decades to include that comprised of both strongly normative, positivist and often 'reductionist' science as well as that, which draws on including perspectives from various users (e.g. farmer-rust type programmes). In most cases associated with such knowledge creation; dialogues are essential with a number of actors from



adaptation to climate change and adaptation are varied (the following are extracts from a previous submission for START on this theme, START 2009). In that paper I argued for three considerations for climate change adaptation science and curriculum development. Firstly there is the need to frame such skills training at the very highest levels as a critical endeavour and area of scholarship (both without and within the University context). This is essential so that sufficient budget flows for such developments. In Australia, the Department of the Environment and Water Resources of the Australian Greenhouse Office, has recently investigated some of the skills required for professionals to work in the field of adaptation with one of the aims being to integrate climate change into education and training for key professionals, including engineering, architecture, planners, reserve managers and local government (Dept. of the Environment and Water Resources, Australian Greenhouse Office 2007). To this end the Department commissioned the Australian Research Institute in Education for Sustainability (ARIES) to investigate the needs of professionals in this field including those requirements for architects, landscape architects, planners and engineers. The need for recognition and accreditation in the field of adaptation was a key outcome of this work. As such there is now a recognition that training and skills provisioning needs to be imbedded into current training modules etc. with a strong focus on linking or thinking seriously about current development training and how this can be aligned to adaptation work. The challenge, if one takes a deep approach, is deciding how accreditation is agreed upon, what criteria are used and who does the accrediting? Thus one key requirement is the *official acknowledgement and acceptance* that adaptation training and skills and research is required so that *such training can become endorsed and receive the recognition* required to make this a serious area of training and research in various training institutions.

Secondly, the different areas of expertise and enterprise needed vary with the topic under investigation. One may, for example, require specific training on health, planning and development, water resource management, disaster risk reduction depending on one's area of interest and expertise. This training will also vary across levels and 'beyond' current disciplines and will thus include broad meta-level thinking and training on climate change and adaptation both horizontally (e.g. broad theoretical training and principals – horizontal) and vertically (e.g. basic training in the various disciplines e.g. health, development planning etc. – vertical), and training that is required at a very specific skills level. Increasingly, for example, the additional roles of effective and reliable communication in climate change is becoming a key issue, but this cannot merely be the adding-on of an extra module in communication studies at the end of a course, or the addition of a small 'extra' (usually termed outreach) at the end of a research project.

Finally, there is a growing recognition that any training or set of activities for sustained change requires an understanding of *how people learn and sustain changes in behaviour*. The inclusion of disciplines usually located outside the traditional domain of climate science is thus needed e.g. psychology and science education. There is also the need for considering various modes of learning and there are thus a growing number of efforts to focus activities on 'learning by doing' activities. Some useful inputs in this regard have recently been made by Gujt (2007) and Taylor *et al.* (2006), who for example, outline the following key areas requiring attention: understanding social change; frameworks, methods and concepts of social change; the critical roles of relationships in change including the role of donors in shaping change; the role of scales, etc. Of interest to adaptation work was the observation that usually in practice, creating an appropriate assessment and learning process, requires mixing and matching




and then adapting a combination of various frameworks, concepts and methods (Gujt, 2007: 5). In a similar vein, Fazey *et al.* (2007) also identifies four main requirements for the resilience to withstand changes that speak directly to flexibility in behaviour as well as acknowledging the inclusion of disciplines in the science of education, in cognitive and social psychology, for a rich dialogue on and for climate change curriculum design. One can imagine, for example, future climate change meetings where climate modellers are challenged with credible narratives and scenarios that have been derived from local and traditional community observations and community practice (with little 'hard' science input). Ways are then thought out to possibly enhance and feed these into the co-design of current, climate-based assessments and models.

CONCLUSIONS

Adaptation to complex interacting stresses, for example, climate variability, climate change, HIV/AIDS, environmental degradation, etc. will require a new type of university graduate and thinker – one who can think about, and make decisions that are flexible and can keep pace with the changing environment in which we live. A key emphasis may be on building effective decision-making capability in, and for, complex risk environments (e.g. climate change) at various levels and scales (e.g. regional, national, local, personal). The repeated calls for flexible approaches, where one can mix and match training often, however, is constrained by the rigidity of set curricula and other bureaucratic requirements of training institutions.

As is evident from this paper, curriculum design for climate change adaptation is NOT a simple undertaking involving the mere tinkering with some silos of knowledge. Training the next generation of students will arguably NOT only require a re-alignment of the curriculum (essentially pouring new wine into old bottles) e.g. marrying a 'bit of biophysical science' with a 'bit of social science' and/or an expanded systems science perspective. Training the next generation of scholars, to be able to think critically around climate change and to implement adaptation action, will require carefully rethinking paradigms and ways in which curricula are framed so as to create a cohort of flexible, interactive thinkers and doers. These curricula, moreover, will not only require knowledge and skills usually vested in and provided by a university, but will require approaches in training and research that are mindful and acutely aware of the needs and perspectives of society informing their understandings of climate change and the wider environmental context in which decision making occurs. Approaches must include ways to *embed* user needs and expectations in the curriculum such as drawing on notions of communities of practice.

It is not only imperative to think critically about the tertiary education curricula to produce graduates who are prepared to deal with global change, it is also necessary to consider existing professionals (adult-based education and life-long learning approaches). Such professionals have already graduated from tertiary education, and thus will not benefit from this curriculum development. They currently occupy decision-making positions in both the public and in the private sector, often at very senior levels, that require them to have levels of understanding to implement effective adaptation and ensure resilience in the face of climate change. Curriculum development will, in some cases, therefore need to be based on needs-based assessments and co-production and co-negotiation of knowledge with key personnel in the relevant fields who can identify skills and knowledge shortages. Capacity building concerns in local settings, e.g. municipalities in South Africa, will thus have to be collaboratively worked



out and cannot be an end of the line, pipe-line insertion of knowledge into the process. Since the tertiary education graduates of tomorrow will likely enter such decision-making positions in the public and private sectors, these needs assessments may well feed back into, and inform the tertiary curriculum development and may also be tied to corporate donor support.

The easy option, as this paper has cautioned against, is to only tinker with the curriculum, on a shallow level and create placeholders and silos with a range of options that essentially glue existing disciplines together. The more difficult, but arguably more rewarding option, as briefly shown in this paper, is to seek and provide spaces for more flexible curriculum design that goes to the production of graduates with skills and with the ability to think critically about the challenges of our time. What is needed is creating the 'safe' spaces for such dialogues to begin to critically consider some of the issues outlined here e.g. the role of multiple validity claims, climate change adaptation ontologism and theory and the need for some critical realism. Students with whom I have had the privilege of sharing such approaches have appreciated such interactions and have become energised, engaged and excited ... perhaps so too ... we can breathe some much needed 'oomph' into some valuable but tired academics and university courses!

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A FRAMEWORK FOR ACTION ON CLIMATE CHANGE AND ADAPTATION IN HIGHER EDUCATION IN SADC

INTRODUCTION

In October 2010, twenty-four Vice-Chancellors, representing universities from ten countries in the SADC region, gathered at the University of Mauritius to discuss the challenges of climate change and adaptation for universities in the region and for the communities in which they are based. This Leadership Dialogue gave space to university leaders to consider both the risks and opportunities of climate change for their institutions and broader communities, as well as the options for dealing with its effects. A key focus of the conference was the extent to which climate change and adaptation concerns are integrated into teaching and learning, research and collaboration and community engagement. This framework for action was a planned result of the dialogue. It pulls together the outcomes of the conference deliberations as a way of focusing university leaders and other stakeholders on a clear set of priorities for future action and engagement.

Internationally there have been increasing calls for universities to play a more active role in understanding climate change impacts, and for developing the capacity to adapt to climate variability. Available knowledge points to the fact that sub-Saharan Africa is one of the most vulnerable regions to climate change, yet its ability to influence global policy development, resource mobilisation and allocation and capacity development is limited.

Specialist inputs were prepared by senior scientists and academics from SADC universities, who are currently working at the cutting edge of climate change and adaptation in a variety of knowledge fields. The arguments of the panellists provided a stimulus for powerful discussions about the role of universities in addressing climate change and adaptation and the measures required to address these



issues. Working in commissions, the Vice-Chancellors identified clear priorities for building the required capacity within universities to deal with the challenges of climate change and adaptation.

CLIMATE CHANGE, ADAPTATION, REGIONAL DEVELOPMENT AND UNIVERSITIES

Southern Africa is particularly vulnerable to climate variability because of poverty, poor social and economic infrastructure, and the over-dependence on climate-sensitive natural resources. Extreme events associated with climate change such as droughts and floods have devastating effects in the region and include loss of life, food shortages, famine, malnutrition, and damage to an already-fragile infrastructure. Climate change therefore exacerbates the burden of poverty, underdevelopment and marginalisation in the region. Climate change must be seen centrally as a development issue, as it fundamentally influences living standards, social well-being, poverty and social exclusion, survival and livelihoods. The links to long-term development priorities and planning must therefore be consciously recognised and addressed in the region.

The role of higher education institutions in filling knowledge gaps for adaptive capacity cannot be contested. The relationship between climate variability, adaptation and development is an under-researched phenomenon, particularly in the SADC region. It is also unclear to what extent new knowledge is being integrated into education to build capacity for adaptation, analysis and for developing solutions. The capacity development needs are on several fronts:

- to create awareness and to sensitise communities, governments and the private sector about the risks of climate variability for development prospects in the region,
- to significantly improve research and knowledge generation on climate change, adaptation measures and the associated costs and benefits,
- to better disseminate information and knowledge amongst all stakeholders,
- to strengthen regional scientific policy development and implementation as well as institutional capacity and
- to improve regional capacity for active participation in international policy networks.

Universities can make a significant contribution to building the resilience of the region to increasing climate variability through teaching and research.

Higher education institutions are centres of teaching and learning, sites of knowledge production, protagonists in local communities, employers, and national assets. This places them in an important position to create awareness of the risks and opportunities of climate change, and to generate the required knowledge to produce innovations to respond to adaptation needs, and to prepare leaders and members of society to live as citizens of a world of increasing complexity. Universities must prepare students and staff with a kind of holistic thinking and associated behaviour that will challenge existing ontological, epistemological and pedagogical approaches currently framing traditional teaching and learning in universities.

Universities can also become important nodes of collaboration networks with communities, governments and the private sector. As employers, universities have the potential to influence large numbers of people. These roles will put tremendous pressure on university systems in SADC, already affected by a number of challenges. However, they do present an enormous opportunity to attract resources in support of ongoing efforts to revitalise universities, renew the academy and to replenish the store of scientists and academics.



Universities will have to confront a broad range of challenges in the areas of learning and teaching, research and knowledge production, and institutional leadership and management, in order to fulfil these multiple roles in developing adaptive capacities, guided by principles and a focused set of priorities.

AIMS AND OBJECTIVES

The need to build adaptation capacity as a response to climate variability is a recent phenomenon. Internationally, universities have played a leading role in this process. In response to the complex challenge of adaptation and development, small pockets of excellence (relative to the needs in the region) are emerging as examples of how universities in SADC are re-orienting curricula; experimenting with innovative pedagogical practices; undertaking research that employs multi-, trans- and interdisciplinary methodologies and analytical frameworks; and building collaborative networks that include a broader range of partners and stakeholders.

These efforts need to be scaled up and institutionalised across universities in the region within the context of revitalising higher education institutions and renewing the academy. The aim of this framework for action is to set the agenda for strengthening the capacity of the higher education sector in the region to address climate variability and adaptation in the exercise of its core missions. Several specific objectives will be pursued in seeking to achieve this aim:

- to generate and share information and knowledge on climate variability, adaptation and development
- to build the capacity of individuals, institutions and communities to adapt to climate variability
- to raise awareness and to sensitise communities and stakeholders in the formulation and implementation of public policy aimed at building adaptation capacity in the region.

This will involve innovations in teaching and learning, and in knowledge production and institutional management.

PRINCIPLES

In a diverse region such as SADC, in which countries and higher education institutions will approach the issue of building adaptive capacity from different starting points, a set of principles are important as a way of ensuring a shared frame of reference, yet at the same time allowing the flexibility necessary to accommodate the differentiated needs of different countries. These principles serve as a guide that will have to be articulated in a way that speaks to the specific country contexts. The following principles have been incorporated into this framework of action:

Institutional capacity building

Interventions need to have, as a design feature and explicit outcome, the revitalisation and renewal of higher education institutions. Resources mobilised and deployed in the higher education sector for the purposes of building adaptive capacity should have as a result, the development of a new generation of scientists and academics, and the strengthening of higher education institutions.

Integration and Integral

Adaptation should be approached as an integral part of development in southern Africa and not as an environmental issue only. Moreover, a holistic perspective that integrates, where feasible, multiple paradigms, perspectives, disciplines, methods and practices.

Collaborative

Collaborative action recognises that there are many actors which are interdependent, each bringing with them resources, expertise and insights for developing innovative solutions to the challenges of climate variability and adaptation. This is a source of strength.

INNOVATION AND CAPCITY BUILDING IN TEACHING AND LEARNING

Studying and learning about climate change, adaptation and development defies traditional disciplinary boundaries, knowledge structures, traditions and practices. However, various innovations are emerging in universities across the region. Initiatives are underway to determine what kind of changes are being introduced in programmes such as work undertaken by START, the global change System for Analysis, Research and Training non-governmental research organisation, and the African Climate Research and Education Network (ACRE). There are examples of staff capacity-building taking place in universities in the region such as the work done through the Mainstreaming and Sustainability in African Universities Partnership (MESA). There are examples of experimentation with new and specialised programmes. Various possibilities are being explored, which include: the introduction of non-credit bearing courses that involve communities, other stakeholders and students; the introduction of a generic module for all; and working towards the design and implementation of a joint degree at the regional level.

These initiatives face many barriers. Climate science involves proactive engagement with uncertainty, for which reductionist paradigms and theories offer little assistance. Climate variability and adaptation is a complex issue, given the dynamics flowing from the interaction of various system components. Inter-, multi- and transdisciplinary approaches, to curriculum design and development is required and will involve working across and beyond disciplines. Moreover, context and place is widely acknowledged as important, since climate impacts vary from place to place. Taking this uncertainty and complexity into consideration, there are concerns that the curriculum is already too crowded and that there is very little time to update courses. Perceptions of academic staff that climate change and adaptation is irrelevant as well as the lack of staff expertise in this field, together with limited institutional drive and commitment further limit the scope for curriculum innovation. Several priorities have been identified to address these constraints and to promote re-curriculation.

Priorities and actions

The development of new and specialised programmes that draw on environmental science, geography, the humanities and other relevant disciplines, is an immediate priority for strengthening and encouraging innovation in teaching and learning. This includes the development of short courses, aimed at university students and other stakeholders, introducing the concepts of climate change, adaptation and development. It further includes a review of undergraduate programmes to determine the extent to which these issues can be incorporated and mainstreamed into existing curricula, as well



as in the development of specialised programmes for postgraduates. The development of a generic model at a regional level should also receive attention. Specific interventions should include:

- Internal curriculum reviews to identify opportunities for re-circulation and the development of new programmes at undergraduate, postgraduate and professional development levels.
- Development of staff capacity focusing both on short-term workshop-based training activities, and longer term in-depth courses aimed at introducing academic staff to the key concepts and issues, and its implications for curriculum development and delivery.
- Promotion of staff and student exchange and the sharing of learning and teaching resources related to climate change, adaptation and development.

INNOVATIONS AND CAPACITY BUILDING IN RESEARCH AND KNOWLEDGE PRODUCTION

There is a limited availability of published work on climate change, adaptation and development in southern Africa undertaken by scientists, researchers and academics from this region. The research conducted is mainly carried out through collaboration between scientists in the region and from developed regions. The inferences drawn, perspectives developed, and solutions proposed are based on scanty data because there is limited past and ongoing work. It is only recently that climate change, adaptation and development has emerged as a research focus, often driven by the interests of donors. Fledgling research networks are connecting scientists and academics around monitoring climate change and its impacts; undertaking baseline data for early detection purposes; vulnerability assessments; and broadening recognised forms of knowledge including traditional and community generated knowledge.

Priorities and actions

The connections between climate variability, adaptation and development remain tentative. Sustaining these research processes and outcomes and scaling them to a level that is significant to the region will require investment in such networks and in the institutions where they are hosted. Using climate change research as a platform for developing the skills of young researchers with the aim of increasing the pool of researchers in this field is an opportunity that should not be missed. Interventions in support of the following are proposed:

- Increasing the opportunities for multi and transdisciplinary research that draw on the insights and methods from a range of disciplines.
- Strengthening of climate change, adaptation and development research capacity within universities.
- Enhancing the development of climate change research networks.
- Increasing multi and transdisciplinary research.
- Improving research communication in order to strengthen the ties between the scientific community and society.

INSTITUTIONAL INNOVATION AND CAPACITY BUILDING

Higher education institutions play an important role in several respects. Institutions have the function of information gathering and dissemination, resource mobilisation and dissemination, capacity building and skills development and collaboration with other institutions. All of these functions are important for; creating incentives to act, for framing the issues and how they are approached, and for changing institutional cultures. Given the multi-disciplinary nature of the climate change,



adaptation and development, institutional leadership and change management is important for supporting collaboration across disciplines within the institution. The mechanisms and incentives for mainstreaming climate change are in the hands of university administrators. In addition, there is a need for internally enabling structures that bring together different academics, students, and other stakeholders in dynamic formations. The idea of climate change observatories within universities has been mooted as one such innovation.

Priorities and actions

The key priority, from an institutional perspective, is to create the conditions and to actively support the mainstreaming of climate change, adaptation and development in institutions in the region. This will involve action on several fronts:

- Identifying and supporting champions within the university hierarchy to lead the process of mainstreaming climate change, adaptation and development in the institutions
- Introducing university-wide seminars and programmes to create awareness on campuses
- Undertaking assessments of the adaptation measures required on campuses
- Establishing Vice Chancellor mandated structures to initiate discussions and to strengthen communication
- Establishing specific mechanisms to support collaboration among institutions and scientists

IMMEDIATE NEXT STEPS

Leadership and resources are required to activate the identified priorities and interventions. Two specific mechanisms have been proposed on account of each:

Deputy Vice-Chancellor Working Group

The establishment of a climate change, adaptation and development working group, comprising Deputy Vice Chancellors (DVCs) from universities in the region, convened by SARUA and led by the University of the Cape Town, was proposed as an institutional mechanism to set the agenda for integrating climate change concerns into the higher education sector.

Adaptation and Development Capacity Building Scheme

The establishment of a regional capacity building scheme is required to mobilise and leverage resources for investment in curriculum development, and for knowledge production and institutional capacity building. SARUA was tasked to approach possible funders and partners for this purpose, and to work out the technical modalities for its success.

