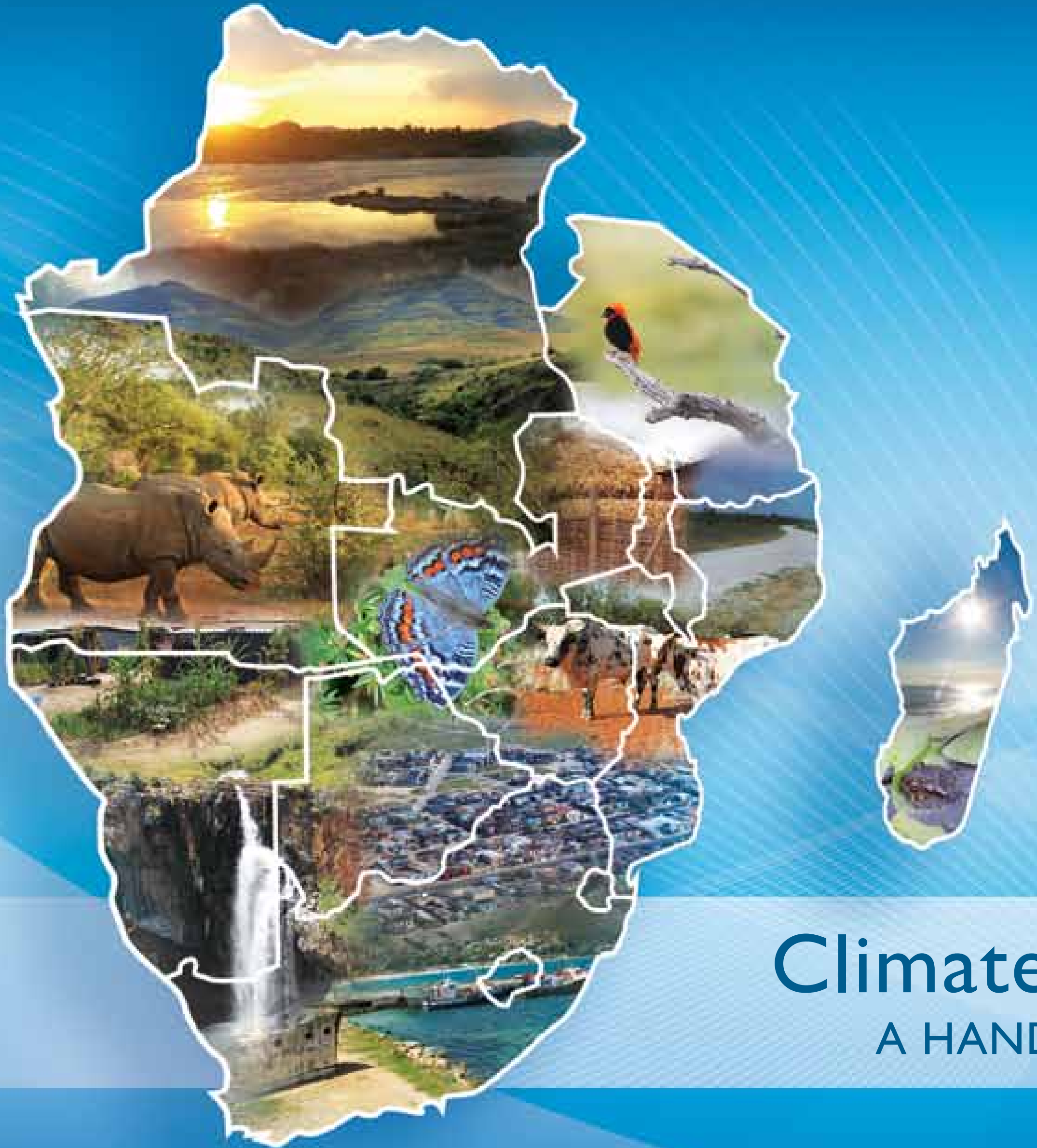

Climate Risk and Vulnerability

A HANDBOOK FOR SOUTHERN AFRICA

Editor: Claire Davis

Foreword

At the time of writing, the 17th Conference of the Parties (COP17) to the United Nations Framework Convention on Climate Change (UNFCCC) approaches. Unprecedented global and regional attention is currently being directed towards climate variability and change. Whatever the outcome of the international negotiations, southern Africa will largely have to take upon itself the responsibility of understanding and responding to climate change. Many promising initiatives in this regard have, indeed, long been underway on the subcontinent.

This handbook represents a contribution to efforts in southern Africa to better understand climate variability and change, likely impacts and possible responses. In this way, scientists and practitioners on the subcontinent continue the journey of making our science usable.

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Introduction

By Claire Davis

The Climate Risk and Vulnerability Handbook for Southern Africa was conceived and designed with the intent to provide decision-makers with up to date information, appropriate for country planning, on the impacts and risks of climate change and variability. It presents a selection of information, translated to communicate climate change processes, key existing and emerging trends, impacts and the possible measures that could be taken to reduce these impacts.

Southern Africa is likely to be significantly impacted by future climate change with the latest climate change projections for the region indicating that both temperature and evapotranspiration are likely to increase into the 21st century. Climate change is likely to alter the magnitude, timing, and distribution of storms that produce flood events as well as the frequency and intensity of drought events (DEAT, 2000; Fauchereau et al., 2003). Southern Africa has existing critical vulnerabilities that may exacerbate the effects of such climatic change in most sectors due to the direct dependence on the natural environment for livelihood support, amongst other factors. Understanding these climatic changes and their possible impacts on society is thus essential in critical sectors in southern Africa in order to improve strategic adaptation response.

Until fairly recently, work investigating the impacts of and responses to climate change tended to be more prolific in the northern hemisphere. In Africa there are fewer scientists per capita, and academia struggles to retain talent since the public sector is under-resourced and currently lacks the level of prestige of its northern counterparts. As such, climate change information has not been easily accessible in southern Africa, and has tended to be provided in a minimally usable format, at spatial scales challenging for local-level planning, with little translation, capacity building, and follow-up with stakeholders involved in decision-making. That said, increased public awareness of the issue, and the concomitant growth in political commitment to mitigation and adaptation, have made the need for accurate communication more pressing. In many countries, decision-makers are seeking information from a wide range of disciplines on the potential impacts of climate change on environmental and socio-economic systems. Within the Southern African Development Community (SADC), a number of calls have been made for improved planning under climate change, and for access to climate information as well as mitigation/air quality information, not least by the SADC Secretariat themselves. At the March 2011 meeting of the SADC Programme on Science and Technology Support for Climate Change Response, for example, SADC member states indicated increased access to climate change information (projections and updated impact studies) as a priority in undertaking response and adaptation as part of in-country gap analysis around climate change.

In South Africa, the Department of Science and Technology (DST) has funded the creation of an atlas of local risk and vulnerability within a global change context. The objective of the South African Risk and Vulnerability Atlas (SARVA) (http://www.rvatlas.org) is to equip decision-makers in the public and private sectors with information on the impacts and risks associated with global environmental change; bridging the gap between science and policy by improving access to information. A hardcopy version of the Atlas was launched in 2010 and distributed to each of the 262 local municipalities in South Africa. The Atlas (Archer et al., 2010) provides national, provincial, and municipal-level information related to aspects such as water (surface and ground), forests, biodiversity, human health, and agriculture as well as social, economic and institutional dimensions. In addition to the hardcopy volume, SARVA directly supports access to and visualisation of data and global change information through the development of a geospatial database (http://rava.qsens.net).

South African Risk and Vulnerability Atlas Electronic Spatial Portal

The electronic spatial database involves South African researchers and a range of South African institutions from various disciplines to continuously update the content with new research and data. The web-based electronic database (http://www.rvatlas.org) provides access to a large collection of scientific data and knowledge in and about South Africa. The portal will in the future include some regional data for southern Africa. The portal is organised according to themes; including Socioeconomic, Settlements, Weather and Climate, Groundwater, Surface Water, Forestry, Biodiversity, Air Quality/Emissions. Some examples of information to be found within these themes include projections of climate change at local scales, by different models, for the 21st century; assessments of the risk of coastal flooding due to sea level rise; probabilities of drought and water shortages; population densities; economic activity and poverty levels. It can be searched in many ways, and delved into at many levels of simplicity or complexity. The system is free and 'open access'. The electronic spatial portal (http://www.rvatlas.org) allows users to plot maps linking various aspects of climate change to different sectors, thus highlighting areas of particular risk and/or vulnerability. Registered users can also contribute their own content, and control the visibility and publication life cycle of their content.

In broad terms, the portal is designed to serve a stakeholder community as a resource for the referencing, description, discovery, management, and optional archiving of relevant data sets and information objects. The Atlas data will be updated on an on-going basis.


SADC Climate Risk Capacity Building

The rate, spatial scale, and magnitude of human-induced change are unprecedented. There is unequivocal evidence that human activities are affecting the Earth's system at the global scale. Increasingly strong evidence suggests that the functioning of this system is changing in response. Find out more

Supporting website (http://www.rvatlas.org/sadc)

A USAID-funded project and an extension of the South African Risk and Vulnerability Atlas into the southern African region is currently being led by the Climate Studies, Modelling and Environmental Health Research Group at the Council for Scientific and Industrial Research (CSIR) in South Africa. Acknowledging that climate and other environmental changes may impact many sectors of southern African society, this project aims to build capacity among the Southern African Development Community (SADC) member states in understanding information on climate change impact and risk in the context of early-warning strategies and planning. The SADC Atlas is intended to act in a complementary manner to other initiatives and will operate through existing SADC mechanisms, for example the Southern African Regional Climate Outlook Forum (SARCOF), as well as with individual country stakeholders to engage in capacity building and technical backstopping. Plans for capacity building will support the use of the climate-related information presented in this volume and will ideally contribute to supporting southern Africa's pathway to a resilient and sustainable future.

The scope and purpose of the handbook

The spatial context for this handbook is southern Africa, a region broadly considered to include 15 members of SADC: Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. This handbook is aimed at decision-makers within the SADC member states who are operating at either the local, national or regional scale. It will also serve as a reference guide to those currently engaged in impacts and adaptation research.

The Climate Risk and Vulnerability Handbook for Southern Africa was conceived and designed with the intent to provide decision-makers with up to date information, appropriate for country planning, on the impact and risk of climate change and variability. It is structured according to four key questions: "has the climate in the region changed over the last 100 years relative to the current climate state?", "how can we expect the climate to change at the inter-annual scale and at the multi-decadal scale?", "what are the likely impacts of such climatic changes in key sectors?", and "how should we deal with these adverse impacts?".

Climate change is likely to alter the magnitude, timing, and distribution of storms that produce flood events as well as the frequency and intensity of drought events. [Picture: Linda Davis]

Background information on the process of global and regional climate change as well as the associated terminology and definitions is provided for decision-makers new to the climate science arena. This handbook is designed to be easily accessible, with more of an emphasis on illustrations, maps, and information boxes in order to ensure that the key messages are translated and communicated effectively. Case studies drawn from a wide range of activities and organisations operative in the region are used within Chapters 1, 4 and 5 to identify key impacts and to illustrate how these risks are successfully being managed in southern Africa. The handbook presents a selection of case studies from SADC member states. Not all countries are represented, but will hopefully be included in a second edition. Value-added resources, such as more maps and illustrations not selected for this publication as well as any new case studies will be made available through the website (http://www.rvatlas.org/sadc).

Future climate information is separated into shorter-term seasonal forecasts (Chapter 2), and longer-term climate change projections or scenarios (Chapter 3). Seasonal climate forecasting focuses on projections in the coming year season. Decadal forecasts (medium term) of climate for the coming 10 years are not yet well developed over southern Africa and have thus not been included in this volume. High-resolution projections of regional climate change obtained from dynamical and statistical downscaling techniques are presented and discussed in this volume. These projections are focused on the 2036-2065 timescale and describe the expected future characteristics of the climate relative to the present-day climate (1961-1990). A multi-model approach has been taken in this handbook when presenting future climate change scenarios; an ensemble of models is presented rather than a single model outcome. While this does not provide discrete answers, it provides a valuable perspective on the range of potential climate futures, which are equally plausible.

Chapter 1: Southern Africa's climate: Current state and recent historical changes

By Claire Davis and Alec Joubert

Over southern Africa, there is good evidence to suggest that temperatures have been increasing over the last century. No clear evidence exists for a change in mean annual rainfall, which demonstrates year-to-year variability.

1.1. Introduction

Southern Africa[1] is a predominantly semi-arid region with high rainfall variability, characterised by frequent droughts and floods. It is also widely recognised as one of the most vulnerable regions to climate change because of low levels of adaptive capacity[2] (particularly among rural communities), combined with a high dependence on rain-fed agriculture (IPCC, 2007).

As stated earlier, the purpose of this handbook is to provide decision-makers with up-to-date information, appropriate for country planning, on the impact and risks of climate change in the southern Africa region. In this chapter, we provide an introduction to the concepts of climate, climate variability, and climate change. We also describe the current climate and variability of the southern Africa region and examine evidence for recent changes in climate, both globally and for the region, in order to provide a context for the projections of future regional climate change provided in Chapter 3. All of this information can then be integrated as we assess the impacts and risks of climate change and attempt to respond to these changes by both mitigating and adapting to climate change in the region.

1.2. Understanding climate, variability and change

When we speak of climate, we are referring to the long-term average of the individual weather conditions that we experience every day (see Box 1.1). Our climate is important because it determines both how and where we live, which foods we can grow, our sources of water for irrigation and drinking, and how we organise our societies and our economic activity. We do expect our climate to change over time. These changes occur both naturally, as integral parts of how the global and regional climate systems function, as well as in response to additional influences due to human activity. We explore these concepts, and evidence for such changes, further in the sections which follow in this chapter. Before we do this, however, it is important to provide a basic description of climate variability and change.

Natural climate variations may be simply linked to the passage of seasons at different times of the year, or from year to year. Global climate also varies on timescales of many thousands of years. These so-called Milankovitch cycles describe changes in the earth's orbit around the sun, the angle (or tilt) of the earth's axis and changes in the axis of rotation of the earth. All three result in extended periods of cooler (and drier) or warmer (and wetter) conditions for the global climate system. On inter-annual timescales, the most important example of natural climate variability is the El Niño-Southern Oscillation (ENSO) phenomenon (see Box 1.2). Variations in sea-surface temperatures and the exchange of moisture and energy between the ocean and atmosphere over the Pacific Ocean basin result in variations which affect the global climate system. The impacts of ENSO variability on southern African climate are discussed further in Section 1.3 on page 8.

We refer to climate change when we are describing alterations to prevailing climatic conditions which persist for long periods of time (decades to millennia). These may be caused by natural variability. There is increasing evidence, however, which demonstrates that the global climate

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[1] Southern Africa is broadly defined here as Africa south of the equator.

[2] The *adaptive capacity* of society is associated with a variety of social factors which affect people's ability to anticipate, cope with, and respond to change (see Chapter 5).

system is changing in response to the influence of human activity (IPCC, 2007). Increasingly, the phrase "climate change" is used to refer to changes in global and regional climate in response to those human influences (see Box 1.3). We explore evidence for recent changes in global and regional climate, as well as attempts to attribute changes in global climate to a uniquely human influence, in Section 1.4 on page 14. We explore evidence for recent climate change in southern Africa in Section 1.5 on page 16.

1.3. Current climate of southern Africa

The climate of southern Africa is strongly determined by the position of the subcontinent in relation to the major circulation patterns of the southern hemisphere, the complex regional topography and the surrounding ocean currents. The southern African region is located between the equator and the mid-latitudes and is bounded by the warm Indian Ocean on the east coast and the cold Atlantic Ocean on the west coast. The relief ranges from sea-level to a plateau at about 1250 m and extends to mountains exceeding 3000 m in height. The combination of these factors leads to different climate types and regimes across the region — coastal desert from about 32 degrees south to the border of Namibia with Angola, a temperate climate over the interior central plateau, a subtropical climate over the low-lying coastal regions of the south-east, and a Mediterranean climate in the southern part of South Africa.

Data used to create the maps used in this chapter to illustrate the current climate of southern Africa, as well as recent changes in the region's climate, are sourced from the high-resolution gridded dataset provided by the Climatic Research Unit of the University of East Anglia (CRU TS 3.1).

Rainfall

Southern Africa is described as a predominantly semi-arid region with high intra-seasonal and inter-annual rainfall variability, with extreme events such as droughts and floods occurring frequently. The amount and seasonal distribution of rainfall are the most important factors to consider when looking at rainfall across southern Africa.

Box 1.1: Explaining weather and climate

Weather

Weather describes the set of meteorological phenomena we experience on a daily basis. Weather conditions might be sunny and hot, or cloudy and rainy. We expect changes in weather to occur from day to day.

Climate

By *climate* we mean the average of individual weather states, taken over sufficiently long periods of time. While weather impacts our daily lives, climate influences our decisions about where to live, and where and how to grow food. In this way, it directly influences how societies and economies develop and flourish. Changes in climate are associated with more fundamental changes to the global climate system, involving interactions and feedbacks between the atmosphere, the oceans, land and ice surfaces and all living things (the biosphere).

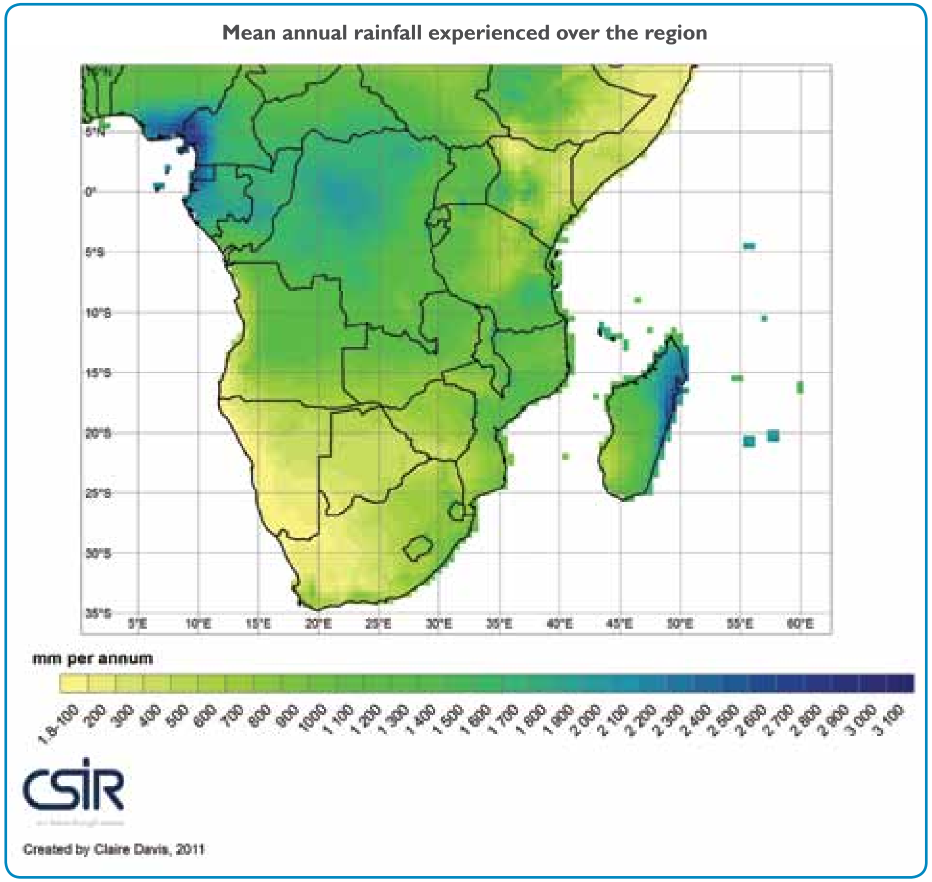
www.sabc.co.za/weather

There is a high degree of spatial variation in rainfall across southern Africa. The average rainfall for the region is just less than 1000 mm per year[3]. The highest amount of rainfall occurs in the tropics and in the highlands of eastern Madagascar which can receive up to 3100 mm per year. Rainfall tends to decrease to the north-east and to the south-west of the equator, with some arid areas receiving less than 100 mm per year. The majority of the region receives between 500 and 1500 mm per year, with the more semi-arid regions of the south receiving between 250 and 500 mm per year (Figure 1.1).

Rainfall over most of southern Africa is markedly seasonal, except for the south coast, the arid south-west and the moist tropics. The majority of the rainfall occurs in the summer half of the year (October to March). Rainfall occurs all year round in areas around the equator and in eastern Madagascar (Figure 1.2) and some areas, for example Tanzania, experience two rainy seasons — one from March to May and another lighter one from November to January. In general, southern Africa is dominated by summer rainfall with October to March being the main rainfall season (Figure 1.2). The rainy season reaches a peak between December and February when most of southern Africa receives 80% of its annual rainfall, with some parts receiving as much as 90% (Hobbs et al., 1998). Tropical cyclones occasionally make landfall on the Mozambican and South African coastlines, bringing significant rainfall and associated flooding to Mozambique, the northern parts of South Africa, and Zimbabwe. The south-west coast of South Africa is sufficiently far south to be influenced by mid-latitude cyclones (disturbances associated with the belt of westerly winds in the southern ocean) in the winter months, during which most of the annual rainfall occurs (Figure 1.2).

Southern African inter-annual rainfall variability is known to be linked to the El Niño-Southern Oscillation (ENSO) phenomenon (see Box 1.2). During warm (cool) ENSO events, dry (wet) conditions generally occur over much of the summer rainfall region of southern Africa. For example, in 1982/83 below average rainfall and droughts in many parts of the region coincided with a strong El Niño event. The influence of El Niño is strongest in the south-eastern region of southern Africa and reaches a maximum in late summer (January-March) (Lindesay, 1998).

Other important determinants of rainfall patterns in southern Africa include the Inter-Tropical Convergence Zone (ITCZ) and the Botswana Upper High Influence (anticyclone centred over Botswana). The ITCZ is a region characterised by high convective activity resulting in high rainfall in several countries within the sub-region in the summer months when its position shifts into the southern hemisphere. The ITCZ phenomenon is suppressed by the Botswana Upper High Influence (BUHI) which occurs from time to time and contributes to the aridity of Botswana and Namibia. A persistent BUHI can result in drought in the region.



Mean annual rainfall experienced over the region

Created by Claire Davis, 2011

Figure 1.1: Mean annual rainfall over southern Africa (calculated from 1901-2009 mean).

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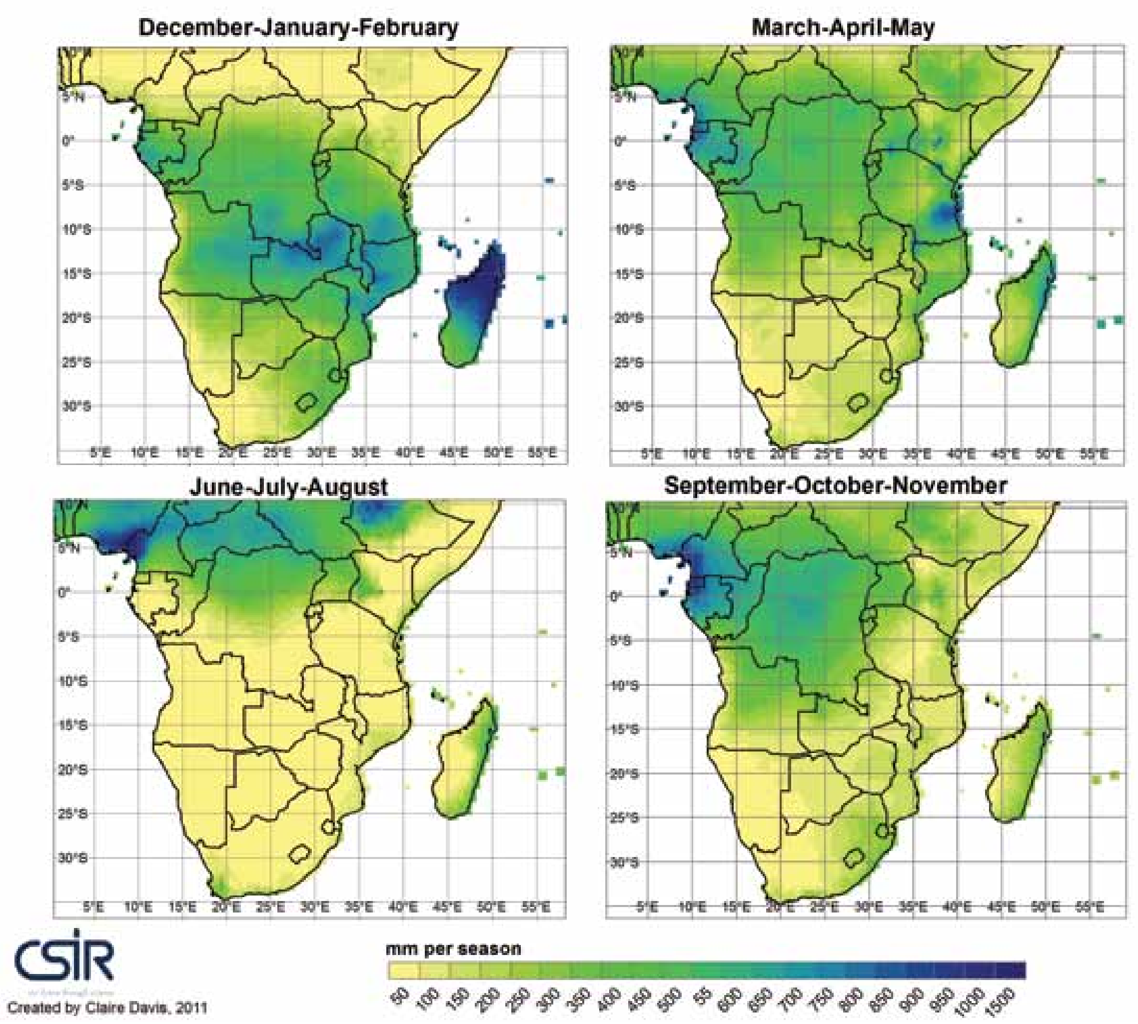
[3] based on an average for the period 1901-2009, derived from the high-resolution (0.5°x0.5°) gridded dataset provided by the Climatic Research Unit (CRU) of the University of East Anglia – CRU TS 3.1 (Mitchell and Jones, 2005).



Seasonal rainfall (summer, autumn, winter and spring) experienced over region

CSIR

Created by Claire Davis, 2011

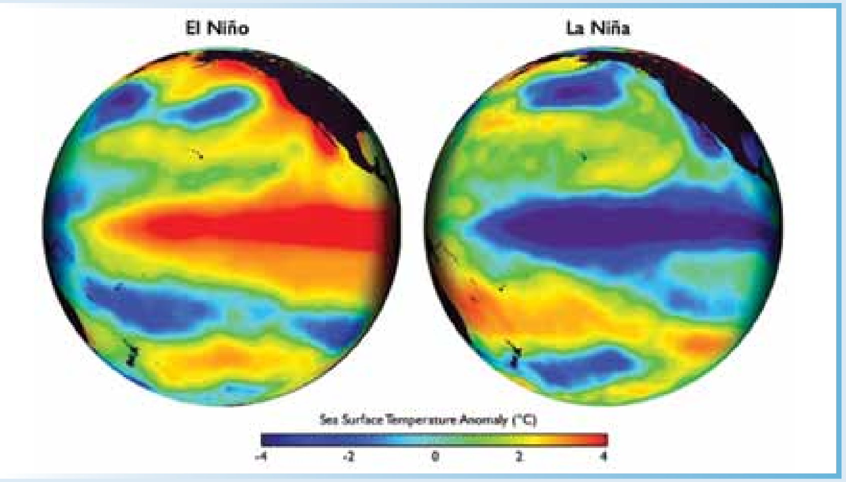
Figure 1.2: Seasonal rainfall totals (mm per season) over southern Africa (calculated from 1901-2009 mean).

Box 1.2: El Niño-Southern Oscillation (ENSO) Variability

Perhaps the most well understood example of climate variability is the naturally-occurring phenomenon known as El Niño-Southern Oscillation (ENSO), an interaction between the ocean and the atmosphere over the tropical Pacific Ocean that has important consequences for weather around the globe. The ENSO cycle is characterised by spatially coherent and strong variations in sea-surface temperatures, rainfall, air pressure and atmospheric circulation across the equatorial Pacific and around the globe. An El Niño event typically occurs every three to seven years.

El Niño refers to the warm phase of the cycle, in which above-average sea-surface temperatures develop across the east-central tropical Pacific (see below). La Niña is the cold phase of the ENSO cycle.

These changes in tropical rainfall affect weather patterns throughout the world. For example, over southern Africa, El Niño conditions are generally associated with below-average rainfall years over the summer rainfall regions, while La Niña conditions are associated with above-average rainfall conditions.



Patterns of sea-surface temperature during El Niño and La Niña episodes. The colours along the equator show areas that are warmer or cooler than the long-term average. Images courtesy of Steve Albers, NOAA and ClimateWatch Magazine (http://www.oar.noaa.gov/climate/t_observing.html).

Relative humidity

Patterns of average moisture content over southern Africa show a distinct west-to-east gradient across the subcontinent (below the equatorial region), with the humidity being the lowest over the western interior and highest over the east due to the source of moisture from the Indian Ocean (Figure 1.3). Humidity also displays distinct diurnal and seasonal variations, with humidity reaching a minimum in winter and maximum in summer. This means that the east-west gradient is more pronounced in summer compared to winter. The relative humidity remains high over the equatorial regions throughout the year.

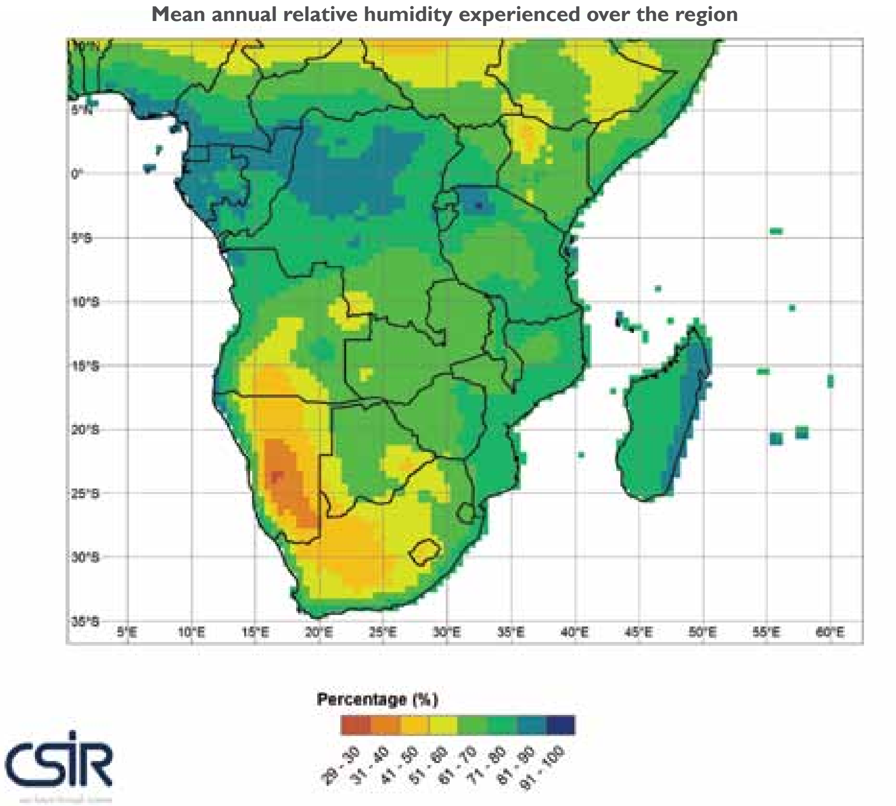

Mean annual relative humidity experienced over the region

Figure 1.3: Mean annual relative humidity (%) over southern Africa (calculated from 1901-2009 mean).

Temperature

Southern Africa has a warm climate and much of the region experiences an average annual temperature above 17°C. The month-to-month variation in temperature tends to be gradual.

Across the region, mean annual minimum temperature ranges from 3 to 25°C (Figure 1.4a) and mean annual maximum temperature ranges from 15 to 36°C (Figure 1.4b). The lowest temperatures occur along the escarpment. Frost is common in winter on the interior plateau and at higher altitudes, for example the Drakensberg Mountains of South Africa. The highest maximum temperatures are observed near the equator, the Kalahari and in the lowlands of north-eastern South Africa, Zimbabwe and Mozambique. The greatest diurnal temperature range (difference between the daily maximum and minimum temperature) is observed over the central plateau regions and the highland areas, where the lowest and highest day temperatures can differ by up to 19°C (Figure 1.4c). In contrast, the coastal and equatorial regions experience a much smaller diurnal temperature range. Temperatures along the coast are influenced by the temperature of the adjacent oceans and the nature of the Benguela and Agulhas currents. The eastern coastline is warmed by the Agulhas current which flows southwards from the equator, whereas the western coastline is cooled by the Benguela current which flows northwards from Antarctica.

Mean temperature is greatly influenced by extremes in maximum and minimum temperature and is consequently a good indicator of seasonal changes in temperature across the region. For most of the region, summer is experienced from December to February, autumn from March to May, winter from June to August, and spring from September to November. In summer the temperatures are highest over the desert regions of Namibia and Botswana and exceed 27°C (Figure 1.5). Cooler conditions are experienced over the interior plateau regions and to the south-west, where temperatures may be below 22°C (Figure 1.5) due to the cloud cover associated with the summer rains. In winter the temperature regimes display a latitudinal gradient where temperature decreases southward (Figure 1.5). The coldest temperatures are experienced over South Africa, including Lesotho, extending to the southern parts of Namibia where temperatures average less than 15°C (Figure 1.5).

Temperatures experienced over the region

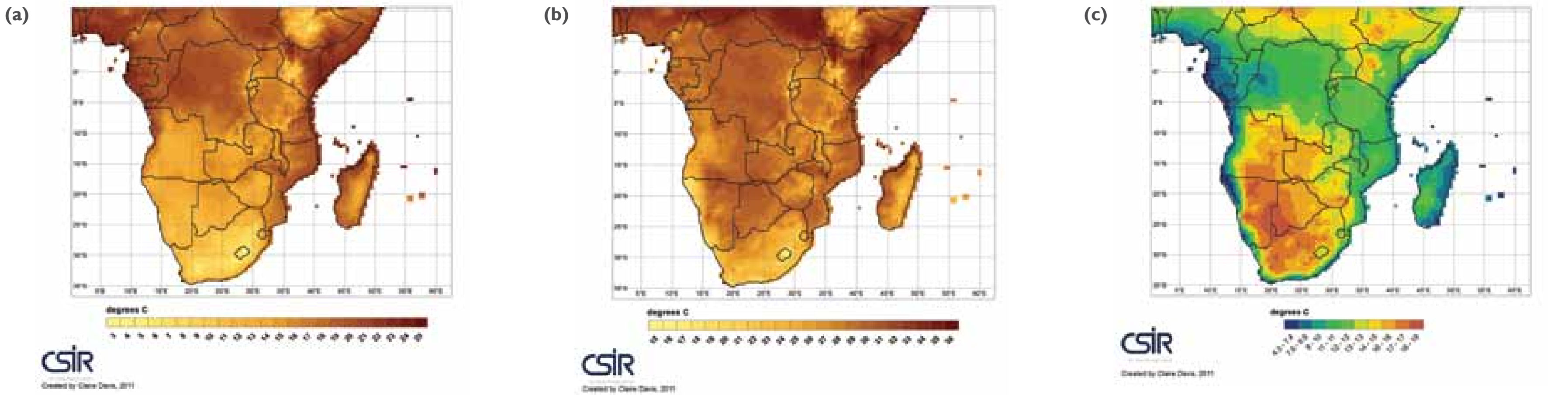
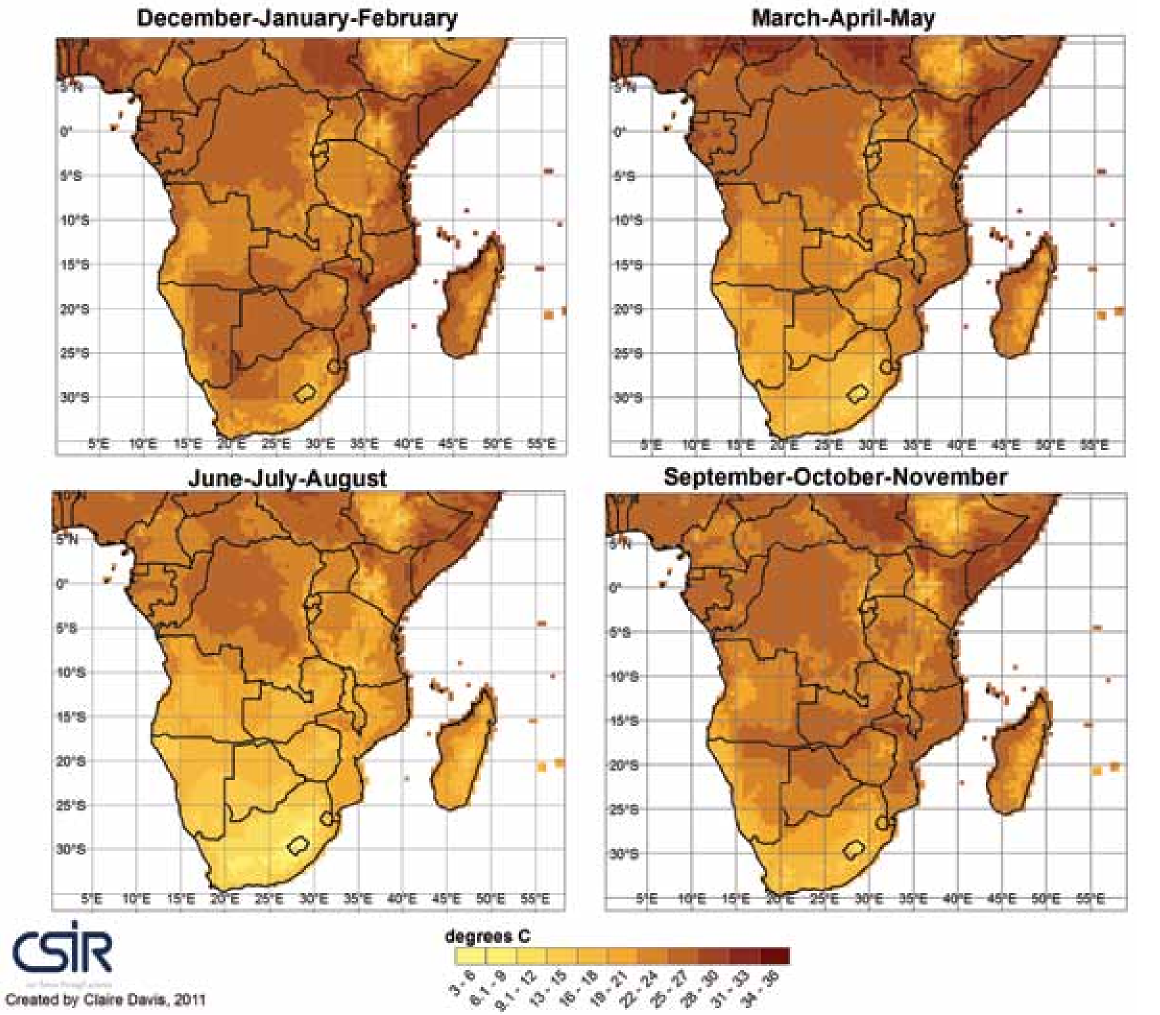


Figure 1.4: Mean annual minimum (a) and maximum (b) temperature, as well as diurnal temperature range (c) over southern Africa (calculated from 1901-2009 mean).

Seasonal temperatures (summer, autumn, winter and spring) experienced over the region



Created by Claire Davis, 2011

Figure 1.5: Seasonal average temperature over southern Africa (calculated from 1901-2009 mean).

1.4. Observed changes in global climate

It is widely recognised that there has been a detectable rise in global temperature during the last 100 years, and that this rise cannot be explained unless human activities are accounted for (IPCC, 2007). In this section, we briefly introduce evidence of recent changes in global average temperature (detection) and also evidence that these changes can be linked to human activities (attribution). We also present evidence of recent climate change over the southern Africa region.

Detection and attribution of global climate change

In 2010, global average temperature was 0.53°C above the 1961-90 average. Along with 1998, 2010 is widely recognised as the warmest year on record. In fact, the World Meteorological Organisation has confirmed that the ten warmest years on record have all occurred since 1998 [4]. The regional distribution of temperature increases is not uniform, however, and some regions have experienced greater change than others, especially the interior of continental regions such as southern Africa. The *rate* of global average temperature increases has also increased during the latter half of the 20th century, suggesting that increases in global average surface temperature are accelerating (see Figure 1.6).

The fundamental physical processes through which human activities are changing the global climate system are explained in Box 1.4. Very briefly, increasing emissions of atmospheric greenhouse gases (primarily through the burning of fossil fuels) are enhancing the natural greenhouse effect, resulting in climate changes which are manifested at both global and regional scales. We know that atmospheric carbon dioxide (CO_2) concentrations are increasing, thanks predominantly to observations from Mauna Loa observatory in Hawaii, which began in 1958 (Figure 1.7). Concentrations fluctuate every year based on the annual cycle of uptake and release of CO_2 in the vast forests which cover much of the landmasses of the northern hemisphere (the red line in Figure 1.7). The most striking feature of Figure 1.7 is, however, the high consistent upward trend in atmospheric CO_2 concentrations since observations began (seasonally-corrected data are shown as the black line in Figure 1.7). Annualised atmospheric CO_2 concentrations at Mauna Loa have grown from 316 ppm in 1959 to 390 ppm in 2010. The most recent measure (June 2011) is 394 ppm.

Computer models of the earth's climate system are unable to simulate the warming observed over recent decades unless they include the effects of anthropogenic emissions of greenhouse gases (Figure 1.8). Simulations of the earth's climate which include only natural forcing (e.g. solar variability due to both internal and orbital variations, volcanic activity, etc.) show a cooling of the earth after 1960, which is at odds with the observed warming (see Figure 1.6). This has led the Intergovernmental Panel on Climate Change (IPCC) to conclude recently that most of the warming, *on a global scale*, of the last 50 years is *attributable* to human activities.

Understanding how global climate change may affect regions and individual countries is, however, still a matter of research, and is inherently associated with greater uncertainty. So while the observed global level changes serve to highlight that climate change is a reality and that there is evidence that suggests continuing and potentially accelerating change, it is necessary to explore how regional and local climates may already be changing, as well as how they are expected to change in the future.

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[4] WMO press release, January 2011 (http://www.wmo.int/pages/mediacentre/press_releases/pr_906_en.html).

Global temperature trends

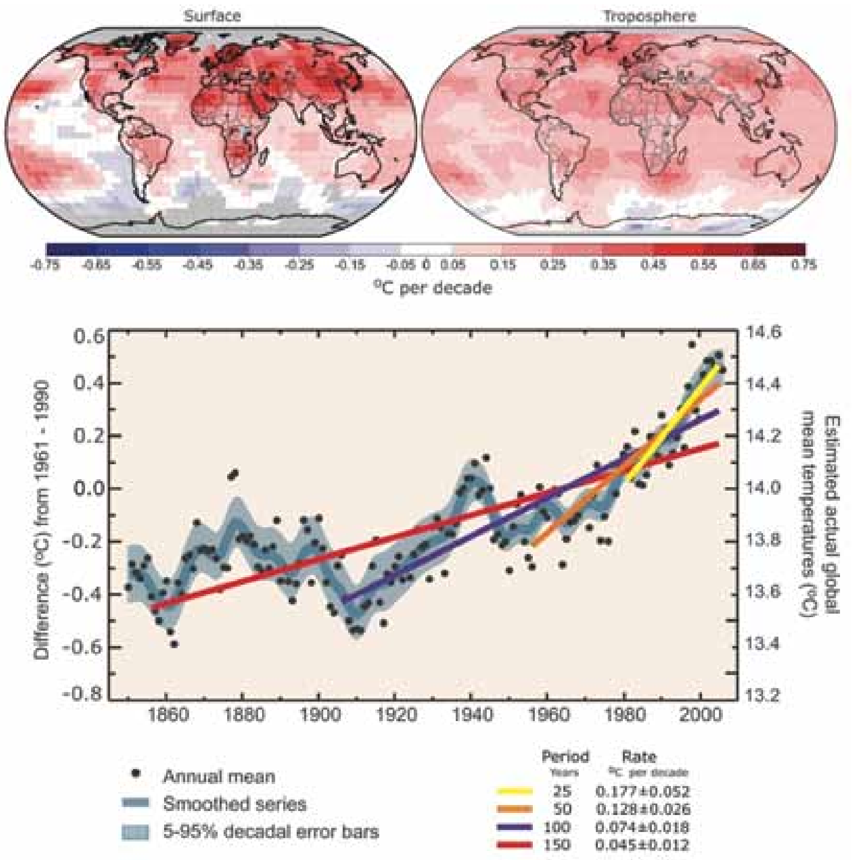


Figure 1.6: Distribution of global temperature trends (1979-2005) for the surface (left) and troposphere (right) from satellite records. Below: the average global temperature since 1850, indicating the increased rate of change during the latter part of the 20th century (IPCC, 2007).

Atmospheric CO$_2$ at Mauna Loa Observatory

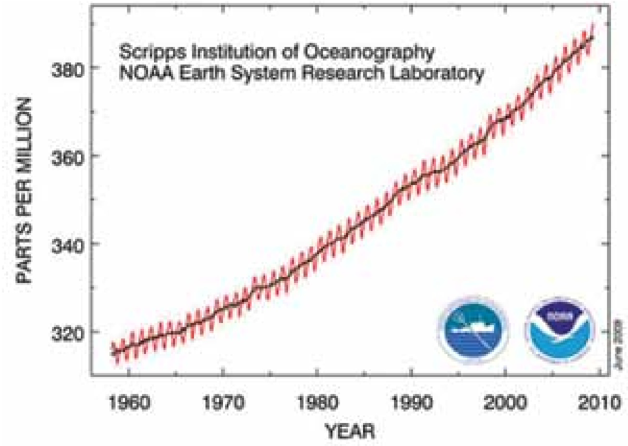


Figure 1.7: Atmospheric CO$_2$ concentration (ppm) from Mauna Loa observatory, Hawaii, as of June, 2011[5].

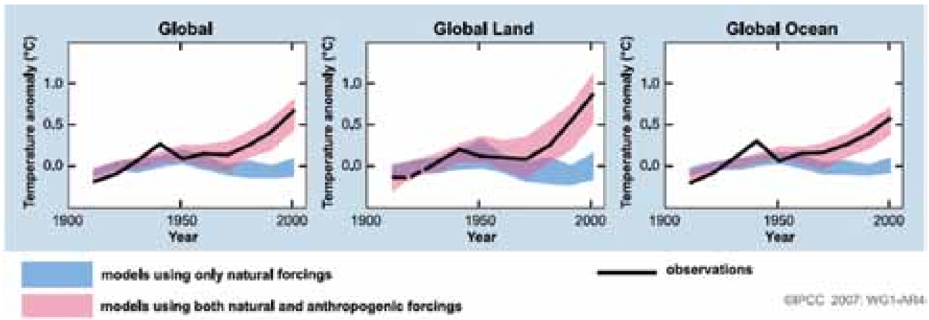


Figure 1.8: Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings (IPCC, 2007).

[5] US National Oceanographic and Atmospheric Administration, Earth System Research Laboratory, (http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full), accessed 3 May 2011.

Box 1.3: Climate variability vs climate change

Climate variability

Climate variability refers to variations in climate on all spatial and temporal scales beyond that of individual weather events. This variability may be caused by natural internal processes within the climate system (so-called *internal variability*). Variations may also be caused by *external* influences which may be due to naturally-occurring phenomena (such as periodic changes in the earth's orbit around the sun) or anthropogenic causes (IPCC, 2007). One of the most important (and widely known) examples of natural climate variability is the El Niño-Southern Oscillation (ENSO).

Climate change

Climate change refers to a change in the average weather experienced in a particular region or location. The change may occur over periods ranging from decades to millennia. It may affect one or more seasons (e.g. summer, winter or the whole year) and involve changes in one or more aspects of the weather, e.g. rainfall, temperature or winds. Its causes may be natural (e.g. due to periodic changes in the earth's orbit, volcanoes and solar variability) or attributable to human (anthropogenic) activities, e.g. increasing emissions of greenhouse gases such as CO_2, land use change and/or emissions of aerosols. In contemporary society the term 'climate change' often refers to changes due to anthropogenic causes. When changes in climate occur, they directly impact livelihoods, food security and potentially how societies, economies and political systems function.

Global warming

Global warming refers only to the overall warming of the Earth, based on average increases in temperature over the entire land and ocean surface. It is important to note that climate change is more than simply an increase in global temperatures; it encompasses changes in regional climate characteristics, including temperature, humidity, rainfall, wind, and severe weather events, which have economic and social dimensions.

1.5. Observed trends in southern African climate

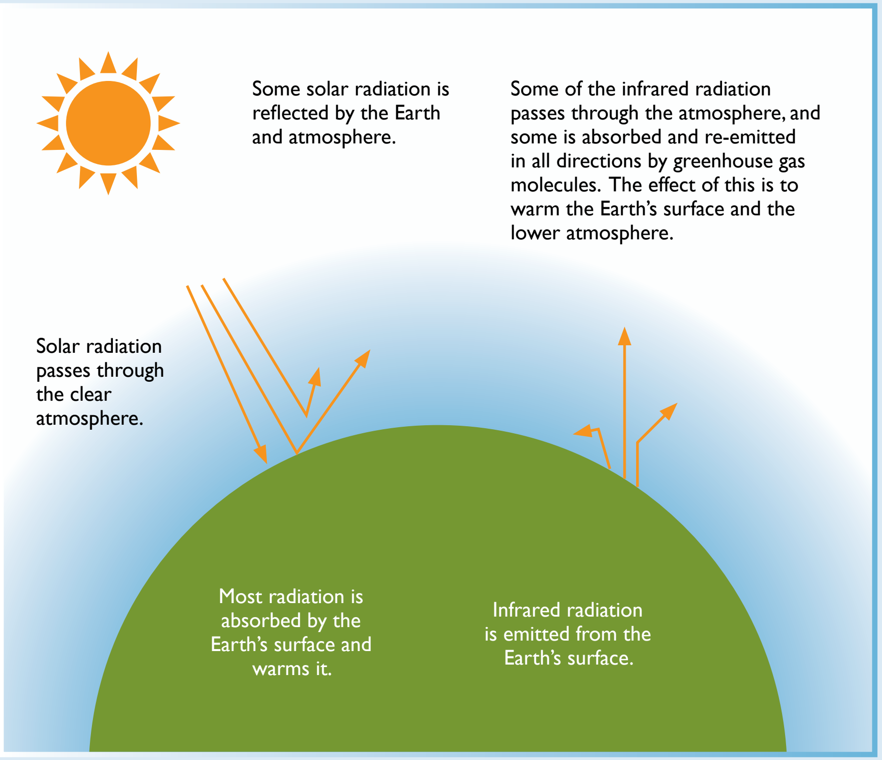
One of the best ways of understanding how southern African regional climate may change in future is to examine how it has changed in the past. While it is certainly possible that climate may change in ways we have not yet observed, reconstructions of past climatic fluctuations and evidence of more recent changes, based on available observational records, provide a good first indication of the direction and magnitude of possible future changes. This is particularly true of observational records which cover the most recent past, as we know already that we have begun to observe the pattern of a human influence on global climate records over the last century. Detecting and attributing regional climate trends is considerably more difficult than doing so for global climate, however. This is because of a number of factors, chief among them the lack of an accurate, long-term, well-maintained and dense network of observational stations to detect regional climate signals. The important influence of local features of the landscape – mountains and water bodies, for example – on regional climate variability, also makes attributing observed regional climate trends to a human cause more difficult. Despite these difficulties, we examine the observational record for southern Africa for evidence of climate trends over the last century. The following two sections detail the results, as an example, from the analysis of the temperature and rainfall high-resolution gridded dataset (1901 to 2009) provided by the Climatic Research Unit of the University of East Anglia (CRU TS 3.1). As discussed above, these trends provide the context for projections of future regional climate change which will be discussed in Chapter 3 of this handbook.

It is important to note here that long-term climate observations and models are not the only means to determine changes in climate. Most rural communities in Africa have always relied on indigenous knowledge to help them deal with climate variability and change (see case study on page 21). A key question when dealing with indigenous knowledge is how it can be integrated successfully with scientific knowledge in order to develop climate change mitigation and adaptation strategies (see Chapters 4 and 5).

Box 1.4: What causes climate change?

The Earth's climate system is driven by energy that is continuously received from the sun. The bulk of this energy is in the short-wavelength part of the electromagnetic spectrum. About 30% of the incoming solar energy is reflected back to space by clouds and the Earth's surface before it can warm the planet. About 70% of the incoming energy is absorbed by the oceans, continents and the atmosphere. The absorbed heat is later re-emitted in the form of infrared radiation, or transferred by sensible and latent heat fluxes. Certain gases in the troposphere and stratosphere absorb most of the outgoing infrared radiation before it can escape to space, thereby warming the atmosphere before the heat is once again re-emitted. These are referred to as greenhouse gases (GHG) and include water vapour (H_20), carbon dioxide ($C0_2$), nitrous oxide (N_20) and methane (CH_4). Without the presence of these gases in the atmosphere, the average temperature at the surface of present-day Earth would be about -18°C. The warming effect of the greenhouse gases, called the 'greenhouse effect' or 'natural greenhouse effect', results in the average surface temperature being about +14°C (IPCC 2007).

Anthropogenic emissions of greenhouse gases have increased steadily since the industrial revolution, thereby warming the globe and setting in motion a range of other changes to the climate system. The rate of emissions has been steadily increasing over time. Computer models of the Earth's climate system are unable to simulate the warming observed over recent decades unless they include anthropogenic emissions of greenhouse gases. Computer models of the Earth's climate which include only natural forcing (e.g. solar variability due to both internal and orbital variations, volcanic activity, etc.) simulate a cooling of the Earth after 1960, which is at odds with the observed warming (see Figure 1.8). This has led the Intergovernmental Panel on Climate Change (IPCC) to conclude recently that most of the warming of the last 50 years is attributable to human activities.



Temperature

There is strong evidence, based on analysis of minimum and maximum temperature trends, that the region is getting warmer. The trends are displayed as departures (or anomalies) from the 1961-1990 average in Figure 1.9. After the mid-1970s, these anomalies are almost all positive; approximately 0.8°C above the 1961-1990 average over the last two decades. These anomalies are also larger in more recent years, suggesting that the rate of increase in minimum and maximum temperatures is increasing. This is consistent with detected increases in global annual surface air temperatures (Figure 1.6) and over southern Africa since 1900 (Hulme et al., 2001; Kruger and Shongwe, 2004).

Trend analysis of temperatures across southern Africa reveals that annual minimum and maximum temperatures have increased at an average rate of 0.057°C per decade and 0.046°C per decade, respectively between 1901 and 2009[6]. Further analysis reveals that the periods of most rapid warming occur post 1970, a period for which the rate of increase in both average

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[6] Graphs available at http://www.rvatlas.org/sadc).

annual minimum and maximum temperatures is statistically significant at the 95% confidence level. After 1976, minimum temperatures began increasing by 0.27°C per decade and maximum temperatures by 0.25°C per decade. This demonstrates again that temperatures have begun to rise more steeply during the latter years of the 20th century and the first decade of the 21st century. Projections of temperature change (Chapter 3), show that temperatures are expected to continue to increase and so too is the rate of increase.

Examination of extreme temperature trends also reveals evidence of change (see Figure 1.10). The lowest recorded annual minimum temperature has increased gradually at an average rate of 0.162°C between 1901 and 2009, statistically significant at the 95% confidence level. The highest recorded annual maximum temperature has increased more gradually at an average rate of 0.075°C between 1901 and 2009, statistically significant at the 95% confidence level. The larger rate of increase in minimum temperatures has been observed before by Alexander et al., 2006 who suggest a general trend toward less severe very cold events. After 1995, the highest observed maximum temperatures begin to increase at a statistically significant rate of 0.85°C, suggesting that the frequency of hot years is increasing.

Rainfall

Changes in rainfall are typically harder to detect due to the fact that rainfall varies so much from place to place and from year to year across southern Africa. Existing evidence for rainfall trends suggests moderate decreases in annual rainfall over parts of southern Africa (for example Kruger, 2006). There is also evidence from other studies which shows that inter-annual rainfall variability over southern Africa has increased since the late 1960s and that droughts have become more intense and widespread in the region (Fauchereau et al., 2003). Evidence from the time series of rainfall anomalies for the southern African region as a whole (Figure 1.11) used here does not show any trend towards decreased annual rainfall or any changes in variability, however. The pattern of anomalies does demonstrate that year-to-year rainfall variability is high across the region, and has been a persistent feature of the region's climate for many years. These alternating patterns of above-normal/below-normal rainfall periods clearly illustrate the rainfall cycles prevalent in southern Africa (discussed earlier in this chapter) where extreme wet and dry years have been recorded, which resulted in floods and droughts. In 1999-2000, for example, tropical cyclone Eline caused widespread flooding in southern and central Mozambique, south-eastern Zimbabwe and parts of South Africa and Botswana. In 1982-1983 (El Niño year), 1986-87 and 1991-92 serious droughts were experienced that caused a decrease in crop and stock production in many parts of the region (Vogel, 1994).

Where records are of sufficient length there have been detectable increases in the number of heavy rainfall events (Solomon et al., 2007) and over southern Africa regional studies have shown that the length of the dry season and the average rainfall intensity has increased (New et al., 2006). Furthermore, a study considering changes in extreme rainfall events over South Africa (Mason et al., 1999) found that 70% of the country has experienced a significant increase in the intensity of extreme rainfall events between 1931-1960 and 1961-1990. Regional differences between the north-eastern and central parts of South Africa were also noticed.

Temperature Trends (1901-2009)

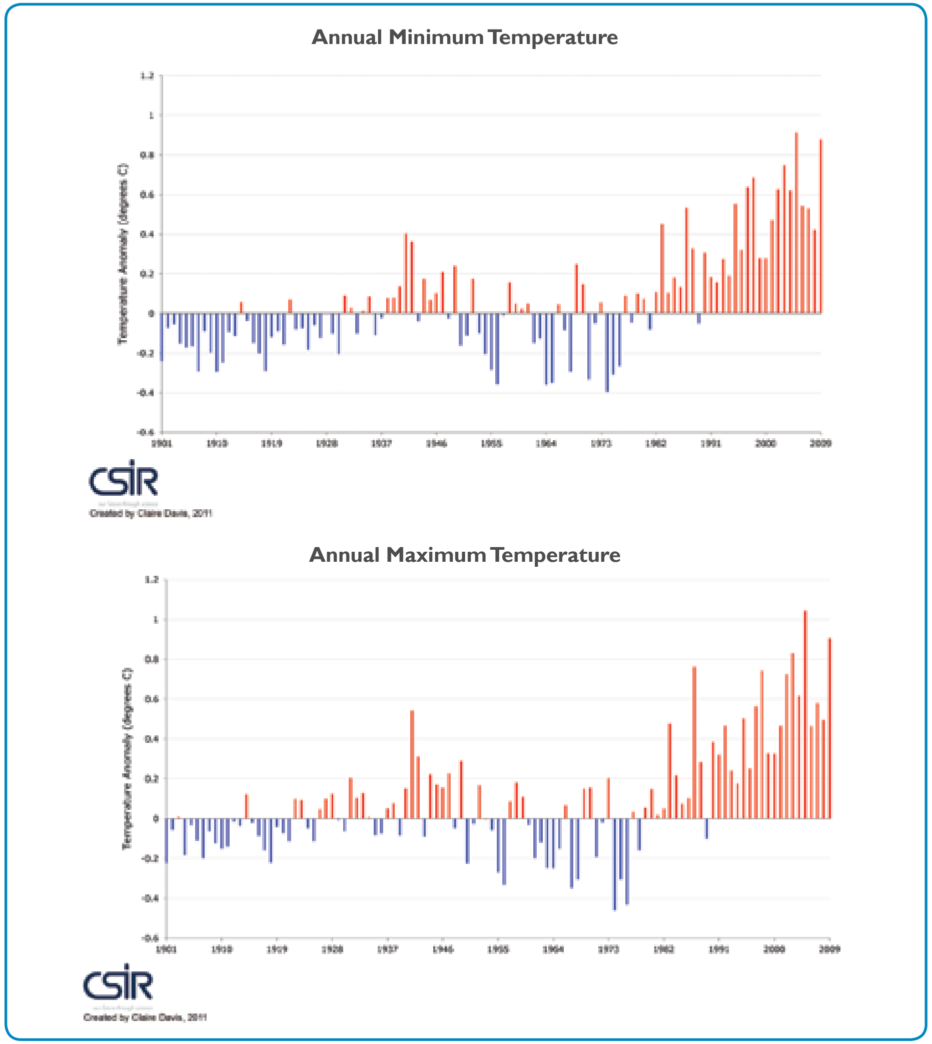

Figure 1.9: Annual minimum (top) and maximum (bottom) temperature anomalies for the whole southern Africa region (1901-2009). Red represents a positive anomaly and blue a negative anomaly in temperature with respect to the long-term average climatology (1961-1990 mean).

Temperature Trends (1901-2009)

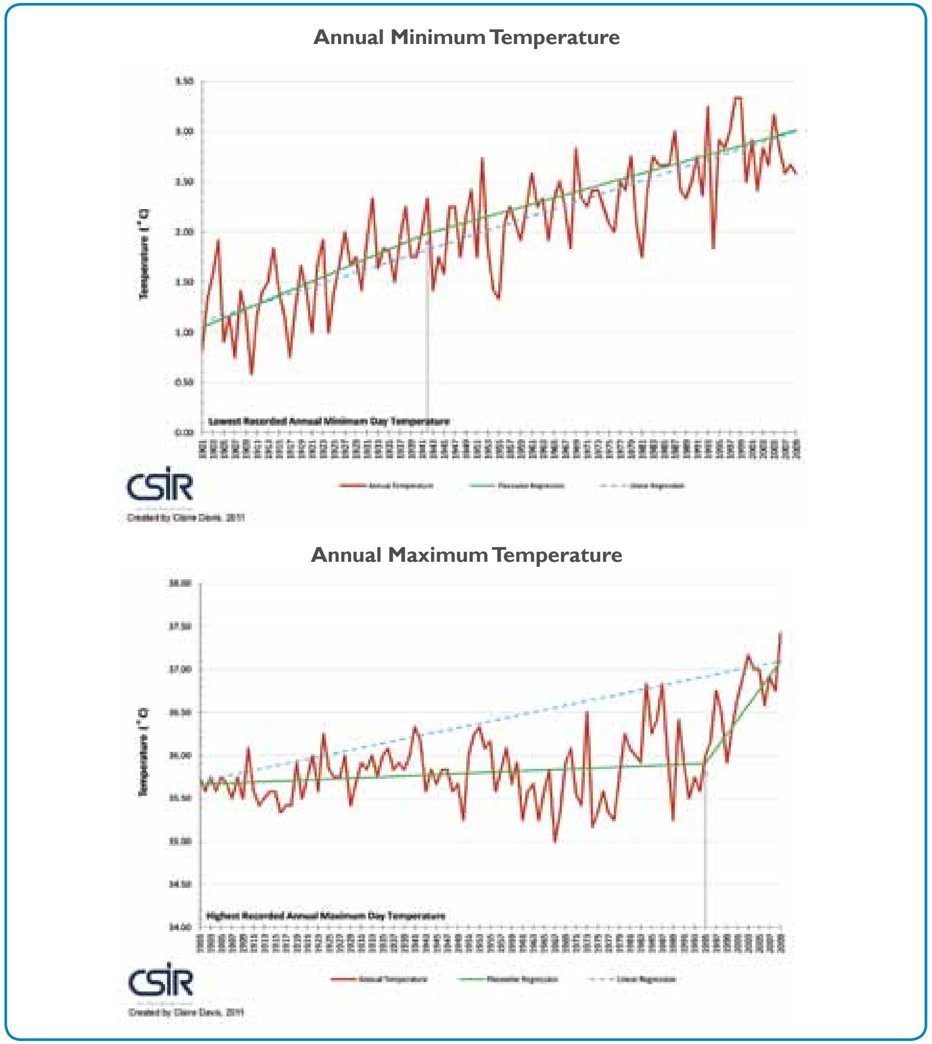

Figure 1.10: Trend in the lowest recorded annual minimum day temperature (top) and the trend in highest recorded annual maximum day temperature (bottom) for the whole southern African region from 1901 to 2009. The solid red line represents the observed temperature, the dotted line represents the linear trend, and the solid green line represents the results from a segmented regression analysis[7] with the breakpoint indicated by the arrow.

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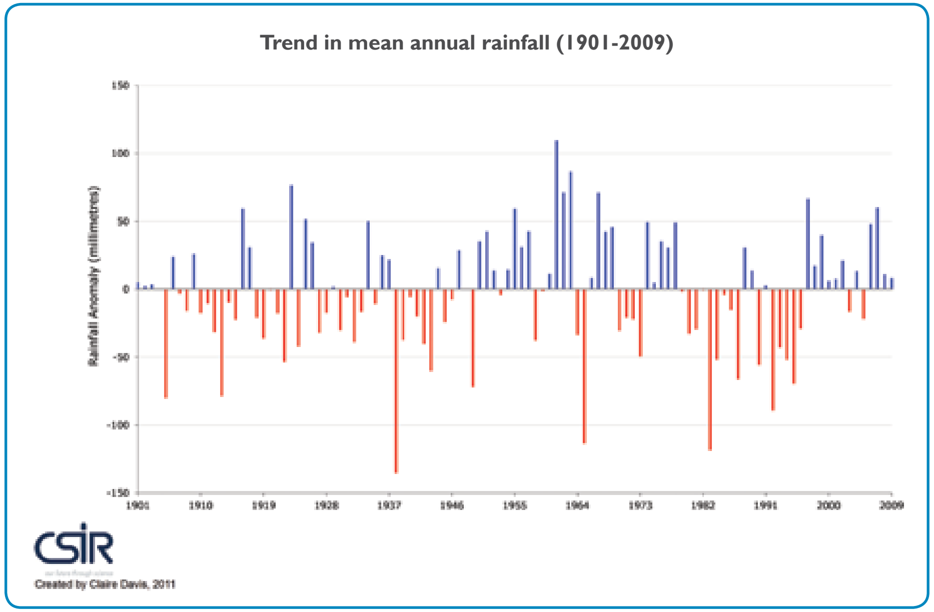
[7] A breakpoint is useful to quantify when an abrupt change in temperature has occurred and is the point at which the coefficient of determination (R^2) is maximised (Ryan and Porth, 2002).


Trend in mean annual rainfall (1901-2009)

Created by Claire Davis, 2011

Figure 1.11: Annual rainfall anomalies for the whole southern African region (1901-2009). Blue represents a positive change in rainfall and red represents a negative change in rainfall with respect to the long-term average climatology (1961-1990 mean).

1.6. Summary and conclusions

In this chapter we have introduced the concepts of climate, climate variability and climate change, all of which are crucial to understand how to plan and prioritise interventions in the face of climate change. We have also explained how human activity is changing the global climate system, and shown evidence for observed changes in global climate over the last century. As part of this discussion, we have also demonstrated that some of these global changes – notably in surface air temperature – can be unequivocally linked to a human influence. In the last section of this chapter, we also examined evidence from observational records of climate trends over the southern African region. Over southern Africa, there is good evidence to suggest that temperatures have been increasing over the last century, and that the rate of warming has been increasing – most notably in the last two decades. No clear evidence exists for a change in mean annual rainfall, and rainfall time series remain dominated by the patterns of inter-annual rainfall variability which predominate over much of the summer rainfall region of the subcontinent.

Having now provided a background for climate change science, as well as evidence for changes in both global and regional climate, the next chapters explore our ability to predict future climate. In Chapter 2, we explore how to forecast climate on seasonal and inter-annual (a few years forward) time-scales, and how these forecasts can be used to assist in decision-making for agricultural and other applications. In Chapter 3 we explore how to project future regional climate changes due to increasing emissions of greenhouse gases. The context provided in the chapter, which describes evidence for climate change in our recent past, will be directly relevant when we consider the range of possible future climate changes over this region. Later in this handbook, these chapters are integrated with assessments of risk and vulnerability to climate change (Chapter 4), as we explore how to mitigate and adapt to climate change (Chapter 5) in the southern African region.

CASE STUDY: Farmer perceptions regarding variability and change in local climate conditions in Zimbabwe and Zambia

By Chipo Plaxedes Mubaya

A study on understanding farmer perceptions regarding variability and change in climate conditions and their possible causes, was conducted in Southern Zambia and South-western Zimbabwe in the four districts of Monze and Sinazongwe in Zambia and Lupane and Lower Gweru in Zimbabwe. This study was driven by available literature which underscores that while at the centre of the adaptive process, there is the individual farmer who is free to make a specific choice such as what to plant, how much land to cultivate and the resources to be employed (Crosson, 1986, 1993), there is an alternative approach which underscores how individuals perceive their environment and make decisions, with mal-adaptations attributed to problems in perception, cognition or the lack of available information (Diggs, 1991; Saarinen, 1966; Taylor et al., 1988). This literature points towards the central role that farmer perceptions play in adaptation, making it essential for this study to understand to what extent farmers perceive climate conditions and what may be causing them. Understanding of farmers' perceptions of causes of climate change may be important and decisive in determining farmers' responses and mitigation measures to the crisis, even at local level.

This study employed both qualitative and quantitative methodologies. The qualitative methods of data collection used include Participatory Rural Appraisal (PRA) techniques such as historical trend analysis and Focus Group Discussions (FGDs). The quantitative method used is the household questionnaire survey. FGDs were used to establish the general perceptions regarding climate change and variability and possible causes. Historical trend lines were used to elicit information on specific historical trends in farmers' perceptions regarding changes in climate over a period of 20 years and as far back as they could recall. Specifically, participants were asked to recall major occurrences that had a bearing on climate and weather, community resources, and even the political situation. The questionnaire survey collected data on indicators for good and bad crop production seasons and years considered to be good or bad over a ten-year period. Questions in the survey also related to changes in weather patterns over a ten-year period in relation to agriculture and what might have caused these changes. General household characteristics were also captured in this survey.

Data from the questionnaire survey indicate that above 70% of the farmers in all the four districts have been aware of significant changes in weather patterns over the past five years. Climate variability was emphasised by farmers to be on the increase, specifically by citing a recent phenomenon of floods and excessive rains. Farmers indicated that they had witnessed floods (in Zambia) and excessive rains (in Zimbabwe) more so in the seasons from 2007 to 2009. Earlier episodes of floods and heavy rains were reported to have been witnessed in 1978/79 and 1999/2000. These farmers also cited droughts in the 1992/93, 1995/96 and 2001/02 seasons. Farmers in both countries generally concurred that in the 1980s it was easy to predict the coming season, and these seasons were distinct, but now rains have become more and more unpredictable beginning around the late 1980s and early 1990s. Moreover, they also highlighted that now they are experiencing shorter rain seasons than before. Rains used to start in October and stretch up to April, but now rains were coming late, around November, and in most cases ending around February.

The greater proportion of farmers in both countries perceived climate change as purely a natural phenomenon, cited as natural changes in winters, low/high temperatures and changes in wind movement, among other things. Farmers also associate changes in climate with social and spiritual factors. FGDs found that farmers in Lower Gweru and Lupane linked the political crisis in Zimbabwe at the time of the research and the decline of social and cultural practices to the variability in climate. Farmers asserted that causes of climate change have been due to factors such as the wrath of cultural spirits and God who have meted out punishment to Zimbabwe. The punishment has been for the failure of people to continue to appease their spirits and conduct traditional rites such as the rain-making ceremony (*mukwerera*) for asking for rain from God and for showing gratitude for the rains in the previous season. Similarly, some farmers in Monze associated the beginning of climate variability with the ascendancy of one of their presidents into power. The period of his leadership was marred with controversy and linked to economic problems in Zambia at this time.

Farmers' perceptions regarding flood incidence in the study area in the 1999/2000 season correspond with available rainfall data (Stern, 2007), which show that the 1999/2000 season was a La Niña season. General perceptions captured from farmers say more about variations than deviations from some long-term trend, implying that farmers may have witnessed climate variability rather than climate change. This finding is consistent with an analysis of climate data for the Southern Province done by Nanja (2004); ICRISAT (2009). The foregoing picture of increasing climate variability in the four sampled districts is consistent with the sombre picture detailed in literature on climate variability and change in Africa in general and southern Africa in particular.

There appears to be an increasing trend towards a late start to the rainy season, prolonged mid-season droughts, and shorter growing seasons in southern Africa (Cooper et al., 2007; Love et al., 2006; Twomlow et al., 2008 and Waiswa 2003). Moreover, variability in the annual rainfall total in Zambia's Southern Province is more pronounced from the 1990s to date, where rainfall totals have frequently been seen below the 20 percentile and 80 percentile. The two lowest rainfall totals were also experienced from 1991 (Nanja, 2004; ICRISAT, 2009). Moreover, an observation was made based on climate data for Zambia's Southern Province that all along, the major problem in the South has been inadequate rain and so the risks have been concerned mainly with drought. Floods are a recent phenomenon in southern Africa (Stern, 2007).

If farmers are not aware of the extent to which anthropogenic activities may alter climate-related processes, the implication for adaptation and mitigation may be negative. The fact that significant percentages of farmers in all districts were not aware of possible causes of climate change may imply that these farmers would not make efforts to address human activities that may contribute to alterations in climate conditions. Furthermore, when there are political, social and economic problems in a country, farmers tend to link them to climate change. The cultural context and spiritual world view play a critical role in shaping farmers' perceptions and attitudes, a factor which may cloud farmers' consciousness of the negative effects of human activities on the Earth systems. What is emerging is the idea that climate change cannot be disassociated from the political, social (including the cultural and spiritual realms) and economic context. Farmers try to make sense of what is happening in their environment based on the socio-cultural framework in which they operate.

Acknowledgements

The author is grateful for funding from IDRC and DFID through Climate Change Adaptation in Africa (CCAA) and also for additional funding from START and CODESRIA. The author also thanks the following people who contributed as collaborators and researchers in the field work: researchers from Zambia Agricultural Research Institute (ZARI), Zambia Agro-Met and researchers and students from Midlands State University (MSU), Zimbabwe and ICRISAT, Zimbabwe as well as advisors to this work: Dr Jemimah Njuki of ILRI, Professor Francis Mugabe, Professor Andre Pelser and Dr Godfrey Kundhlande, the latter both from the University of the Free State.

Chapter 2: Seasonal forecasts: Communicating current climate variability in southern Africa

By Willem A. Landman, Mark Tadross, Francois Engelbrecht, Emma Archer van Garderen and Alec Joubert

Seasonal forecast models are potentially extremely useful tools for managing risks due to climate variability, and so forecast producers are constantly seeking ways to improve their performance and skill.

2.1. Introduction

As seen from the previous chapter, climate is not constant and varies considerably over southern Africa. Seasonal forecasts are a means of helping users make informed decisions related to such climate variability (IRI, 2001). In southern Africa, seasonal rainfall and temperature forecasts have been made for almost two decades already and these forecasts have been developed to improve the ability of users to cope with fluctuations in rainfall and temperatures on a seasonal time scale. Seasonal climate forecasts are defined as probabilistic predictions of how much rain is expected during the season and how warm or cool it will be, based primarily on the principle that the ocean (sea-surface temperatures) influences climate and weather. Forecasts are usually issued for a period of six months and suggest the total amount of rainfall expected over that period, but not the distribution of rainfall within that period or the initiation of the rainy season. Similarly, seasonal forecasts give guidance on the temperature regime most likely to dominate during a coming season.

Climate model projections summarised in Chapter 3 indicate that southern Africa's surface temperature, as well as minimum and maximum temperatures, is likely to rise during the 21st century (superimposed on existing observed increased temperatures shown in Chapter 1). Further, regional climate modelling suggests that mid-summer rainfall over South Africa may become more extreme (see Chapter 3). These model projections are unable to say much about the prospects of a wet summer period over South Africa or the chance of an El Niño event to develop over the next few months. Climate models may also be configured to make predictions of the seasonal-to-interannual variations of the climate, a modelling approach generally referred to as seasonal forecasting.

2.2. Why seasonal forecasting is possible

Weather changes on a daily basis, by definition. While modern forecasting systems can accurately predict weather events (frontal movement, winds, thunderstorms, etc.) one or two days into the future, making predictions for three or four days in advance is less skilful. In fact, weather forecasts for southern Africa beyond seven days are for the most part meaningless. A prospective user may thus ask - how then is it possible to make seasonal forecasts with any skill? The answer is that at seasonal lead times, it is possible to predict deviations from the seasonal average of weather, i.e. the seasonal climate, with some skill. While these forecasts cannot predict the timing of a particular weather event with any accuracy, forecasts of the likelihood, or *probability* of above- or below-average conditions (rainfall or temperature, for example) are possible.

Much of the skill in predicting departures from normal seasonal totals or averages, often associated with atmospheric circulation patterns, has its origin in the slowly changing conditions at the earth's surface that can influence the climate. The most important surface condition affecting climate is the sea-surface temperature (SST), and, particularly, the SST in the tropical zones. The feature of the surface conditions that gives them the ability to influence the average of the weather conditions over an extended future period is the slowness with which they can change, and therefore the extended period over which they can exert their consistent influence. When the SST is higher than normal, it usually remains that way for several months, and sometimes for as long as a year or more, such as during the El Niño or La Niña (i.e., the warm and cold phases of the ENSO – the El Niño/Southern Oscillation) episodes of the tropical Pacific Ocean.

Box 2.1: Explanation of terminology used in seasonal forecasting

Probability-based forecasts

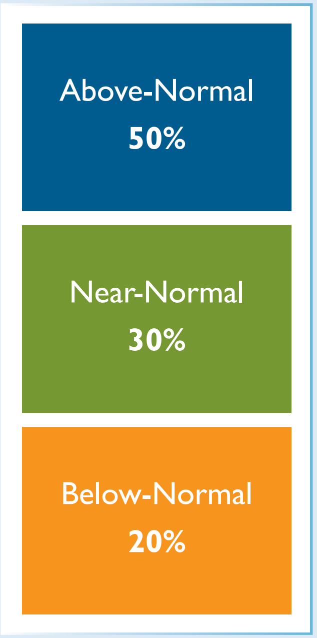
Seasonal forecasts are based on probabilities, as described above. Often, a forecast for tropical SST or seasonal rainfall conditions for the forthcoming season will provide an estimate of the probability of experiencing above-, below- or normal conditions. Such a *tercile*-based forecasting system assumes that, on average, there is an equal chance (based on past climate observations) of receiving above-, below- or normal rainfall in the next forecast period. In a *tercile*-based approach such as this, these *climatological* probabilities would be 33.3% in each category.

Note, firstly, that the sum of the probabilities across all three categories totals 100%. The probability in each category gives an indication with how much confidence a forecast is issued for that particular category. Over southern Africa, rainfall forecast probabilities are typically low and may never exceed 50%. Forecaster model developers strive towards optimal forecast systems, and such systems should, among other things, be able to produce reliable forecasts. A forecast system is considered reliable if there is a consistency between predicted probabilities of an event such as drought and the observed relative frequency of drought.

Forecast skill

Forecasters are always careful to ensure that their forecasts are in fact *skilful,* i.e. that the forecast does provide usable information about the probable conditions in the forthcoming season that are better than merely guessing that conditions will be normal, according to the long-run average conditions for that region. In general, if a forecast does not provide skill, i.e. using the forecast does not provide better information than simply using the long-run average estimate, then in general, no forecast should be provided and the user is advised to use long-run average conditions as the best forecast conditions in the forthcoming season.

Source: International Research Institute for Climate and Society (IRI)



The reason why seasonal climate forecasts (an indication of what might happen over the coming 3-6 months) over southern Africa are possible is not only linked to the Pacific Ocean, but also to the oceans around southern Africa. The surface temperatures of these ocean basins have a well documented effect on how the atmosphere on average may behave over the subcontinent, which may additionally be influenced by the slowly changing land surface. Forecast models have been developed to predict the future state of the global oceans and also how this state may influence seasonal-average weather. In fact, with the advent of state-of-the-art coupled ocean-atmosphere models, seasonal anomalies may be predicted with elevated levels of skill. Verification of a wide range of forecast models indicates that rainfall and surface temperature predictability over southern Africa is highest during the mid-summer period when tropical influences start to dominate the atmospheric circulation over southern Africa. Spring rainfall and temperatures over the region are poorly predicted on a seasonal time scale, while higher skill is found for the autumn months.

2.3. The evolution of the science of seasonal forecasting in southern Africa

Objective modelling of the variability of the seasonal climate of southern Africa originated as recently as the early 1990s. Initially, operational forecasts were entirely based on statistical models, with a strong emphasis on SST anomalies as predictors, and issued as deterministic statements on the expected evolution of seasonal rainfall and temperature anomalies across southern Africa several months ahead. However, during the end of the 1990s dynamical global circulation models (GCMs) were starting to be used for operational seasonal forecasting. In addition to the use of GCMs, statistical models continued to be used to empirically recalibrate and downscale forecasts to regional and station level. For a short while dynamical downscaled forecasts were also issued operationally. The latest operational seasonal forecasts produced within South Africa are based on *multi*-model ensemble prediction systems that incorporate probabilistic forecasts produced by models being run at both local and international centres (e.g. see www.gfcsa.net).

2.4. Types of products

The chaotic inherent variability of the atmosphere requires seasonal climate forecasts to be expressed probabilistically (see Box 2.1). At present, the most commonly used way to visualise seasonal forecasts is to display them on maps that show the likelihood of predicted rainfall and temperature anomalies exceeding certain predetermined thresholds. These thresholds are typically terciles values or the 15th and 85th percentile values of the climatological record (Figure 2.1). The latter thresholds are being used to predict whether or not a coming season will be extreme. Another significant contribution from the South African modelling community is the development of an operational El Niño – Southern Oscillation (ENSO) probabilistic forecast system, also based on a multi-model forecast approach (Figure 2.2). Other ways of indicating the probabilistic nature of forecasts is to use the mean or median of a model ensemble to indicate the most likely outcome, with a measure of statistical confidence also provided to indicate how significant the mean or median change is given the spread of the model ensemble.

2.5. Usability

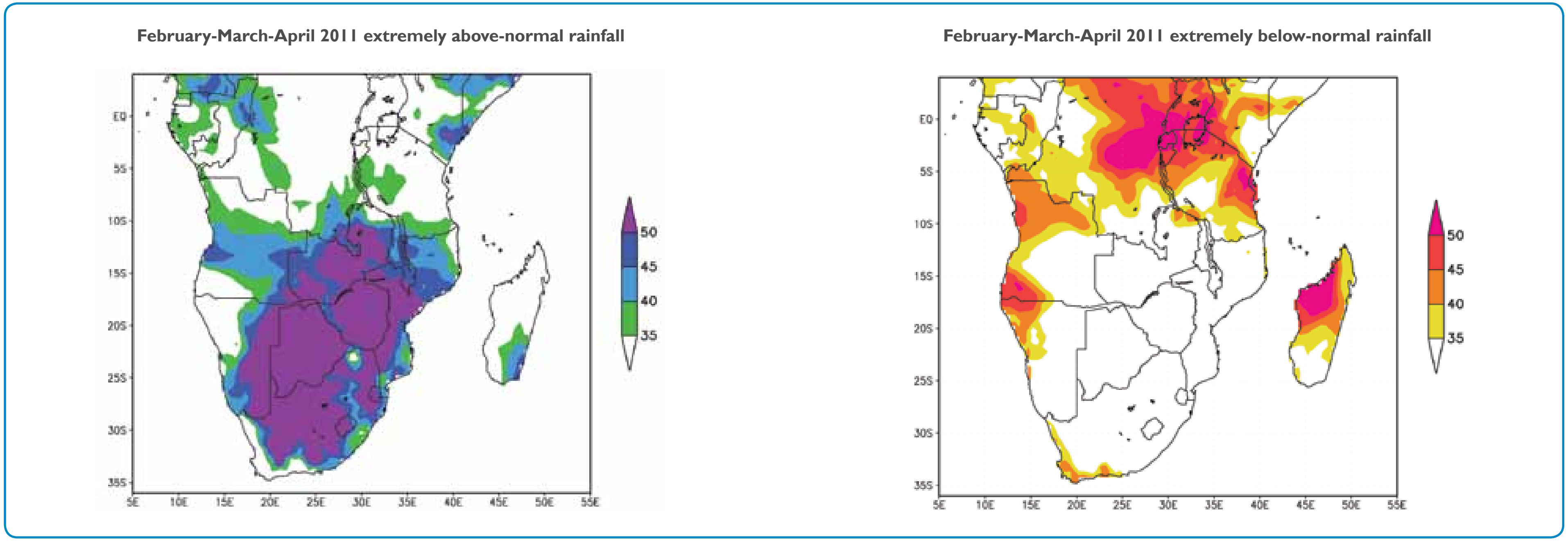
Seasonal prediction systems, if carefully targeted and of sufficient skill, can be a useful tool for reducing the risks related to seasonal climate extremes. While climate change projections are suggesting an increase in rainfall and temperature extremes during mid-summer over southern Africa, these extremes are not expected to happen every year and seasonal forecasts can indicate whether or not a coming summer season is to be associated with such extremes. However, a problem identified with seasonal forecasts is that there are large uncertainties in the predictions. For example, weather forecasts for the next day may be predicted correctly nine out of ten consecutive days, but for seasonal time scales, even during the mid-summer season of highest predictability, forecast are typically correct only about three out of five summer seasons.

There are also, moreover, difficulties in understanding forecast implications. For example, as stated previously, most of the seasonal rainfall and surface temperature forecasts are typically presented in rainfall and temperature categories representing probabilities for the highest, middle and lowest third of seasonal values to occur. However, these probabilities almost invariably lack a high level of confidence (for example, the highest forecast probabilities for temperatures are most frequently around 50% or 60%, compared to the climatologically expected probability of 33% associated with three categories). Moreover, the seasonal-mean temperature as target variable does not necessarily map well onto heat-wave occurrence. Although higher-than normal seasonal-mean temperatures will often be associated with a higher risk of heat-waves, it is possible for the seasonal-mean temperatures to be unusually high but yet for no heat-waves to occur because of the frequent occurrence of moderately hot days during the season. On the other hand, the seasonal-mean temperature may be unusually low, but yet isolated heat-waves may occur.

Thus even when seasonal predictions are understood properly, it may not be obvious how to use them since the uncertainty in the predictions is very high and the predicted variable may not be immediately relevant to an impact or decision, as demonstrated in the previous example. This notion does not imply that seasonal forecasts cannot be useful. These problems simply emphasise the need for the development of tools that can translate such information to quantities directly relevant to end-users, and thus for better communication between modelling centres and end-users. Delivery and uptake of seasonal forecast information is thus as substantial a challenge as the actual production of skilful seasonal forecasts.

2.6. The future of seasonal climate modelling

Seasonal forecast models are potentially extremely useful tools for managing risks due to climate variability, and so forecast producers are constantly seeking ways to improve their performance and skill. Predicting extreme climate anomalies in advance for the coming season, offers disaster management authorities the ability to prepare and respond in time. However, many of the more widespread disasters (e.g. floods and droughts) are only simulated to a limited degree by the coarse resolution GCMs, suggesting improvements may come through downscaling, running the GCMs at a higher resolution (to capture the influence of topography) and improvements to the simulated interactions between the land, ocean and atmosphere. Furthermore, the changing climate (through increases in anthropogenic emissions) needs to be incorporated into seasonal forecast schemes as the baseline climate state is constantly changing. Modellers in the region are contributing to the international effort of improving models. Such efforts include the development of fully coupled models to be run at high horizontal and vertical resolutions in order to better resolve oceanic and atmospheric processes and by producing large forecast ensembles, all of which require an increase in computing power. Such modelling efforts are also trying to address the prediction for time scales between that for weather forecasts (typically seven days ahead) and seasonal forecasts, and between seasonal forecasts and multi-decadal climate change projections. One example of this is an experimental 'attribution' forecast, which attempts to show how seasonal forecasts are themselves affected by climate change. However, prediction on decadal time scales is a relatively new field of modelling


February-March-April 2011 extremely above-normal rainfall

February-March-April 2011 extremely below-normal rainfall

Figure 2.1: Multi-model probabilistic forecast for the likelihood of February-March-April 2011 rainfall totals exceeding the 85th (extremely wet; left panel) and 15th (extremely dry; right panel) percentiles of the climatological record. This forecast was issued early January 2011. The bars on the right-hand side of the panels reflect the forecast probabilities. [Note: the larger part of South Africa was associated with unusually high rainfall totals observed during the forecast period].

research and although no one can argue against the potential usefulness of predictions for the next 10 years, decadal climate predictions will be highly experimental until we have developed a much better understanding of the physical mechanisms of decadal climate variability. Model development and improvement efforts and the study of the climate system with expanded ocean, land, atmosphere and ice observational networks are needed to achieve these objectives.

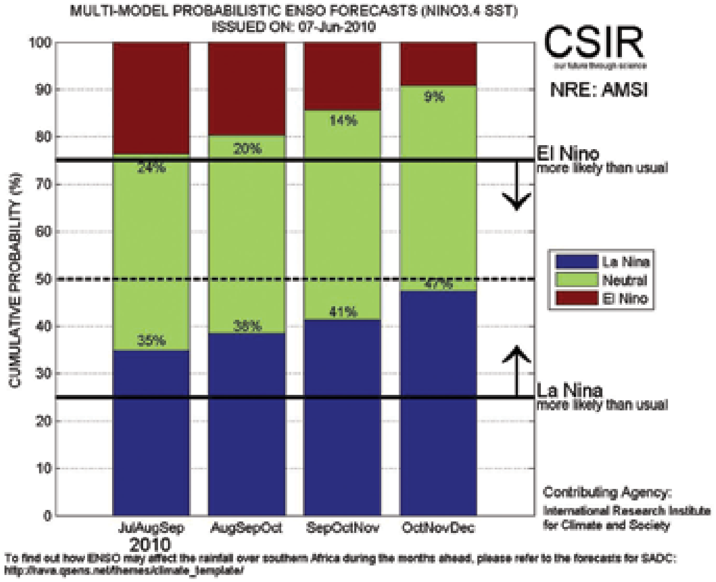


Figure 2.2: Multi-model probabilistic El Niño-Southern Oscillation (ENSO) forecast, issued in early June 2010 for the period July to December of the same year. This forecast shows how the likelihood of a La Niña event to occur during the 2010/11 summer season increases toward the end of the year. [Note: the observed La Niña of 2010/11 was identified as an event of moderate strength].

Training stakeholders in southern Africa on the effective use of seasonal forecasts for preparedness and response planning.

Chapter 3: Regional scenarios of future climate change over southern Africa

By Mark Tadross, Claire Davis, Francois Engelbrecht, Alec Joubert and Emma Archer van Garderen

Global Climate Models, statistical downscalings and dynamical downscalings all show an increase in projected temperatures. A decrease in winter (JJA and SON) season rainfall over the southwestern part of South Africa is indicated, whereas southeastern South Africa generally receives more rainfall. During SON, rainfall is consistently suggested to decrease over parts of Zambia, Zimbabwe and western Mozambique.

3.1. Introduction

Across the globe, increasing surface temperatures over the recent past point to a "discernible human influence on climate" (IPCC, 2007). As stated earlier, the Intergovernmental Panel on Climate Change – the global scientific body that regularly assesses and reports on the scientific developments around climate change – has concluded that climate change is happening, and that it is "virtually certain" to be due to human activity. The human activities that are thought to cause climate change include the burning of fossil fuels and deforestation, that in turn lead to an increase of greenhouse gas concentrations in the earth's atmosphere.

In this chapter, we provide projections of regional climate change so that decision-makers can better understand the nature of the projected changes, and how to take this into account when formulating and implementing adaptive strategies.

3.2. Determining future climate

Global Climate Models (GCMs) are the fundamental tools used for assessing the causes of past change and projecting future change. They are complex computer models based on the laws of physics, which represent interactions between the different components of the climate system such as the land surface, the atmosphere and the oceans. Since future levels of greenhouse gas emissions in the atmosphere are dependent on our behaviour and policy choices – crucially whether or not we continue to depend on fossil fuels or switch to renewable energy sources – the models simulate climate under a range of emission scenarios. Each scenario represents a plausible future (see Box 3.1 and 3.2). This is an important reason why the IPCC Fourth Assessment Report projects future global average temperature change to be in the range of 1.1°C to 6.3°C degrees by the end of the century: the lower estimate of 1.1°C is based on an emissions scenario where behaviour and policy mean that fewer greenhouse gases are emitted; whereas the higher estimate of 6.3°C is a "worst case" scenario, where emissions continue to increase at a rapid rate. That there is a range of future possibilities is an important concept to understand clearly, as it means that we can only suggest futures that may be more *likely* than others.

Global climate models

GCMs can reliably and skillfully project changes in temperature, because the physical processes responsible for warming are well-captured by the models. But these models are often less-skilled in translating that information into changes in rainfall and other parameters at the local scale. This is because GCMs are typically applied at a spatial scale of 200-300 km, and often cannot capture the physical processes and features of the landscape which are important determinants of local and regional climate. For example, thunderstorms occur on spatial scales which are too small for GCMs to resolve. This means that GCMs are unreliable estimators of rainfall in regions where convection (the physical process which produces rainfall in thunderstorms) is important. 'Downscaling' techniques, which translate changes in large-scale atmospheric circulation (which GCMs generally reproduce well) to finer spatial scales, are widely preferred for projections of climate change at local and regional scales.

Box 3.1: Is one GCM better than another at projecting future change?

While some GCMs are better at simulating the present observed climate than others, this does not necessarily mean that they are better at simulating future change. Comparing one GCM against another and against observations is also not an easy task; whilst one GCM may better simulate monthly mean rainfall and temperature, it may not be better in simulating the daily frequency or diurnal cycle of rainfall. Another problem when trying to choose a single 'best' GCM is that the future scenarios are all linked to the representation of physical and dynamical processes within that specific model - this may create the impression of a narrowly determined future, which may not fully span the range of potential future change.

It may be, however, that a GCM is unable to capture important features of the regional climate e.g. the annual cycle of rainfall, which reduces confidence in its ability to simulate key processes. Under these circumstances it may legitimately be argued that the GCM should not be used to assess future changes. A suitable approach is therefore that we seek the largest number of GCMs (excluding those that can be shown to be unsuitable) and that future change is expressed either as a range of future changes or as a summary statistic (e.g. median) of the distribution of projected changes, with some measure or recognition of the spread of possible future climates also provided.

Box 3.2: Predictions, projections and scenarios of climate change

Predictions are an attempt to forecast the future state of the climate over relatively short timescales. The most well-known example is that of weather predictions, although other examples include climate predictions over seasonal or inter-annual timescales. An important feature of all predictions is that they are verifiable; because of their shorter duration, performance of the forecast can always be compared against what actually happened.

A *projection* is a statement of a possible (hopefully likely) future state of the climate system dependent on the evolution of a set of key factors over time (e.g. emissions scenarios – see below). Given the long-term nature of climate projections, they are generally not verifiable in the short term.

A *scenario* is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative of how the future can unfold. A set of scenarios is often adopted to reflect the possible range of future conditions, which can be based on changes in the climate system, socio-economic circumstances or other potential future changes. The IPCC published its Special Report on Emissions Scenarios (SRES) which describes a range of possible scenarios based around four 'storylines': A1, B1, A2 and B2. These storylines assume different paths of development for the world, greater weight being given to environmental (B family) or economic (A family) considerations, and more global (A1, B1) or regional (A2, B2) development. Each of these scenarios has an associated emissions pathway for the period 2000-2100. These emission pathways describe the amount of greenhouse gases (and other atmospheric gases) emitted through human activity in the future. GCMs can then use these future emissions (which define changes in the concentration of these gases in the atmosphere) to model the future climate.

Determining regional climate change

As stated earlier, the spatial resolution of GCMs is too low (200-300 km grids) to accurately represent the circulation patterns and physical processes (e.g. convection) that determine climate at regional and, particularly, local scales. In order to generate more detailed simulations of regional and local climate, two main types of downscaling methodologies may be employed – statistical (empirical) and dynamical downscaling (see Box 3.3). Downscaling is the term used to describe the process through which the projections of change from GCMs are translated to the regional and local scales. The downscaled scenarios at a finer spatial scale are more useful for assessing local and regional impacts, adaptation and developing policies.

Downscaled projections are increasingly being used in studies of regional impacts and adaptation worldwide, and it is thus critical that the advantages and limitations of these data sets are well understood. A key limitation of all downscaling techniques is that its performance is highly dependent on the quality of the input data, and that downscaled data may inherit assumptions and errors in the GCM simulations. A suite of GCM and downscaled projections should be used in any impact and adaptation assessment, in order to consider the range of climate change projections. Although downscaled simulations are in theory expected to provide a more accurate description of regional climate and its expected future change, the higher resolution offered by these simulations does not necessarily mean higher confidence in the projections.

Understanding risk and uncertainty

While we often have a relatively more accurate description of past climatological events, we can never be certain about what will happen in the future. For this reason, the issue of uncertainty is crucial to understanding future climate change, especially when designing adaptation strategies that will benefit both present and future socio-economic situations. Uncertainty

Box 3.3	**Statistical (empirical) downscaling**	**RCMs (Regional Climate Models)**
Definition	Large-scale climate features are statistically related to local climate for a region – historical observations are utilised	A dynamic climate model (either a limited-area model or variable resolution global model) is nested/nudged within a GCM
Advantages	▪ Station scale output ▪ Less computational resources required ▪ Available for more GCMs, allowing an assessment of probabilities and risks ▪ Can be applied to any observed variable, e.g. streamflow	▪ 10-50 km resolution output ▪ Physical interactions and local fine-scale feedback process (not anticipated with statistical methods) can be simulated ▪ Improved simulation of regional climate dynamics ▪ Can include additional processes not included by the GCM simulations ▪ Consistent with GCM simulations ▪ Do not rely on the assumption of stationarity[1] in climate (Wilby et al., 2003)
Limitations	▪ May not account for some local scale interactions, e.g. between the land and the atmosphere ▪ Assumes present-day statistical relationships between synoptic and local-scale climates will persist into the future (Wilby et al., 2003) ▪ Requires high quality observational data ▪ Choice of predictor variables can change results ▪ Results do not feed back to the GCM ▪ Choice of statistical transfer scheme can affect results	▪ Computationally demanding ▪ Only a few scenarios usually developed ▪ Susceptible to the choice of physical parameterisations ▪ Not easily transferred to new regions ▪ Limited regional-to-global feedbacks may be considered, but often are not

[1] Stationarity assumes that the mean, variance and other statistical properties are constant in time (and space if applicable).

does not mean that we have no confidence in our projections of future climate, rather, it implies there is a probability or level of confidence associated with a particular outcome. Indeed all climate projections (as well as shorter-range and seasonal forecasts, as shown in Chapter 2) are couched in terms of the probability of particular climate conditions occurring in the future. This is a common framework within which humans operate; determining likely future risks and opportunities, and used in many different applications, for example in financial and investment decision-making.

To be able to assess risk, one needs to consider all sources of information. It is therefore essential that a probabilistic framework is used to develop projections which should incorporate different sources of information. The IPCC defines four sources of uncertainty within projections of future climate change.

- *Natural variability.* There are certain natural forcings of climate that are extremely difficult or even impossible to predict, but that may impact on future climate change. For example periods of enhanced volcanic activity in the future may lead to enhanced concentrations of sulfur dioxide in the stratosphere, which through the reflection of solar radiation back to space will slow down the rate of global warming. Additionally, due to the limiting factor of imperfect observations of current climate and its variability (both in time and space) we have a limited understanding of natural variability. It is difficult to characterise this variability and the degree to which it may enhance or reduce the climate signal due to human activity.
- *Future human activity driven emissions.* Much of future projected change, at least in terms of the magnitude of change, is dependent on how society will change its future activity and emissions of greenhouse gases. Even so, the world is already committed to a degree of change based on past emissions (at least another 0.6°C warming in the global mean temperature). Human responses to managing emissions may result in a projected global mean temperature change of between 1.1° and 6.3°C by the end of the century (IPCC, 2007).
- *Uncertainty in the science.* This is further complicated within Africa because of limited understanding of the regional dynamics of the climate of the continent. There may be aspects of the regional climate system which could interact with globally forced changes to either exacerbate or mitigate expected change, e.g. land-use change.
- *Uncertainty regarding the regional response to large-scale circulation changes.* Equally valid and scientifically defensible downscaling tools may project different responses of the regional climate to larger-scale forcing. That is, there is an uncertainty envelope associated with the different possible outcomes of regional climate to large-scale forcings. Additionally, all downscaling techniques are imperfect in their description of the regional climate system, just as GCMs are imperfect in describing the global climate system. This leads to additional uncertainties regarding projections of regional climate change.

3.3. Projected climate change in southern Africa

Projections based on GCMs

All GCMs used here were included in the IPCC 4th Assessment Report and we focus on GCMs forced with both the SRES B1 (assumes society will reduce its use of fossil fuels and increase clean technology, as well as an emphasis on social and environmental stability) and A2 (which assumes that society will continue to use fossil fuels at a moderate growth rate, there will be less economic integration and populations will continue to expand) emissions scenarios (IPCC, 2000). The choice of these two scenarios gives us a reasonable estimate of the upper and lower limits of projected regional climate changes, consistent with the range provided in the IPCC AR4. Details of the GCMs used for each scenario are provided in Box 3.4.

Rainfall

Figures 3.1 to 3.4 show the median change in rainfall from the available GCMs for each scenario and for each of the four seasons: December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON). Also shown in each figure is the percentage of models which agree on a positive change in rainfall, i.e. high percentages (>80%) indicate that most of the models (13 B1 and 15 A2) project an increase in rainfall, whereas low percentages (<20%) indicate that the models mostly tend to suggest a decrease in rainfall. Percentages close to 50% (e.g. 30-60%) suggest that the different models disagree on the sign of change; i.e. whether it will be positive or negative. This is one way of representing uncertainty in the model projections and this information can be combined with the median (50th percentile) estimates to suggest where the models are confident of increasing or decreasing rainfall.

Box 3.4: GCMs used to derive the projected climate change (from the 1960-2000 baseline period) by 2030-2060[2]

Originating group(s)	*Country*	*I.D.*	*B1 scenario*	*A2 scenario*
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0	Yes	Yes
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T63)	Yes	Yes
Météo-France / Centre National de Recherches Météorologiques	France	CNRM-CM3	Yes	Yes
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.5	Yes	Yes
Meteorological Research Institute	Japan	MRI-CGCM2.3.2	Yes	Yes
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM	Yes	Yes
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0	Yes	Yes
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1	Yes	Yes
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	Germany/Korea	ECHO-G	Yes	Yes
Institut Pierre Simon Laplace	France	IPSL-CM3	Yes	Yes
Instituto Nazionale di Geofisica e Vulcanologia	Italy	INGV-SXG	No	Yes
Institute for Numerical Mathematics	Russia	INM-CM3.0	Yes	Yes
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(medres)	Yes	Yes
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadCM3	Yes	Yes
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadGEM1	No	Yes

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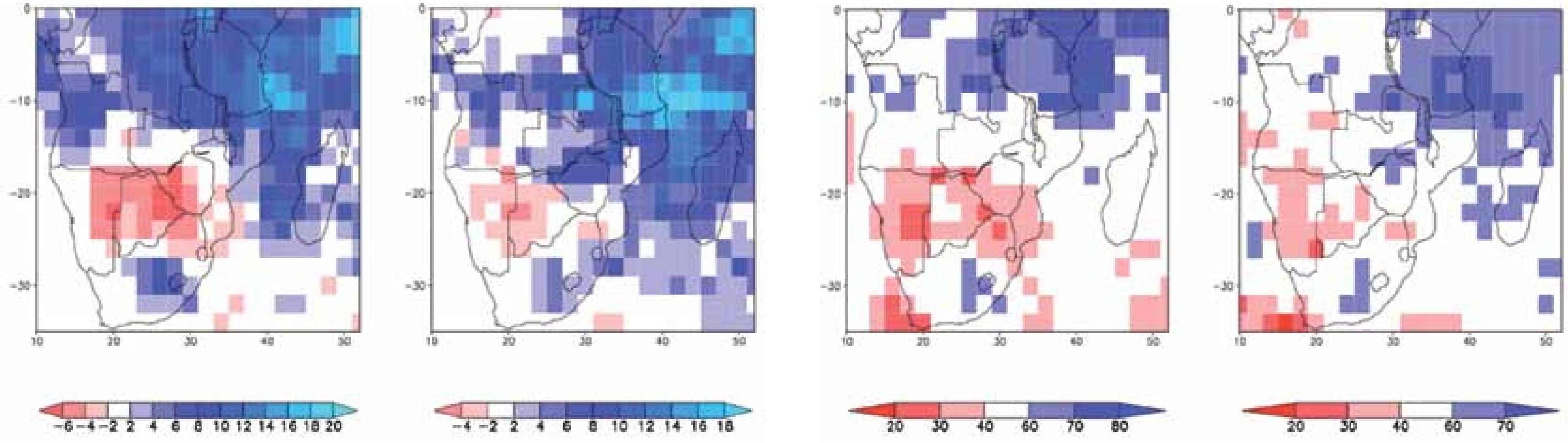
[2] http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

It is notable that there are only subtle differences between the B1 and A2 scenarios, which suggests that for this mid-century period the choice of assumed emissions scenario makes little difference to the projected changes in rainfall, at least when considering a range of GCMs. Given that some differences may be due to the different GCM sets used in each scenario, it is advisable that little attention is paid to the differences between the scenarios.

Figure 3.1 suggests that during DJF, the main rainfall season for large parts of southern Africa, there is a tendency for the models to suggest drying over central southern Africa (though this is usually simulated by less than 70% of the GCMs), with slightly more consistently simulated increases further north over East Africa. Similar tendencies are noted during MAM (Figure 3.2), although with slightly more consistently simulated decreases in rainfall over the southwest parts of the continent. In all cases it should be noted that small and isolated regions (e.g. small patches of blue in the A2 model consistency figure for DJF) should be ignored as they represent only 1 or 2 GCM pixels, at which scale it is debatable if the GCMs have sufficient skill.

For JJA (Figure 3.3) the majority of models are simulating a decrease in rainfall over most of the region. However, since these changes are small and JJA is the dry season in most countries, the impact of this decrease is likely to be minimal. An exception is the southwestern Cape of South Africa, a winter rainfall region for which the general projected decrease in rainfall may be significant. Also of importance is the consistently simulated decreases in rainfall during SON (Figure 3.4) across much of the southern African region. This is the period incorporating the start of the rains and suggests a reduction in early season rainfall.

Projected change in summer rainfall based on GCMs


a) B1 50th percentile

A2 50th percentile

b) B1 Model percentage

A2 Model percentage

Figure 3.1: DJF season: a) Median change in average rainfall by 2030-2060 (mm season^{-1}); b) Percentage of models suggesting an increase in rainfall.

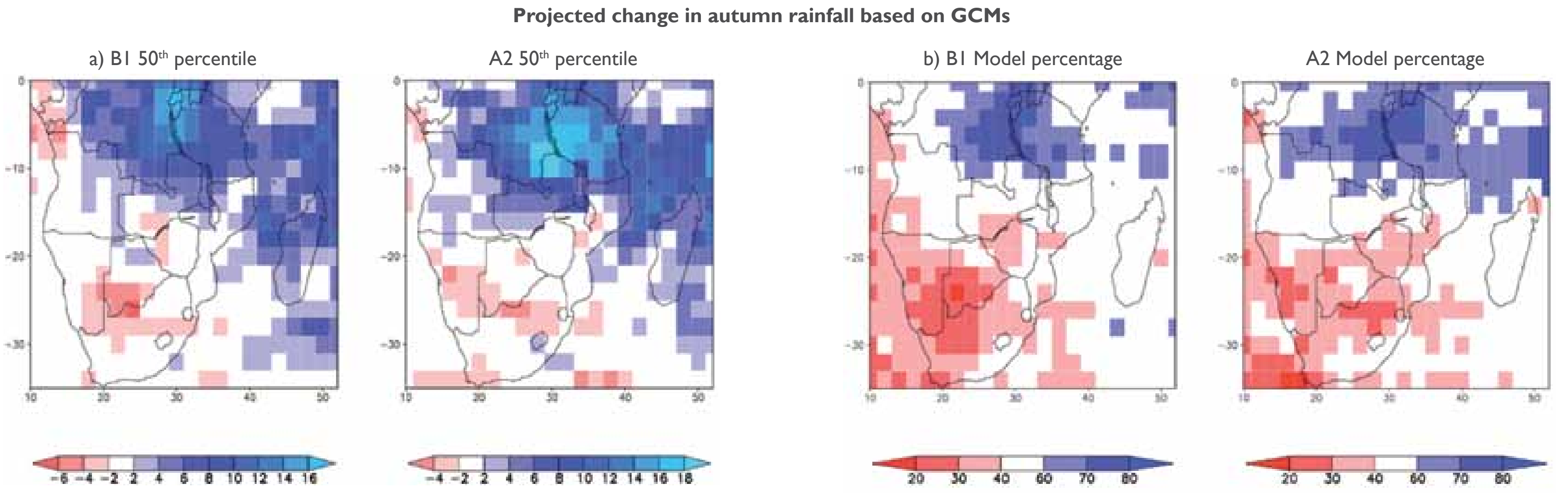


Figure 3.2: MAM season: a) Median change in average rainfall by 2030-2060 (mm season^{-1}); b) Percentage of models suggesting an increase in rainfall.

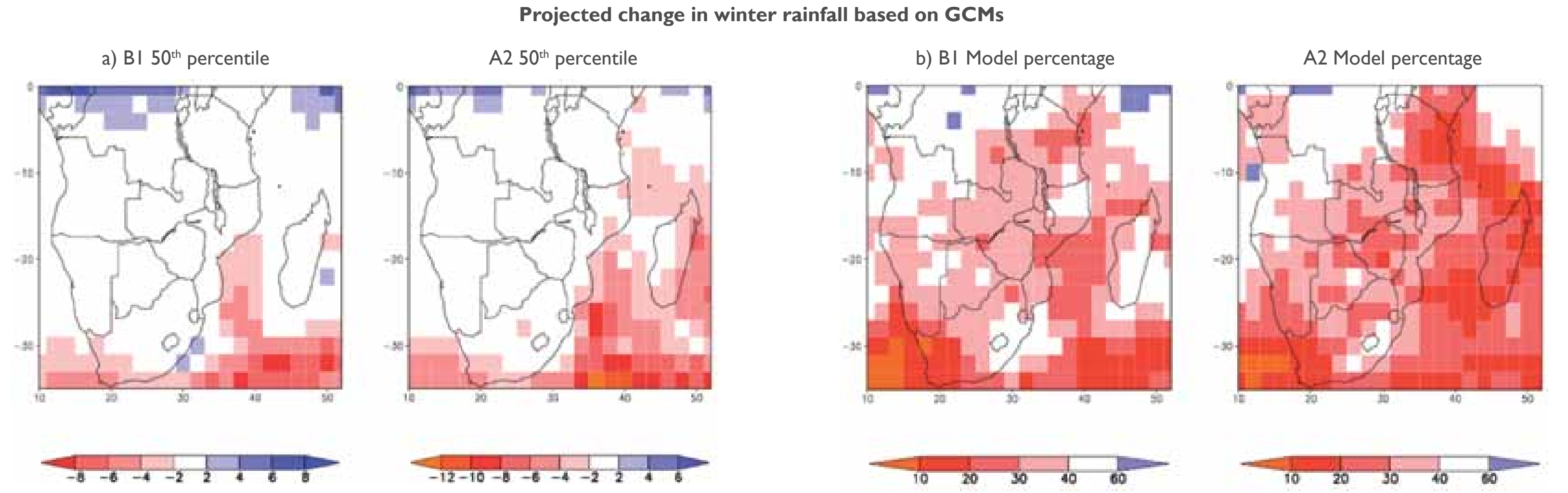
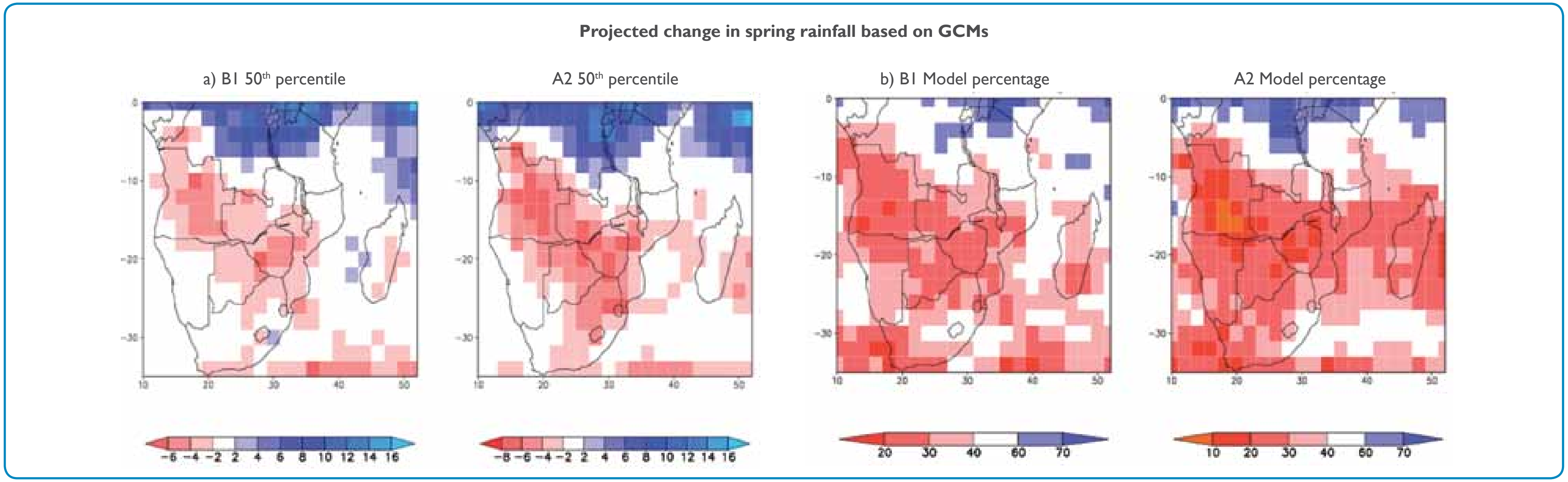


Figure 3.3: JJA season: a) Median change in average rainfall by 2030-2060 (mm season^{-1}); b) Percentage of models suggesting an increase in rainfall.



Projected change in spring rainfall based on GCMs

a) B1 50th percentile

A2 50th percentile

b) B1 Model percentage

A2 Model percentage

Figure 3.4: SON season: a) Median change in average rainfall by 2030-2060 (mm season^{-1}); b) Percentage of models suggesting an increase in rainfall.

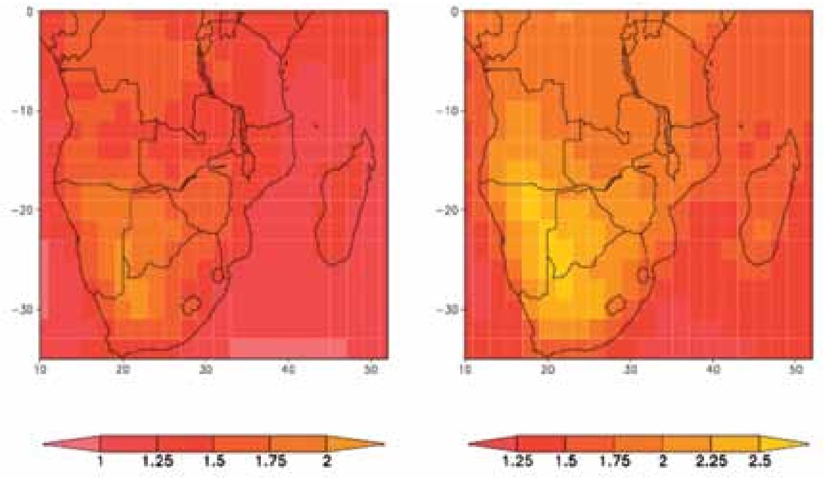
Temperature

Figure 3.5 shows the median change in average annual surface temperature from the GCMs for the B1 and A2 scenarios. Because all models indicate an increase in temperature we do not show the model consistency as we did for rainfall. It can be seen that temperatures are expected to rise between 1 and 3°C over most land areas by approximately 2060. Increases are greatest under the A2 emissions scenario and towards the arid regions in the southwest of the continental landmass, which are also the regions which are suggested to receive the largest decreases in average rainfall in the future. Temperatures are also expected to rise more during the dry seasons of JJA and SON than during the wetter DJF and MAM seasons (not shown). Temperature increases along the coastal regions are projected to be generally lower compared to the interior regions, due to the moderating effects of the ocean (coastal temperatures are largely controlled by those of the surrounding maritime air masses).

Winds

Figure 3.6 indicates the median change in surface (10 m) wind direction and speed simulated by the 15 GCMs under the A2 emissions scenario. We only show the A2 emissions scenario as the changes look similar in the B1 scenario (though slightly smaller) and do not significantly alter the following discussion. For DJF, changes are mostly for an increase in easterly wind flow south of 30°S, which weakens the normal westerly flow in the far south and strengthens the easterly flow further north (south of Madagascar and southwest of the continent). These changes are linked to changes in the regional circulation dynamics, namely the decreasing influence of the westerlies and associated retreat of mid-latitude storms to the south – with a simultaneous increase in the strength of the high pressure anticyclones over the Indian and Atlantic Oceans (notice the increase in offshore flow southwest of the continent).

During MAM the main feature is an increase in the southeast monsoon over the tropical Indian Ocean, which increases the advection of warm moist air over east Africa and contributes to the increases in rainfall seen in Figure 3.2. The most significant feature in the JJA and SON seasons is the increase in the strength of the Atlantic high pressure system, resulting in increased offshore flow near Cape Town. In both seasons there is also an indication of reduced westerly flow to the south, though this is a small change and is likely less consistently simulated by the GCMs.

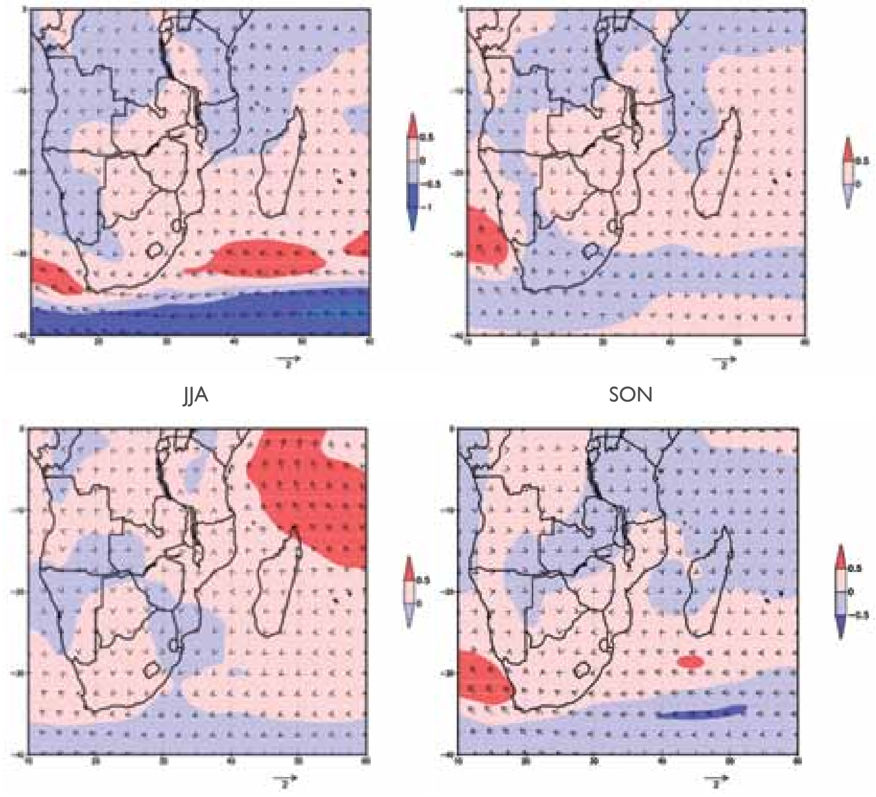


Projected change in annual temperatures based on GCMs

B1 50th percentile

A2 50th percentile

Figure 3.5: Median change in average annual temperature (°C) by 2030-2060, relative to the 1960-2000 period. B1 scenario left and A2 scenario on the right.



Projected change in seasonal wind direction and wind speed based on GCMs

DJF

MAM

JJA

SON

Figure 3.6: Median changes in 10 m wind direction and wind speed (by 2030-2060, relative to 1960-2000), simulated by the 15 GCMs in the A2 scenario. Arrow shows relative scale of 2 ms^{-1}.

Projections based on statistical downscaling of GCMs

Ten GCMs (CGCM3.1(T63), CNRM-CM3, CSIRO-Mk3.5, MRI-CGCM2.3.2, ECHAM5/MPI-OM, GFDL-CM2.0, ECHO-G, IPSL-CM3, MIROC3.2(medres), GFDL-CM2.1; see Table 3.5) were statistically downscaled by the Climate Systems Analysis Group at the University of Cape Town using the Self Organizing Map Downscaling (SOMD) method (Hewitson and Crane, 2006). Satellite-derived rainfall estimates[3] (RFE) at 0.1° spatial resolution produced by the Climate Prediction Centre and ERA-interim[4] reanalysis temperatures (0.75° spatial resolution) are used as the observations for the downscaling. The temperature data compare well with observed temperatures from the Climatic Research Unit (CRU) – presented in Chapter 1 of this volume – whereas biases in the RFE data (too many rain days with 2 mm or less) likely affect the derived magnitude of the projected changes in rainfall. For rainfall, the focus is therefore on the spatial patterns of change in order to identify regions where change is most consistently simulated between the different downscaled GCMs. All the changes assume an A2 SRES emissions scenario and are for the 2036-2065 period relative to the 1961-2000 period.

The downscaled scenarios of rainfall and temperature change over southern Africa are spatially presented in the following section, first for the annual and then seasonal projected changes. The change is expressed as an anomaly; the difference between the projected climate (2036-2065) and the average climate over of the last several decades (1961-2000). For rainfall, the median of all ten statistically downscaled models is shown, whereas for temperature the 10th percentiles, median and 90th percentiles (termed an envelope of change) of the ten statistically downscaled models are presented in order to demonstrate the range of future possibilities.

Rainfall

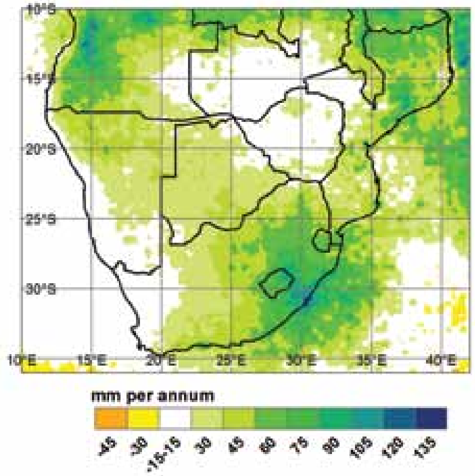
For most of the southern African region, an increase in rainfall of between 10 and 130 mm per year is projected from the median of the 10 statistically downscaled GCMs (Figure 3.7). The magnitude of median changes is small because the median expresses the 'middle' or 50th percentile of a range of downscaled models, some of which project negative and some of which project positive changes. It is therefore important not to assume that this represents the best 'prediction' but rather an indication of the most likely direction of change, i.e. positive or negative. Small areas along the western coast, central Zimbabwe, eastern Zambia and north-eastern Mozambique, suggest a decline in rainfall, whereas western and northern Angola, northern Mozambique, and eastern South Africa (including Lesotho) are simulated to experience higher annual rainfall totals than at present.

Seasonally the main changes occur during SON and DJF and can be summarised as (Figure 3.8):

- increases in rainfall during SON over southeastern South Africa and Angola, with decreases further north over parts of Zambia, Mozambique and Zimbabwe;
- decreases in rainfall during DJF over southern Zambia, Zimbabwe and southern Mozambique.

During all seasons, the winter rainfall region of western South Africa is expected to experience a decline in rainfall (Figure 3.8), whereas other regions of southern Africa are expected to receive more winter rainfall in JJA. Some areas receive more rainfall during MAM (Figure 3.8), which may suggest an extension of the main summer rainy season for some areas; but this remains speculative at present.

Projected change in mean annual rainfall based on 10 statistically downscaled GCMs



Data provided by CSAG
Map created by Claire Davis, CSIR

Figure 3.7: Projected changes in mean annual rainfall (by 2036-2065, relative to 1961-2000) expressed as the change in millimetres and based on the median of 10 statistically downscaled GCMs.

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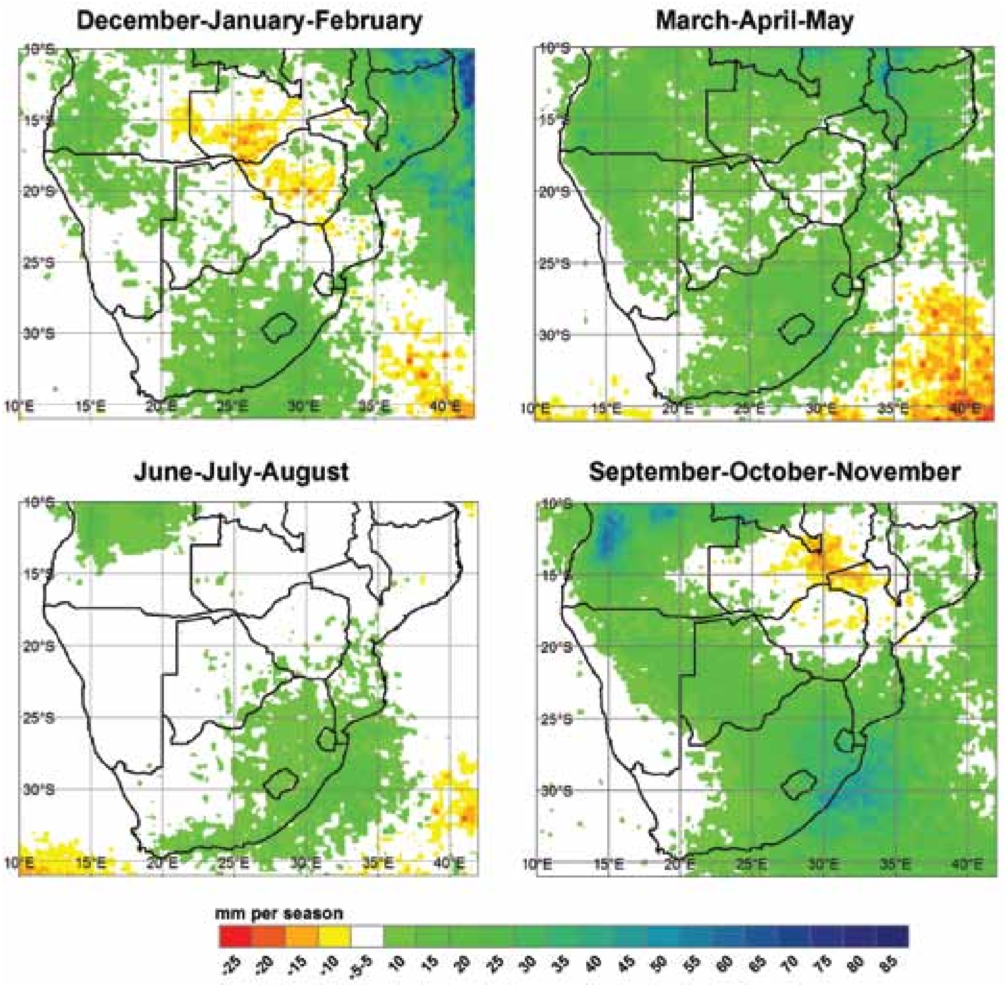
[3] http://www.cpc.ncep.noaa.gov/products/fews/rfe.html

[4] http://www.ecmwf.int/products/data/archive/descriptions/ei/index.html

Projected change in seasonal rainfall based on 10 statistically downscaled GCMs



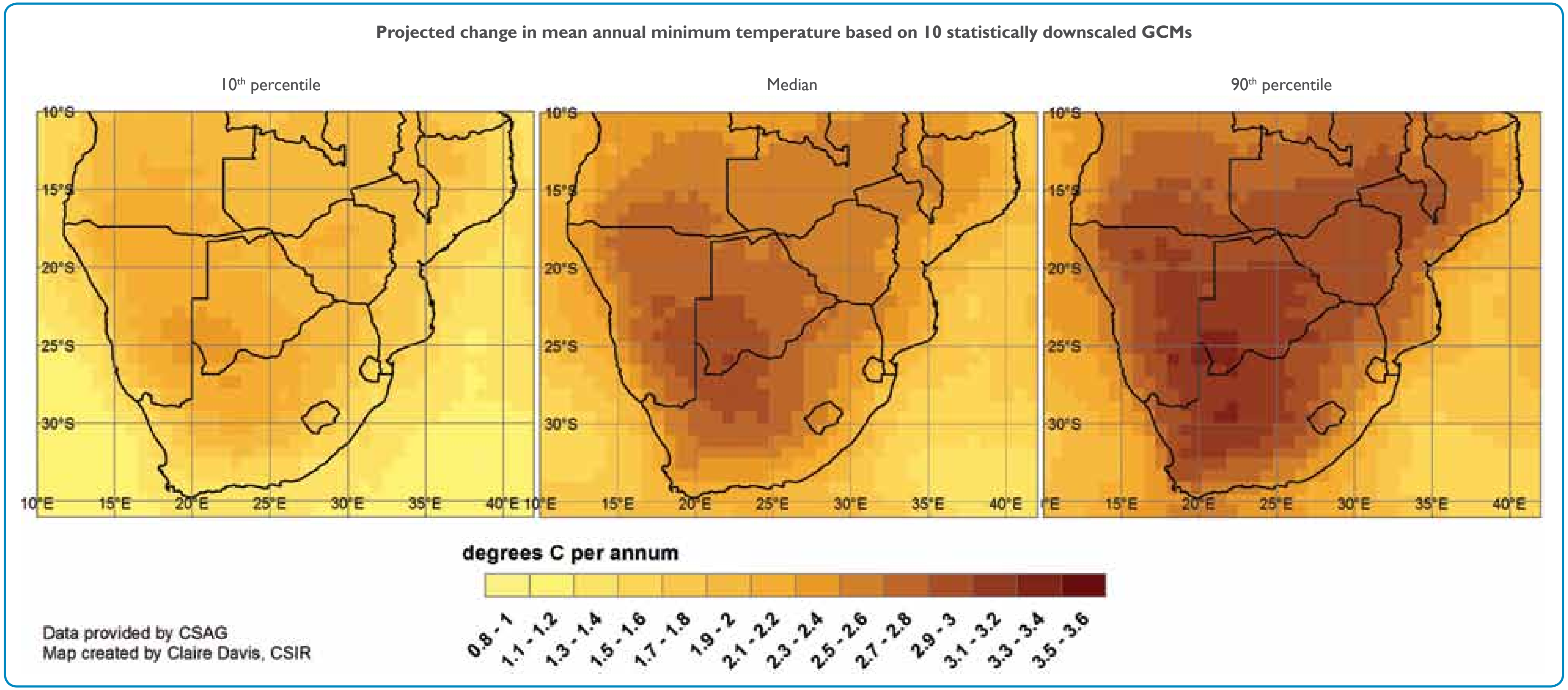
Data provided by CSAG
Map created by Claire Davis, CSIR

Figure 3.8: Projected changes in mean summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall (by 2036-2065, relative to 1961-2000) expressed as the change in millimetres and based on the median of 10 statistically downscaled GCMs.

Temperature

All ten statistically downscaled GCMs indicate an increase in temperature but differ in the magnitude of that increase; the 10th and 90th percentiles indicate the lower and upper bounds of the changes suggested by the 10 downscaled GCMs.

An increase in minimum and maximum temperature is expected across a region of between 0.8 and 3.60° C per annum (indicated by the maps in Figures 3.9 and 3.10). It is expected that the interior regions will experience more intense warming than the coastal areas. Spring (SON) is expected to experience the greatest increase in temperature compared to the other seasons (Figure 3.11).



Projected change in mean annual minimum temperature based on 10 statistically downscaled GCMs

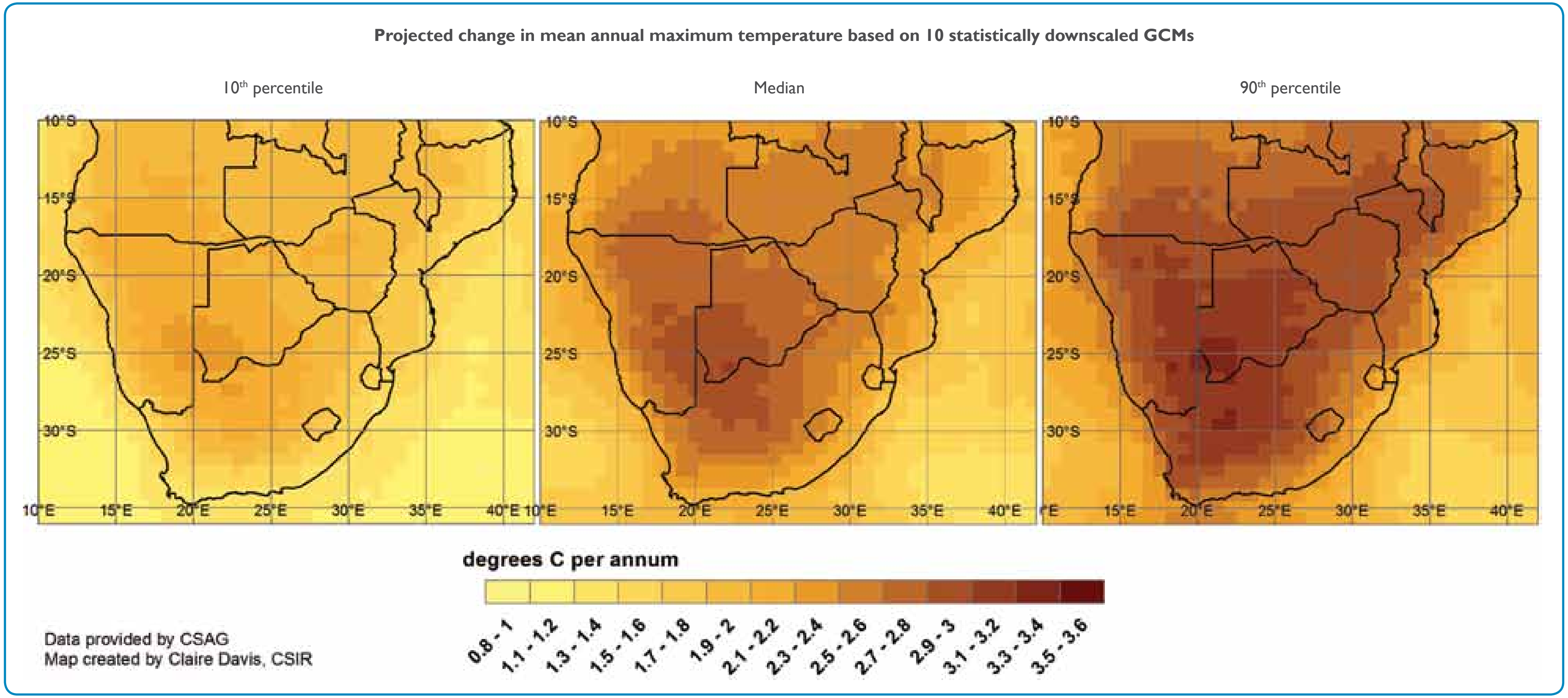
10th percentile

Median

90th percentile

Data provided by CSAG
Map created by Claire Davis, CSIR

Figure 3.9: Projected changes in minimum temperature (°C) by 2036-2065 relative to the 1961-2000 period based on the 10th percentile, median and 90th percentile of 10 statistically downscaled GCMs.



Projected change in mean annual maximum temperature based on 10 statistically downscaled GCMs

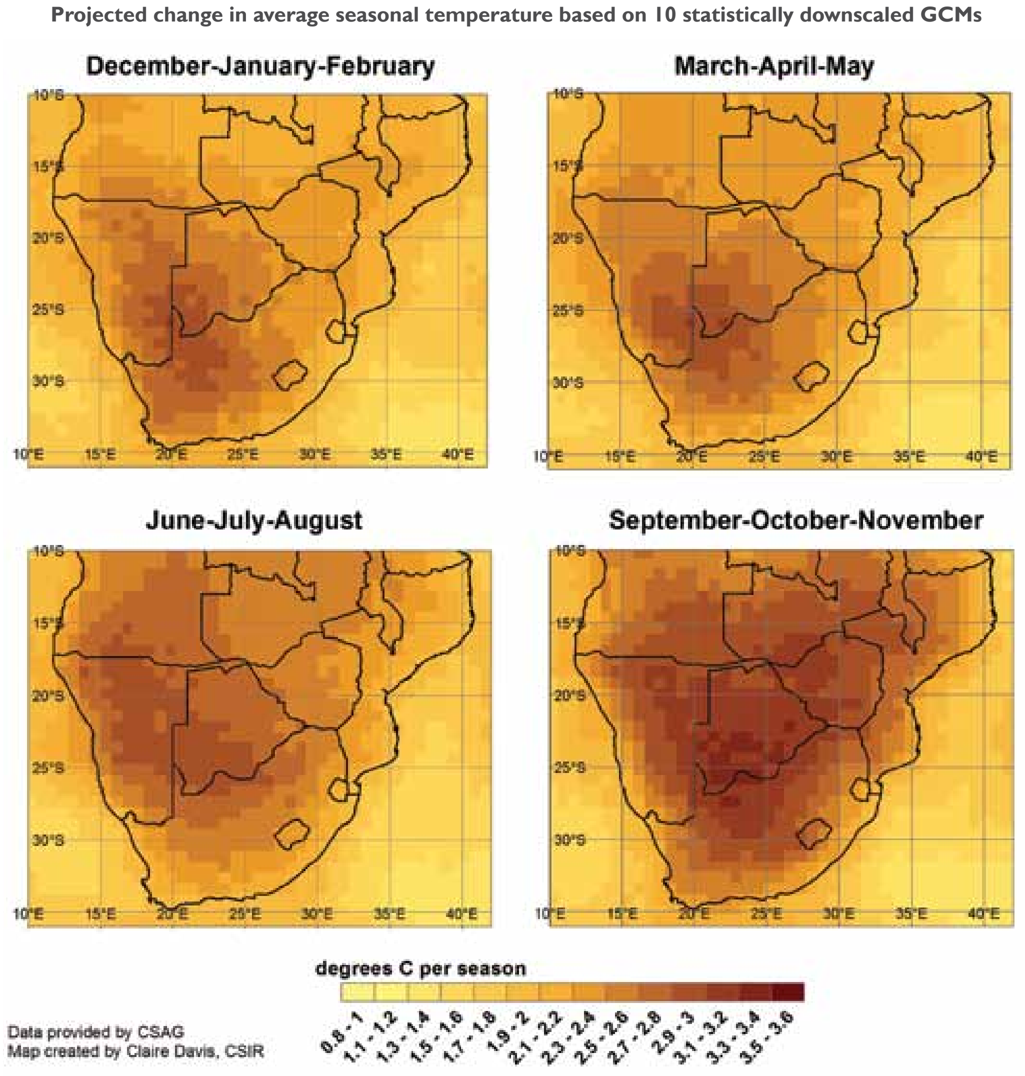
10th percentile

Median

90th percentile

Data provided by CSAG
Map created by Claire Davis, CSIR

Figure 3.10: Projected changes in maximum temperature (˚C) by 2036-2065 relative to the 1961-2000 period based on the 10th percentile, median and 90th percentile of 10 statistically downscaled GCMs.


Projected change in average seasonal temperature based on 10 statistically downscaled GCMs

December-January-February

March-April-May

June-July-August

September-October-November

Data provided by CSAG
Map created by Claire Davis, CSIR

Figure 3.11: Projected changes in average seasonal temperature (°C) by 2036-2065 relative to the 1961-2000 period and based on the median of 10 statistically downscaled GCMs.

Projections based on dynamical downscaling of GCMs

A set of six climate simulations has been performed by the Climate Studies, Modelling and Environmental Health (CSM&EH) Research Group of the Council for Scientific and Industrial Research (CSIR) in South Africa during 2010. In these experiments, a variable-resolution atmospheric global circulation model (AGCM) was applied as a regional climate model (RCM) to simulate both present-day and future climate over southern Africa and surrounding oceans - at high spatial resolution of about 0.5° in latitude and longitude. Boundary forcing data include the 1961-2100 simulated (but bias-corrected) sea-surface temperatures (SSTs) and sea-ice fields of six coupled global circulation models (CGCMs) that contributed to Assessment Report 3 (AR3) of the Inter-Governmental Panel on Climate Change (IPCC) - as well as topography, vegetation, surface albedo and surface roughness fields. All six projections are for the A2 emission scenario. The CGCMs that were downscaled are the CSIRO Mk3.5, UKMO-HADCM3, ECHAM5/MPI-OM, MIROC3.2 (medres), GFDL-CM2.0 and GFDL-CM2.1 (see details in Box 3.4).

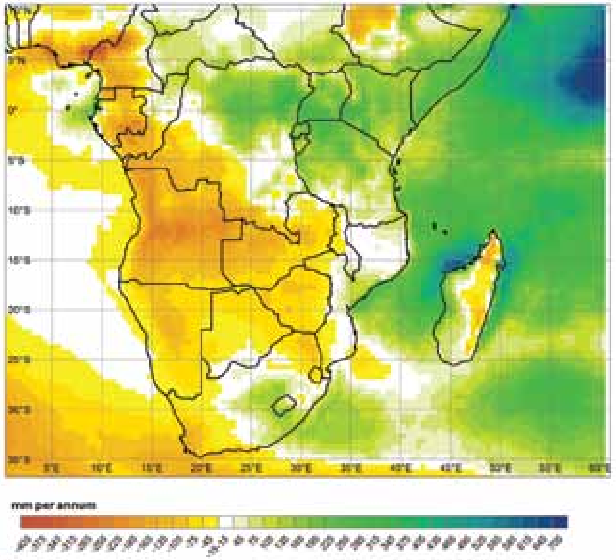
The AGCM used to perform the downscalings is the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Council (CSIRO) in Australia (McGregor, 2005). Earlier climate projection studies using CCAM over southern Africa, including verification of the model's ability to simulate present-day climate, are described by Engelbrecht et al., (2009) and Engelbrecht et al., (2011).

Rainfall

The median of change of the six dynamically downscaled models indicates that most of the southern African region is most likely to experience a decrease in annual rainfall (Figure 3.12), with rainfall increases suggested over east Africa and the central interior of southern Africa. This pattern of change is to a large extent consistent with that of the GCM median projection described earlier, indicating that the tendency of the set of models in each case is similar. The dynamic downscaling of changes in seasonal rainfall totals is similar to the pattern of change in the annual rainfall totals. Of particular interest is the relatively large rainfall decreases projected for the southwestern Cape of South Africa in JJA, and of relatively large rainfall increases projected for East Africa during DJF (Figure 3.13).

The different median responses of the dynamically and statistically derived rainfall over large parts of southern Africa is partly an example of the fourth type of uncertainty described previously – the uncertainty associated with the response of regional climate to larger-scale forcing and/or imperfect downscaling techniques, as well as different regional forcings applied in each case. It remains to be investigated whether these differences are statistically significant given the range of the different estimates. It may also be noted that the dynamic and statistical downscalings convey robust and consistent messages of future rainfall decreases over the south-western Cape of South Africa, parts of Zimbabwe, Mozambique and Zambia, and of rainfall increases over East Africa and southeast South Africa.

Projected change in annual rainfall based on 6 dynamically downscaled GCMs



Created by Claire Davis, 2011

Figure 3.12: Projected changes in annual rainfall totals (mm) for the period 2036-2065 relative to 1961-2000 based on the median change of six dynamically downscaled GCMs.

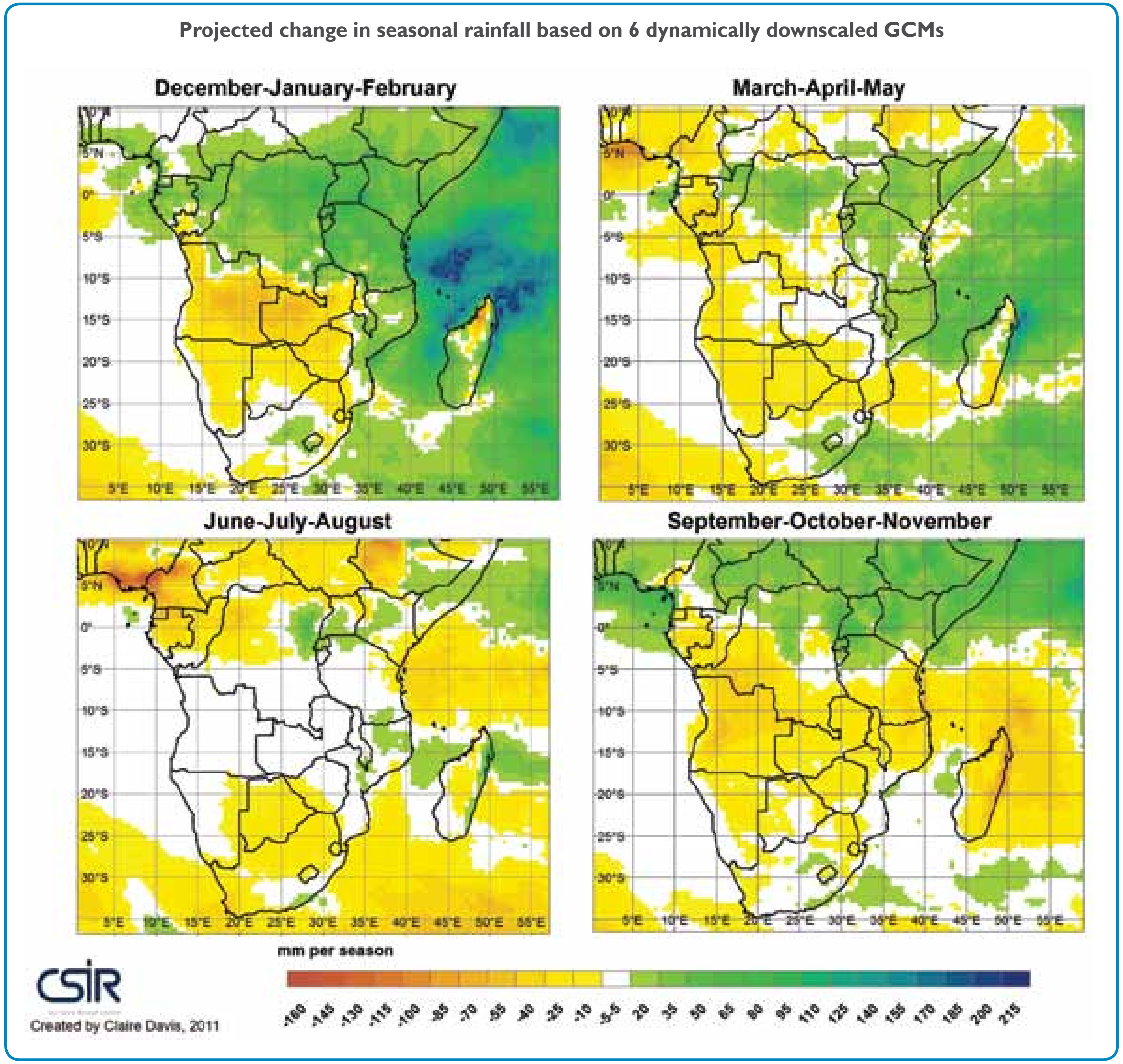
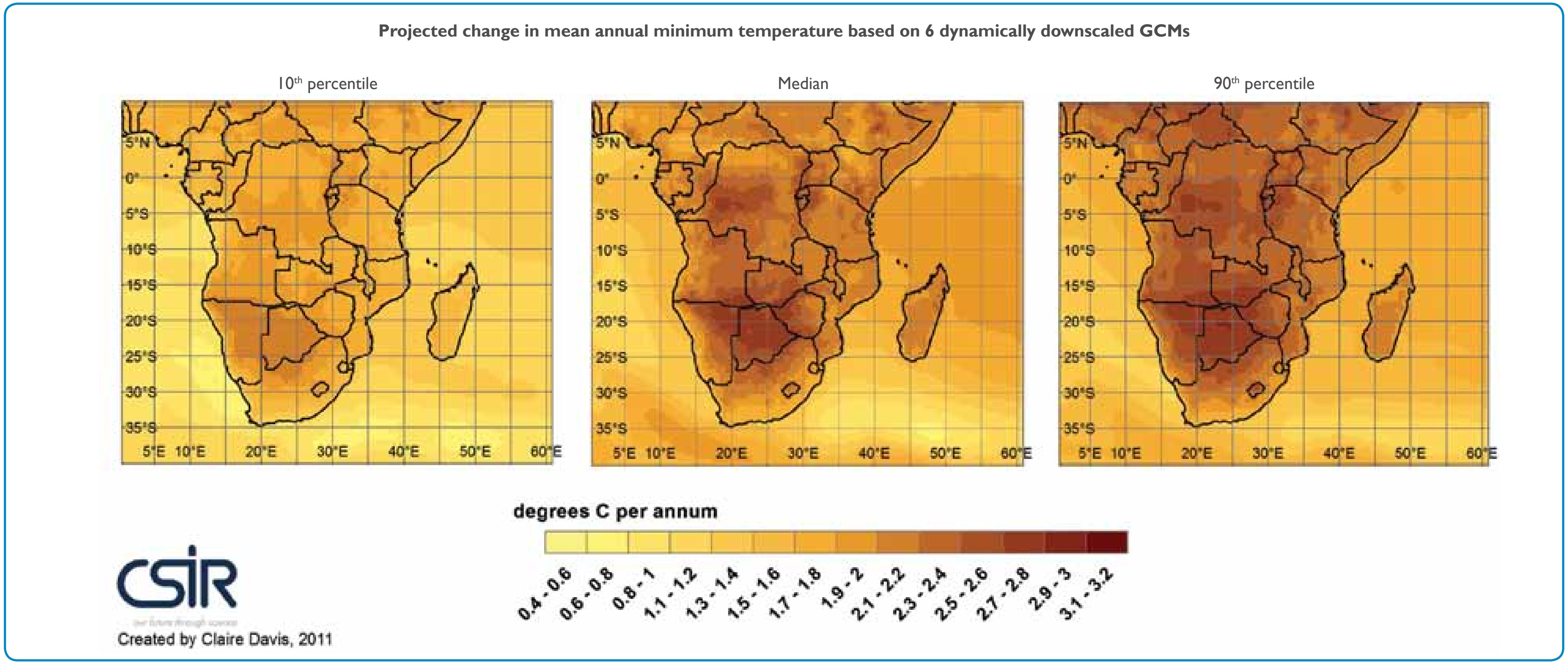


Figure 3.13: Projected changes in mean summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall totals for the period 2036-2065, relative to 1961-2000 based on the median change of six dynamically downscaled GCMs.

Temperature

As with the previous section, all six dynamically downscaled GCMs indicate an increase in temperature but differ in the magnitude of that increase, and as such the 10th and 90th percentiles are shown here in addition to the median.

An increase in minimum and maximum temperature is expected across a region of between 0.3 and 3.20° C per annum, considering the lower (10th percentile) and upper (90th percentile) limits of the models used (indicated by the maps in Figures 3.14 and 3.15), which is slightly lower than projected by the statistically downscaled models. These lower estimates are at least partly influenced by higher topography in the regional model simulations. Again, it is expected that the interior regions will experience more intense warming than the coastal areas. Winter (JJA) temperatures are, however, expected to experience the greatest increase in temperature compared to the other seasons, according to the dynamically downscaled models (Figures 3.16).



Projected change in mean annual minimum temperature based on 6 dynamically downscaled GCMs

10th percentile

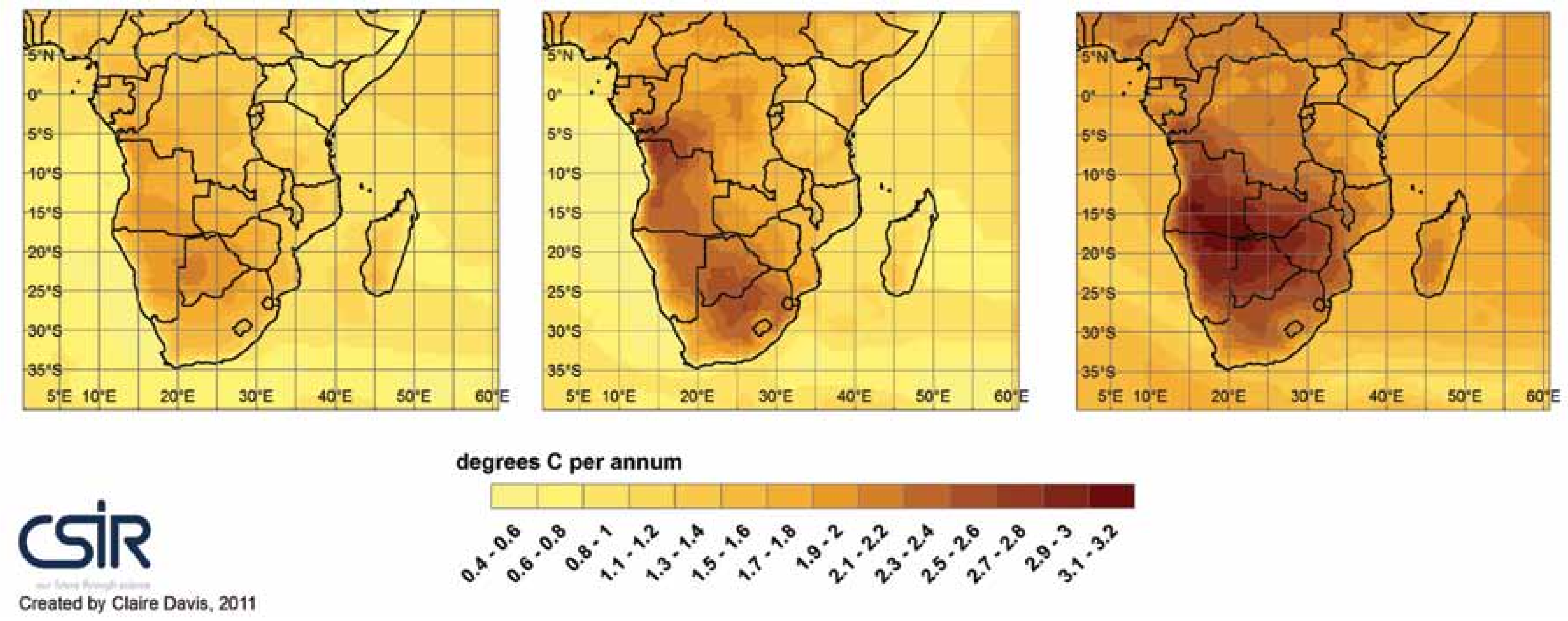
Median

90th percentile

Created by Claire Davis, 2011

Figure 3.14: Projected changes in minimum temperature (°C) by 2036-2065 relative to the 1961-2000 period and based on the 10th percentile, median and 90th percentile of six dynamically downscaled GCMs.

Projected change in mean annual maximum temperature based on 6 dynamically downscaled GCMs



10th percentile

Median

90th percentile

Figure 3.15: Projected changes in maximum temperature (˚C) by 2036-2065 relative to the 1961-2000 period and based on the 10th percentile, median and 90th percentile of six dynamically downscaled GCMs.

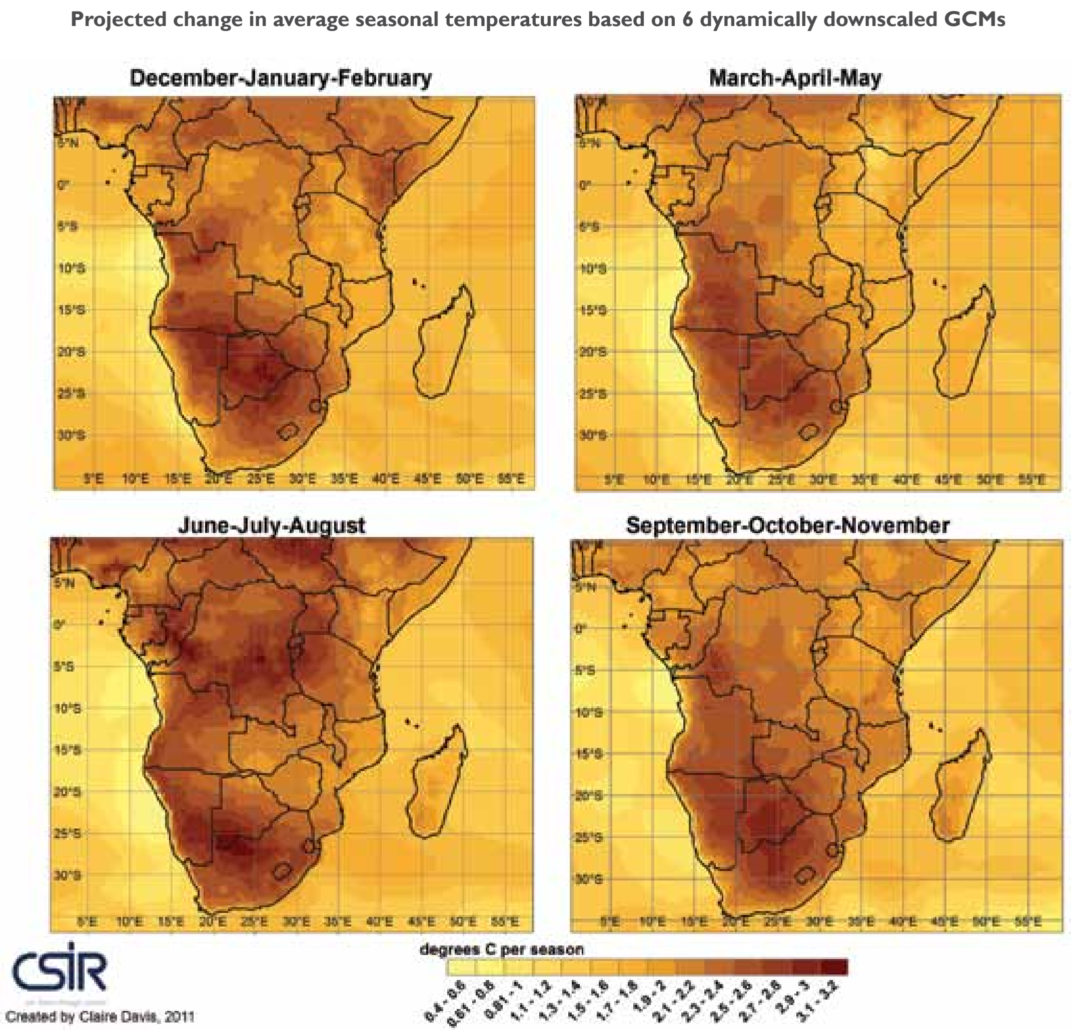


Figure 3.16: Projected changes in average seasonal temperature (°C) by 2036-2065 relative to the 1961-2000 period and based on the median of six dynamically downscaled GCMs.

Projected changes in extreme weather events over southern Africa

Climate change may manifest itself not only through changes in the long-term mean rainfall, temperature and circulation patterns, but also through an increase in the frequency of extreme weather events. As discussed earlier, increasing concentrations of greenhouse gases have enhanced the atmosphere's ability to absorb heat and hold moisture. Not surprisingly, the excess heat and moisture can lead to an increase in the frequency of extreme weather systems such as tropical cyclones and heat waves. The potential for an increase in the likelihood of extreme weather events over the southern African region needs to consider changes in regional circulation patterns and weather systems, as well as the general thermodynamic arguments stated above.

A wide variety of weather systems may bring extreme weather to the southern African region. Of the most important are tropical cyclones (that may bring widespread flooding to Mozambique and northeastern South Africa, e.g. Malherbe et al., 2011) and cut-off lows (often the cause of flooding along the Cape South Coast and Eastern Cape of South Africa, e.g. Singleton and Reason, 2007). Additionally, thunderstorms that frequent the eastern parts of the subcontinent may on occasion be severe and cause localised flash flooding and damaging winds. At the other end of the spectrum, periods of sustained anti-cyclonic circulation and subsidence may cause the occurrence of heat waves and prolonged dry spells over the southern African region – added to this in the future are increases in temperature due to greenhouse gases.

There seems to be no evidence of significant observed trends in the frequency of cut-off lows over the southern African region (Singleton and Reason, 2007), although regional climate modelling studies project a general decrease in the frequency of cut-off lows over the region in response to climate change (Engelbrecht et al., 2009; Engelbrecht et al., 2011). These changes are projected in association with a southerly shift of the westerly wind regime.

The general increase in tropospheric temperature and water vapour argues for an increase in tropical storms and cyclones over the southwest Indian Ocean. However, tropical cyclones are very difficult to simulate even under current climatic conditions, and the projection of their future characteristics is hampered by the coarse resolution of the GCMs (which are unable to capture many of the features which are important for cyclogenesis, e.g. wind shear between the lower and upper atmosphere, the dynamics of the eye of a cyclone and characteristics of the underlying ocean[5]). This results in depressions that only to some extent resemble tropical cyclones being simulated by GCMs. The IPCC points out that changes in tropical cyclone characteristics in the south-western Indian Ocean have not been investigated rigorously (Christensen et al., 2007). An analysis of a number of coupled climate model projections indicated a northward displacement in the tracks of tropical cyclones that make landfall over southern Africa (Malherbe et al., 2010). The projected strengthening of the subtropical high-pressure belt over the southwest Indian Ocean seems to be an important forcing factor driving these changes.

However, these changes in tropical cyclone frequencies and tracks are currently inconclusive. The intensity of tropical cyclones is however often projected to increase, which is also consistent with observed changes (Mavume et al., 2009) and thermodynamic arguments. However, it is clear that further research is needed in order to better project changes in the characteristics of tropical cyclones occurring over the southwest Indian Ocean.

A number of independent regional-downscaling studies have indicated that eastern South Africa may be expected to receive more extreme rainfall events in the future climate. This result has been attributed to increased convection over eastern South Africa in summer (Tadross et al., 2005). Additionally, a wetter eastern South Africa during the austral summer may also result from the more frequent formation of the South Indian convergence zone (SICZ) over the region, with more extreme rainfall resulting from thunderstorms embedded in the SICZ cloud bands (Engelbrecht et al., 2009). Figure 3.17 shows the ensemble median of the projected change in the frequency of occurrence of extreme rainfall events over southern Africa (here defined as 20 mm or rain falling within 23 hours over an area of 0.5°x0.5°) as constructed from the ensemble of CCAM projections (see previous section), for the period 2035-2065 relative to the baseline period 1961-2000. A general increase in extreme rainfall events is projected for South Africa and Mozambique, with the increases most pronounced over the central Highveld regions of South Africa. Slight decreases in the frequency of occurrence of extreme rainfall events are projected for the remaining parts of the subcontinent. This pattern of changes in extreme rainfall events is projected consistently across the different ensemble members and mirrors the changes of average rainfall seen in Figure 3.12. However, given the difficulty in simulating extreme

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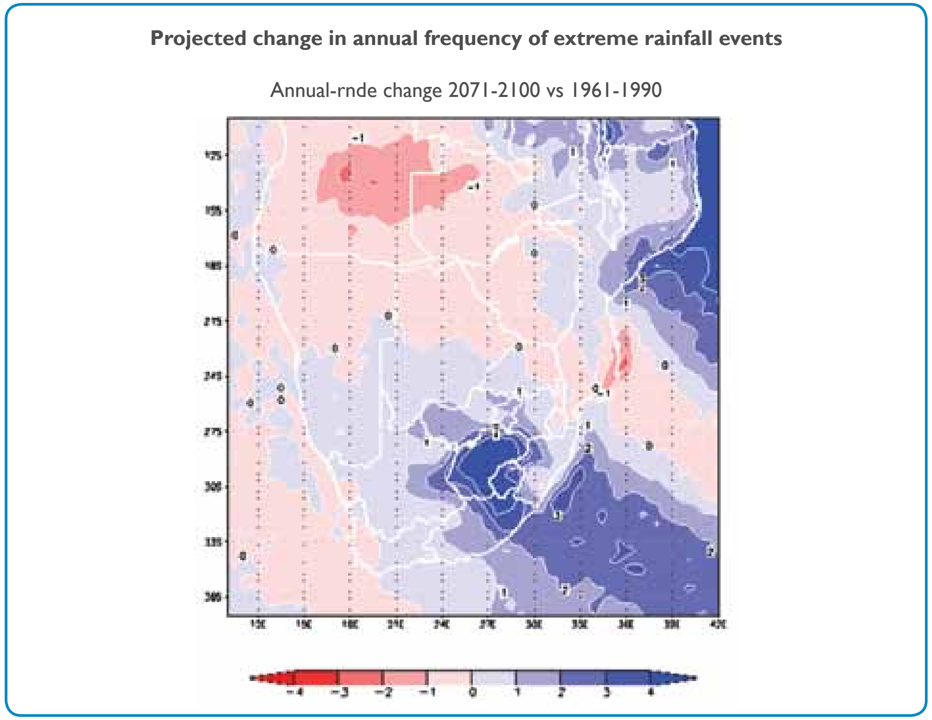
[5] http://wind.mit.edu/~emanuel/anthro2.htm

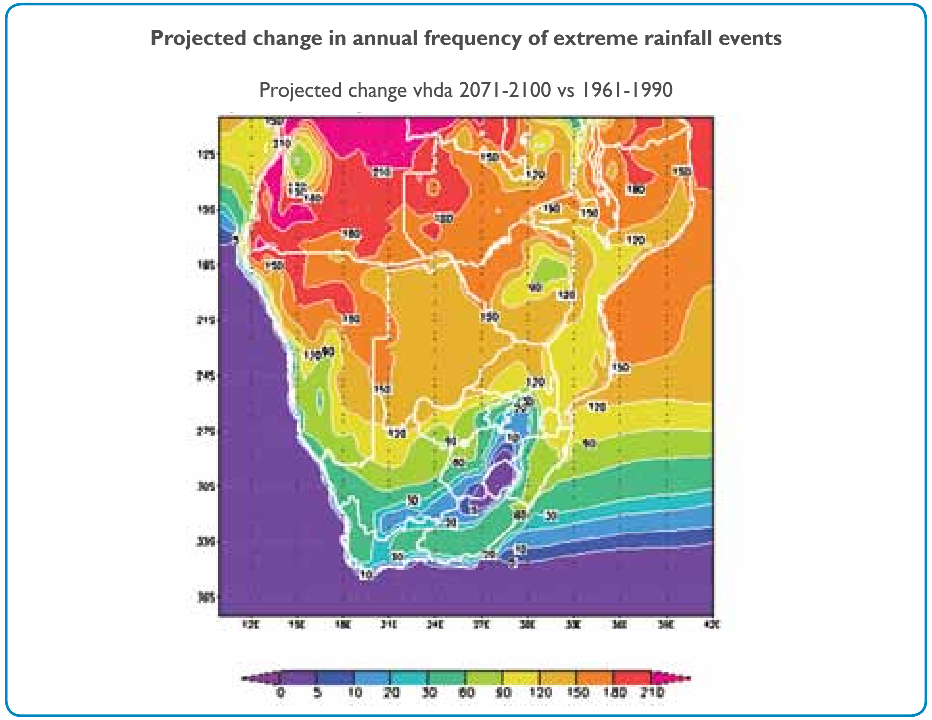
rainfall and its dependence on model paramaterisations, we caution against overinterpretation of these results, as they may be specific to the RCM used here.

Southern Africa is projected to become generally warmer and the increase in average temperature is projected to occur in association with an increase in very hot days (here defined as days when the maximum temperature exceeds 35° C). Figure 3.18 shows the ensemble median of the projected change in the frequency of very hot days over southern Africa, for the period 2035-2065 relative to the baseline period 1961-2000. Drastic increases in the annual frequency of very hot days are projected for a very large part of the subcontinent, with smaller increases projected for the high-altitude and coastal regions of South Africa. This pattern of significant increases in extreme events is projected consistently across the different ensemble members.


Projected change in annual frequency of extreme rainfall events

Annual-rnde change 2071-2100 vs 1961-1990

Figure 3:17: Projected median change in the annual frequency of extreme rainfall events (> 20mm day-1) over an area of 0.5° by 0.5° over the southern African region, for the period 2035-2065 relative to the baseline period 1961-2000. Units are number of events per grid point per year.


Projected change in annual frequency of extreme rainfall events

Projected change vhda 2071-2100 vs 1961-1990

Figure 3.18: Projected median change in the annual frequency of very hot days (maximum temperature exceeding 35° C) over the southern African region, for the period 2035-2065 relative to the baseline period 1961-2000. Units are number of events per grid point per year.

3.4. Reconciling information from different climate change projections and observations

The projected changes in rainfall and temperature for the middle of the 21st century that have been presented are sometimes different (e.g. rainfall) or consistent (e.g. temperature) depending on the method/model used to estimate those changes and whether the method/model is able to capture the responsible physical changes in the regional climate system. Consistently projected future change is a consequence of the following physical changes:

- Increases in temperature (due to changes in atmospheric radiation balance), which promotes convective activity at the surface, especially during mid-late summer;
- Increase in humidity, which increases the amount of moisture available for rainfall once it is triggered;
- Retreat of the mid-latitude storm systems and strengthening of the continental high pressure system during winter (and potentially autumn and spring).

Working messages indicating areas where areas of change are consistent and robust may be viewed in the conclusion below. It should be observed that the GCMs, as well as both the statistical and dynamical downscalings, will relate surface rainfall and temperatures to these physical mechanisms in different ways. Hence, the importance (or relatively dominant role) of each physical mechanism varies between the model projections. The regional expression of change is therefore dependent on the interaction between mechanisms, which may compete with each other (e.g. increases in rainfall intensity may offset decreases in rain days through strengthening of the high pressure system). Ignoring differences in the GCMs used in each ensemble and where median changes are small, this may help explain the difference in the downscaled rainfall simulations through the physical and dynamical methods (Figures 3.13 and 3.18); the drier response in the dynamical downscaling may indicate the relatively important role of higher atmospheric pressure which may suppress rainfall, whereas the wetter response in the statistical downscaling may indicate the relatively important role of moisture and convection in those simulations. The exact details are not clear and require further work, but that the differences are explainable is important; by looking for consistency in the physical mechanisms we may help reduce uncertainty in the projections. Even given the not insignificant differences in how the simulations are constructed, there are still regions and periods when the two downscaled ensembles agree: increases in annual rainfall over southeast South Africa, decreases in rainfall over southern Zambia and Zimbabwe during DJF and decreases in rainfall over central Zambia during SON.

Reconciling these simulated future changes with past observations is also a difficult, yet necessary challenge. Where current trends are in line with projected change, and the physical mechanism related to both is understood, planning and adaptation related to such changes have firm grounds for moving ahead. However, where observed trends disagree with future projections, further investigation is required as the observed changes may be due to natural variability (or the model projections are not reliable). In the case of no consistently observed trends, but projections suggest a change that is physically plausible, further monitoring is necessary to detect any such changes if and when they occur in the future. Such an analysis requires focusing on smaller regions to understand local changes and relating them to larger-scale atmospheric change.

3.5. Summary: Key messages

Box 3.5 indicates key areas of agreement between the different sections of this chapter – namely GCMs, statistical downscalings and dynamical downscalings. Of particular interest to us in deriving working messages are the areas where there are, of course, consistent and robust messages of change.

GCMs, statistical downscalings and dynamical downscalings all show an increase in projected temperatures. Increases in mean, minimum and maximum temperatures are indicated as a consistent and robust finding – with a minimum projected change of 0.3°C, and maximum at 3.6°C. Further, GCMs and both sets of downscalings accordingly indicate increases in very hot days or heat waves (depending on the threshold used for defining critical temperatures).

A decrease in winter and spring (JJA and SON) rainfall over the southwestern part of South Africa is indicated in most simulations, whereas southeastern South Africa generally receives more rainfall. During SON, rainfall is consistently suggested to decrease over parts of Zambia, Zimbabwe and western Mozambique in the GCMs and downscalings shown here.

Box 3.5: Summary and comparison of climate change projections from the GCMs and the two downscaling techniques

	GCM	*Statistical downscalings*	*Dynamical downscalings*
Time-scale	1960-2000	1961-2000	1961-2000
	2030-2060	2036-2065	2036-2065
Rainfall	Decrease over central and western southern Africa during DJF and MAM. Increases further north over east Africa	Increases over Angola, northern Mozambique and southeast South Africa during DJF and MAM	Decrease in rainfall projected for western southern Africa
	Decrease over most of southern Africa during SON and southwest South Africa during JJA	Decreases over Zimbabwe, Zambia, western Mozambique and parts of the south-western coastline during DJF and SON	Increases over East Africa and southeast South Africa
Temperature	Increase in mean, minimum and maximum temperature		
	1 - 3˚C	0.8 - 3.6˚C	0.3 - 3.2 ˚C
Winds	Increase in easterly winds during DJF	Not available	Not available
	Increase in southwest monsoon wind in MAM	Not available	Not available
	Increase in strength of Atlantic high pressure and associated winds in JJA and SON	Not available	Not available
Extreme weather events	Increases in very hot days and heat waves	Increases in very hot days and heat waves	More extreme rainfall events over eastern southern Africa. Increase in very hot days – above 35˚C

Acknowledgements

We wish to acknowledge the modelling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making the WCRP CMIP3 multi-model dataset available. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

Chapter 4: Risks of adverse impacts from climate change in southern Africa

By Katharine Vincent, Tracy Cull, Claire Davis and Emma Archer van Garderen

Southern Africa is vulnerable to climate change, with the sectors of particular concern being water resources, agriculture, health, ecosystems and biodiversity, forestry, human settlements and coastal zones.

4.1. Introduction

The previous chapter presented future climates for southern Africa, based on a combination of statistically and dynamically downscaled regional climate models, as well as GCMs. Key messages indicate warmer temperatures, a likely drying trend for winter in south-western Africa, and a possibly drier spring (October-November-December).

Knowing the nature of projected changes in climate is clearly essential, but it is only one part of the equation to determine the risks of adverse impacts from climate change. For example, a delay in the onset of the rainy season in an already-dry area might pose a greater risk than in a wet area. Similarly, a small increase in temperature may have no bearing on healthy, middle-aged people, but among the elderly might be enough to cause a situation of heat stress, given their already-lower tolerance. Determining the impacts of climate change, therefore, depends not only on the nature of the changes themselves, but the characteristics of the places and people that experience those changes.

In this chapter, the terms hazard exposure, sensitivity (or biophysical vulnerability), adaptive capacity (or its opposite - social vulnerability) and risk are introduced (see Box 4.1 for key definitions). Whether or not climate change is likely to have an adverse impact, or the extent to which the change will cause a problem (or indeed an opportunity) depends on the interaction of these concepts in any one place, and at any one time. The chapter also looks at sectors in the southern Africa region where negative impacts are likely to be high, using a number of case study illustrations. Knowing such information is important for prioritising adaptation interventions, as addressed in Chapter 5.

4.2. Determining the levels of risk from climate change

The risk posed by climate change is dependent on how several factors interact in any one place and at any one time. How this risk is determined has evolved over time. When climate change first appeared as an environmental issue of concern, it was assumed that impacts were dependent on two factors: exposure to the hazard, whether that was temperature or rainfall change, and the sensitivity (or biophysical vulnerability) of the ecosystem that was exposed to the change. In this way, similar levels of exposure to climate change might lead to different impacts in different places. In the middle of a desert, for example, plants are already adapted to high temperatures and therefore an increase of 1°C is unlikely to affect the plant distribution. However, if the same temperature change occurred on the margin between a semi-arid and arid area, where plants might be at the edge of their tolerance, it could cause them to die out, with a resultant change in species composition. As a result the desert margin has a higher sensitivity, or biophysical vulnerability, to climate change.

In the above model of determining the level of risk from climate change, people are recognised in the sense that they occupy (and depend on) ecosystems. More recently, however, it has been acknowledged that humans are active agents in responding to climate change, and have different levels of *adaptive capacity* (or social vulnerability). The adaptive capacity of society is partly determined by various social factors, including gender, ethnicity, religion, class and age. Together, these social factors tend to give rise to differences in human capital (such as levels of education and status of health), financial capital (wealth) and access to governance and institutions, which in turn affect people's ability to anticipate, cope with, and respond to change. Since these all vary on the microscale, the recognition of the role of social factors is particularly important when working at sub-national level.

Box 4.1: Key definitions

Hazard exposure refers to the physical parameters (e.g. rainfall or temperature) of climate change. A hazard exposure can be incremental temperature or precipitation change, which unfolds gradually over a long time, or it can refer to weather-related events, such as droughts, floods and heat waves.

Sensitivity, or *biophysical vulnerability*, refers to the extent to which any unit of analysis (ranging, for example, from one tree to a whole forest) reacts to hazard exposure.

Adaptive capacity, or its opposite - *social vulnerability*, refers to the varying social characteristics of people (at various units of analysis, from individual to community to country) that determine how hazard exposure is experienced. Adaptive capacity/social vulnerability can reflect the status of poverty, health, knowledge/education, and governance (at collective levels). A high adaptive capacity is equivalent to a low social vulnerability, and a low adaptive capacity is equivalent to a high social vulnerability.

Risk is the result of the relationship between hazard exposure, sensitivity (biophysical vulnerability) and adaptive capacity (or social vulnerability), and refers to the likelihood of an adverse impact from climate change.

An entire sub-region may be exposed to the same climate conditions or hazards, so that the sensitivity of the physical environment will be similar across the whole area but the hazard is likely to affect different members of the sub-region in different ways, depending on their adaptive capacity. For example, an elderly person with disabilities is more likely to experience more adverse impacts than a younger person with no health problems.

It is important to note that not all hazard exposure leads to adverse impacts. Some models indicate that eastern South Africa, for example, is projected to experience an increase in rainfall under climate change. Since some of the area is already semi-arid, an increase in rainfall could lead to positive changes in crop productivity (if the soil conditions and distribution of rainfall throughout the season are favourable to crop growth); whereas an increase in rainfall amount of similar quantity in an area that is already prone to flooding could cause problems.

Despite the more recent recognition that human characteristics affect how climate change will be experienced, it is still common to read of impacts that focus solely on the interaction between exposure and sensitivity (or biophysical vulnerability). Part of the reason for this is that determining impacts in this way is easier to do at the large scale with the use of models. Determining adaptive capacity (or social vulnerability) is very scale-specific, and typically difficult and expensive to do, as it either requires primary research with people, or the application of a wide range of social data from statistical surveys. Both approaches are valid and while a combination of the two is the ideal, it is often not possible. For clarity, this chapter sets out the two approaches separately by firstly presenting some projected sectoral impacts of climate change in southern Africa (i.e. analysis that looks only at biophysical vulnerability of different sectors) and secondly, by highlighting selected studies that take into account adaptive capacity (social vulnerability).

4.3. Sectoral impacts – understanding biophysical vulnerability

This section outlines specific information concerning the biophysical vulnerability of a range of sectors to future impacts of climate change. The sectors covered are forestry, crop and livestock production, ecosystems and biodiversity, coasts, human settlements, water resources and human health.

Forestry

Southern Africa's forestry sector is sensitive to climate change as it is partly based on the plantation of non-indigenous species (species that are not typical of southern Africa). Land availability, water demand as well as environmental and socio-economic conditions affect the vulnerability of the sector to climate change. Given the projected increases in temperature and changes in rainfall, certain areas may not be climatically suitable for the production of a specific species (as different species have different climatic constraints, such as mean rainfall and mean temperature) and some areas may no longer be suitable for commercial forestry. Areas that are at present not climatically suitable for forestry may, however, become suitable in the future.

Tree breeding can produce trees that match future projected site conditions (in regions where future site conditions are predictable). Alternative forms of silviculture (the growing and cultivation of trees), such as mixed species forests, agroforestry, and the use of adapted indigenous tree species could yield more resilient forests in areas where site development uncertainty is high or water use restrictions prohibit the use of fast-growing plantation species. Climate change is likely to exacerbate existing declines in river runoff due to water use by commercial plantations, agriculture, woody exotic invasive species, and urban and industrial land use. Consequently, an integrated ecosystem management approach, or 'multiple benefits' approach should be considered. Such an approach should be able to provide an optimal portfolio of land-use forms in an area which could integrate production, environmental, climate change adaptation, carbon sequestration (storage) and mitigation objectives as well as socio-economic aspects for sustainable landscape management. Given the lengthy rotation of commercially grown forest species (7 – 30 years), it is crucial that alternatives for the most effective climate change adaptation strategies are developed and implemented in a timely manner.

Crop and livestock production

Agriculture in southern Africa plays a critical role in the formal and informal economy, in sustaining rural livelihoods and in food security. Agriculture is directly dependent on climatic variables such as temperature and rainfall, which dictate crop and livestock selection for a specific location as well as cultivar choices and cropping calendars. Changes in these climatic variables may alter agricultural productivity in various ways (see Box 4.2) and altered climatic conditions

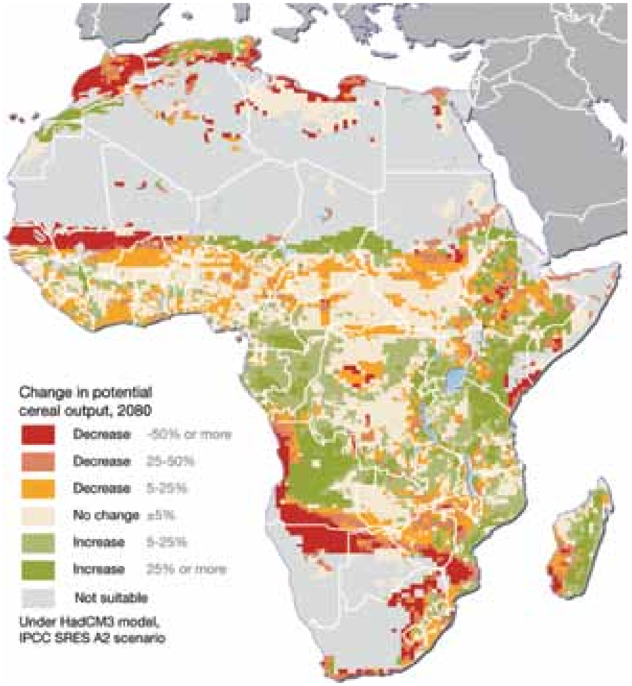
Box 4.2: Impacts of projected climate change on crop and livestock production

Crop production	Direct impacts	▪ Even small increases in mean temperature of between 1° and 2°C are projected to lead to a decrease in crop productivity ▪ Changes in temperature regimes could affect growing locations, the length of the growing season, crop yields, planting and harvest dates ▪ Increased need for irrigation in a region where existing water supply and quality is already negatively affected by other stressors
	Indirect impacts	▪ Predicted higher temperatures are likely to negatively impact organic matter, thereby reducing soil nutrients ▪ Higher temperatures may favour the spread of significant pests and pathogens to a range of agricultural systems
Livestock	Direct impacts	▪ Changes in forage quality and quantity (including the availability of fodder crops) ▪ Changes in water quality and quantity ▪ Reduction in livestock productivity by increasingly exceeding the temperature thresholds above the thermal comfort zone of livestock, which could lead to behavioural and metabolic changes (including altering growth rate, reproduction and ultimately mortality) ▪ Increased prevalence of 'new animal diseases' ▪ Increases in temperature during the winter months could reduce the cold stress experienced by livestock, and warmer weather could reduce the energy requirements of feeding and the housing of animals in heated facilities
	Indirect impacts	▪ Increased frequency of disturbances, such as wild fires ▪ Changes in biodiversity and vegetation structure
Socio-economic/ livelihood impacts		▪ Changes in incomes derived from crop and livestock production ▪ Shifts in land use (including consequences of land reform) ▪ Overall changes in food production and security

are likely to pose new challenges for various crops (see Figure 4.1 for an example), regions and farming systems. With a 2°C increase in temperature and a 10% reduction in rainfall the maize yield for South Africa, for example, is expected to experience a reduction of 0.5 t/ha (Schulze, 2007). The case study on page 55 discusses how livestock might be affected by climate change.

The greatest impact on production is expected to be in the most marginal areas, where low and irregular rainfall is already experienced. In addition, emerging, small-scale farming (including subsistence farming) is often associated with high risk and uncertainty, due to the high dependency on rain-fed agriculture as well as fewer capital resources and management technologies available to farmers.

It is important to consider the full set of drivers changing agricultural productivity, which tend to be complex and integrated at various scales. For example, it has long been established that crop production is not the only determinant of food security – in many southern African nations; for example, members of the population are food insecure despite the countries being net exporters of food crops. In addition to production, access to food is also important, and this is dependent on factors such as the ability to purchase through the market. But a decline in crop production as a result of climate change is likely to adversely affect food security because it will also increase food prices.



Orange and red colours denote a decrease in potential cereal output, whereas green colours denote a possible increase.

Already the climate of large swathes of Namibia, Botswana, South Africa, Lesotho, and smaller proportions of Swaziland and Zimbabwe is unsuitable for crop production. Substantial decreases in the productivity of crop-suitable land in Namibia, Botswana, South Africa, and Zimbabwe are projected. Parts of Angola, Malawi, Mozambique, Zambia, and Madagascar are also projected to experience declines in crop production under climate change. However, substantial increases (over half of each country's area) are projected for Angola, Democratic Republic of Congo, Madagascar, Tanzania, and Zambia.

Figure 4.1: Projected changes in cereal productivity in Africa due to climate change using the A2 socio-economic scenario – current climate to 2080. Source: UNEP/GRID-Arendal, based on data from Fischer et al., (2005)

CASE STUDY: A changing climate for cattle farming in the SADC region

By Emma Archer van Garderen

Nguni cattle, Eastern Cape, South Africa – indigenous to southern Africa; a combination of Zebu (Bos indicus) and Bos taurus. [Picture: Bloemhof Farm]

Farming with domesticated cattle breeds has taken place on the African continent for thousands of years, as evidenced by some of the earliest archaeological signs of pastoral activity.

The appearance of domesticated cattle in rock art, for example, is considered a key sign of evolution of early communities in southern Africa (see, as illustration, Manhire et al., 1986). In more recent times, of course, cattle farming in developing countries has undergone significant change, in response to, for example, changing demands and market conditions (Thornton et al., 2009). The significant increase in global demand for livestock products has led, in part, to changes in the nature of livestock farming; including genetic erosion (for example, the move to temperate breed genetic stock in dairy farming); the move from traditional more extensive production systems to more intensive livestock farming; and the concomitant decreased use of local breeds usually associated with more traditional livestock production systems (Thornton et al., 2009).

Such changes in the nature of livestock production in developing countries, such as those found in the SADC region occur, of course, in the context of a changing climate. Livestock farming is a climate sensitive activity – yet, as Thornton et al., 2009 observe: "...the intersection of climate change and livestock in developing countries is a relatively neglected research area" (pg 113). Although arguments among certain interest groups have recently been made against livestock farming as a non-environmentally sustainable use of land, it should be emphasised that, in South Africa for example, agriculture and land surface change contribute a very small proportion of greenhouse gas emissions (Department of Environmental Affairs 2011). Further, livestock production systems differ markedly, with vastly different implications for the environment in which they are undertaken. In South Africa as well as Namibia, Botswana, Zambia and parts of Mozambique, a large portion of the land surface area is really only suitable for extensive stock farming.

The majority of climate models for southern Africa indicate a likely increase in average, minimum and maximum temperatures as shown elsewhere in this volume. Increased temperatures impact cattle farming in a variety of ways, most particularly in the area of heat stress. Heat stress can impact feed intake, fertility (and pregnancy outcomes), liveweight gain and, under certain conditions, mortality. Different breeds have different thresholds above which they experience heat stress, with locally adapted breeds (often used in more traditional extensive farming systems) tending to be more resilient in higher temperatures. Bos taurus breeds tend to be more productive in temperate climates, while Bos indicus (such as the well-known Brahman) have better thermoregulatory capacity.

For example, more temperate zone adapted breeds such as US Holsteins (Bos Taurus) tend to experience heat stress above 72 THI, or 22°C at 100% humidity (Freitas et al., 2006, Ravagnolo et al., 2000, Sanchez et al., 2009). 30°C ambient temperature "seems to be the critical point at which both Bos taurus and Bos indicus begin to differ in their ability to maintain near normal rectal temperatures and respiratory rates" (Hernandez et al., 2002: 8).

As a result, it is clear that livestock farming under a changing climate will have to take cognisance of existing knowledge around more 'traditional' breeds and livestock management knowledge. Moonga and Chitambo (2010) propose that "well adapted traditional livestock breeds will, most likely, play a very significant role in adaptation to climate risk" (pg 1). Further, Blümmel et al. (2010) call for more resilient livestock production systems through increased support for traditional breeds and higher genetic diversity, asserting that "…conservation needs to be considered as an important component of a broad-based strategy to conserve critical adaptive genes and genetic traits" (pg 139).

As cattle farming in the SADC region experiences significant differences in market, demand and, under certain circumstances, environmental conditions, more local forms of knowledge are clearly receiving increased attention. More traditionally used breeds and grazing systems may, in fact, as detailed above, provide a valuable entry point for considering adaptation.

Ecosystems and biodiversity

Southern Africa has high levels of biodiversity in terms of the number of different species and the number of endemic species. Southern African ecosystems are already experiencing changes, and the IPCC assigns very high confidence to the rapid rate being partly attributable to climate change (Boko et al., 2007). In addition to climate change, the role of land cover change (such as habitat fragmentation) as a result of land use change is increasing the vulnerability of species and ecosystems to climate change and needs to be considered in management decisions. Additional stresses on biodiversity, such as wildfire frequency (which has already shown climate change-related increases in the Western Cape province of South Africa) and alien invasive species (which are likely to be advantaged by changed climates and increased atmospheric carbon dioxide concentrations) may also increase the vulnerability to climate change.

By affecting habitats, climate change will also have implications for the distribution of species, with one study estimating that between 25-40% of mammal species in national parks in sub-Saharan Africa will become extinct (Thuiller et al., 2006). Some examples of ecosystems affected by climate change are provided in Box 4.3.

Nature-based tourism in southern Africa is at risk from climate change due to the effects of changing temperature and rainfall patterns on species distribution. [Picture: Mitzi du Plessis]

Climate change may result in certain "thresholds" being reached that may cause large impacts on ecosystem services and biodiversity. Changes in the timing of plant and animal life cycles are likely to impact conservation areas as this may, in future, change the species assemblages of these areas. Due to a changing climate a disconnect may occur between the timing of behaviour and the available resources on which the behaviour depends. The individual impacts of these changes will likely scale up to have several ecosystem responses, including the range and distribution shifts of species and communities, the composition of and interactions within communities, and the structure and dynamics of ecosystems. Changes in ecosystems and biodiversity due to climate change will thus likely have negative implications for the large nature-based tourism industry in southern Africa. A potential expansion of *Colophospermum mopane* woodlands as a result of climate change, for example, will have strong negative impacts on the tourism experience through potentially reduced numbers of game within these patches resulting in reduced game viewing opportunities.

Coasts

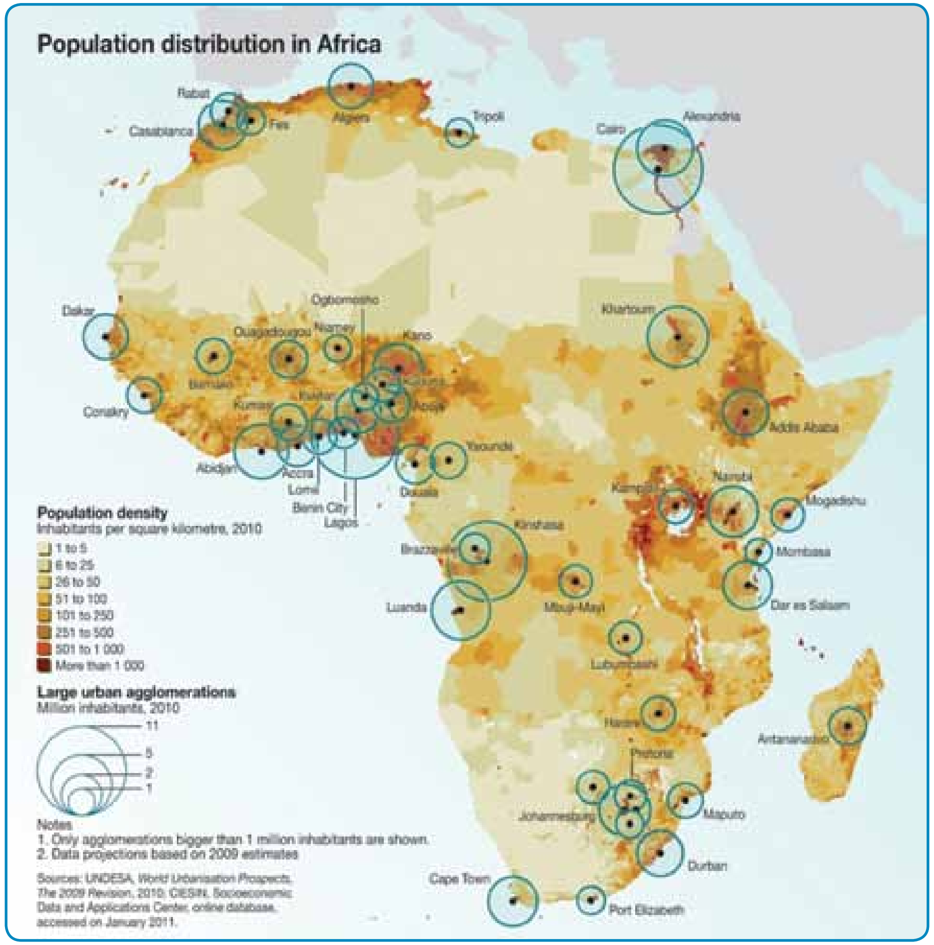
A number of southern African countries have coastlines: Tanzania, Mozambique, South Africa, Namibia, Angola, and the Indian Ocean islands of Madagascar, Mauritius, and the Seychelles. The IPCC has concluded with high confidence that climate change will result in low-lying coastal lands being inundated, with resultant impacts on coastal settlements (Boko et al., 2007). Observations from satellite data show that the sea level rise from 1993-2006 was 3.3±0.4 mm per year (Theron, 2011) and it is expected that sea level rise will continue even if greenhouse gas concentrations are stabilised (IPPC, 2007). Wave height is also expected to increase as a result of increases in wind velocity (see Chapter 3). An increase in storm activity and severity is likely to have the most visible impacts in areas already susceptible to erosion.

Box 4.3: Examples of projected impacts of climate change on ecosystems (adapted from Boko et al., 2007, p 449)

Ecosystem impacts	*Area affected*	*Scenario used*	*Source*
About 5,000 African plant species impacted: Substantial reductions in areas of suitable climate for 81-97% of the 5,197 African plants examined, 25-42% lose all area by 2085	Africa	Investigation of shifts in suitable growing areas under different climate change scenarios (HadCM3 for years 2025, 2055, 2085, plus other models)	McClean et al., 2005
Fynbos and succulent Karoo biomes: Losses of between 51 and 61%	South Africa	Projected losses by 2050	Midgley et al., 2002
Critically endangered taxa (e.g. Proteaceae): Losses increase, and up to 2% of the 227 taxa become extinct	Low-lying coastal areas	4 land use and 4 climate change scenarios (HadCM2 IS92aGGa)	Bomhard et al., 2005
Losses of nyala and zebra: Kruger Park study estimates 66% of species lost	Malawi South Africa (Kruger National Park)	Hadley Centre Unified Model, no sulphates	Dixon et al., 2003 Erasmus et al., 2002
Loss of bird species ranges: (Restriction of movements). An estimated six species could lose substantial portions of their range	Southern African bird species (Nama-Karoo area)	Projected losses of over 50% for some species by 2050 using the HadCM3 GCM with an A2 emissions scenario	Simmons et al., 2004
Sand-dune mobilisation: Enhanced dune activity	Southern Kalahari basin – northern South Africa, Angola and Zambia	Scenarios: HadCM3 GCM, SRES A2, B2 and A1fa, IS92a. By 2099 all dune fields shown to be highly dynamic	Thomas et al., 2005
Lake ecosystems, wetlands	Lake Tanganyika	Carbon isotope data show aquatic losses of about 20% with a 30% decrease in fish yields. It is estimated that climate change may further reduce lake productivity	O'Reilly et al., 2003
Grasslands	Complex impacts on grasslands, including the role of fire (southern Africa)	Rainfall change and variability is very likely to affect vegetation in tropical grassland and savanna systems with, for example, a reduction in cover and productivity simulated along an aridity gradient in southern African savanna in response to the observed drying trend of about 8 mm/yr since 1970	Woodward and Lomas, 2004
Grasslands and savanna	South Africa (Kruger National Park)	Rising atmospheric CO_2 levels may be increasing the cover of shrubs and trees	Bond and Midgley, 2000

As Figure 4.2 shows, southern Africa has a number of large coastal settlements, including Dar es Salaam, Maputo, Durban, Port Elizabeth, Cape Town, and Luanda. Sea level rise may also affect coastal ecosystems, such as mangroves and coral reefs, with consequences for fisheries and tourism. The projection that sea level rise could increase flooding, particularly on the coasts of eastern Africa (including Tanzania), will have implications for health. The accompanying case study outlines the coastal risk from climate change in Dar es Salaam.

The impact of a storm along South Africa's east coast in March 2007. [Picture: Simon Bundy]



Notes
1. Only agglomerations bigger than 1 million inhabitants are shown.
2. Data projections based on 2009 estimates

Sources: UNDESA, *World Urbanisation Prospects, The 2009 Revision*, 2010; CIESIN, Socioeconomic Data and Applications Center, online database, accessed on January 2011.

Figure 4.2: Population distribution in Africa. Source: UNEP/GRID-Arendal (2010).

CASE STUDY: Coastal risk in Dar es Salaam

By Katharine Vincent

Dar es Salaam already has a population of more than two million people, and is situated on the coast of the Indian Ocean, bordered by the Mpiji River to the north, and the Mzinga River to the south. As a result of its physical location, Dar es Salaam is exposed to floods, sea level rise and coastal erosion. It is at high risk of climate change as biophysical vulnerability to exposure coincides with high social vulnerability.

The risks of climate change relating to this coincidence of hazard exposure and biophysical and social vulnerability include adverse effects on transport, tourism, health (outbreak of cholera, malaria), fishing, and aquaculture and water supply.

A recent study attempted to quantify the number of people and associated economic assets in the coastal zone of Dar es Salaam, which could be exposed to coastal flooding due to extreme water levels through the 21st century, considering a range of sea-level rise and socio-economic scenarios (Kebede and Nicholls, 2010).

The results show that about 8% of Dar es Salaam lies within the low elevation coastal zone, below the 10 m contour lines. In 2005 this area was inhabited by more than 143,000 people, of which 30,000 people and US$35 million of assets were in the 1 in 100 year flood plain. By 2030, with no climate-induced sea-level rise, the number of people exposed to the 1 in 100 year flood increases to between 60,000 to 106,000 (and US$219-388 million of assets), depending on the population growth scenario. When sea-level rise is taken into account, a total number of people ranging between 61-64,000 people (US$2330236 million of assets) and 107-110,000 people (US$392-404 million of assets)(depending on population growth) across the sea-level rise scenarios are estimated to be potentially exposed to coastal flooding by 2030. The exposure increases significantly with time, reaching over 210,000 people and about US$10 billion assets by 2070 under the highest sea-level rise scenario and first population growth scenario.

These results suggest that the increasing risk of climate change to Dar es Salaam is driven more by increasing social vulnerability (rapid population growth and urbanisation) than by exposure to sea-level-rise changes.

Human settlements

People living in areas characterised by densely populated and sprawling settlements with high concentrations of poverty, limited access to employment, livelihoods and socioeconomic services are considered to be more vulnerable to the physical impacts of climate change. For example, the risk of water-borne diseases due to changes in rainfall patterns and temperature increases expected with climate change is likely to be increased in households without proper access to potable water. The resources spent in the community to deal with people affected by water-borne diseases may divert money away from capital investments necessary for economic development. In addition, these communities are dependent on a range of natural resources for firewood, wild fruits and herbs, medicines and craft materials, which contribute to their livelihoods. These resources are already under increasing pressure and future use, combined with changes in production as a result of climate change, may lead to unsustainable levels of harvesting.

Settlement outside Cape Town, South Africa. [Picture: Claire Davis]

People who reside in informal settlements have been identified as one of the most vulnerable populations globally. In these areas, adequate and timely provision of basic services such as water, electricity, and sanitation to residents is frequently hampered by lack of resources. Informal settlements are often vulnerable to water-related disasters such as floods and severe storms, particularly in cases where the communities are located on flood plains and there is an absence of proper water infrastructure. In some cases infrastructure which has been built to handle a historic range of weather-related conditions will not be adequate for the intensity and variability of future weather events.

Water resources

Water resources are directly impacted by current climate variability and it is expected that climate change could impact resources significantly in the future. This is likely to place increased pressure on water resources, ultimately threatening the sustainability of future availability, which depends on both supply and demand pressures. Water is a critical sector since it effectively cuts across most other sectors in terms of it's impact. In South Africa, for example, water is considered a priority adaptation area in the White Paper on Climate Change Response.

Likely major risks to water resources in the SADC region include:

- decreased availability of water in rivers as a result of net effect of increased temperatures and increased evaporation, coupled with shifts in the timing and amounts of rainfall;
- changes in the concentration and timing of high and low flows due to changes in rainfall;
- increased incidence of floods if the incidence of very heavy rain events increases; and
- increased risk of water pollution and decreased water quality linked to erosion and high rainfall events (which increase the presence of sediments, nutrients, dissolved organic carbon, pathogens and pesticides) and increased water temperature (which promotes algal blooms).

The impacts of climate change on water resources are likely to be exacerbated by changes in land-use and poor land-use management (Meadows, 2006). The political and practical imperative to improve access to water for both rural and urban poor may create further stress on the hydrological system as a result of the increased human demand (Schulze et al., 2001).

Human health

The health of humans is closely linked with their surrounding environment. The IPCC Fourth Assessment Report concluded with high confidence that human health in Africa could be negatively impacted by climate variability and change (IPCC, 2007). Changing temperatures and rainfall patterns will alter the ecology of some disease vectors, thereby changing the ranges of certain diseases. Much research in this regard has tended to focus on malaria (Figures 4.3 and 4.4 below show possible changes in characteristics of the malaria transmission season), but there are also risks of changing ranges for dengue fever, meningitis and cholera. Documented direct health effects of climate change include extreme events such as floods, droughts and heat stress. Indirect health effects of climate change (see Figure 4.5) include the spread and/or increase of the incidence of infectious and vector-borne diseases, water-borne pathogens, water quality, air quality, and food availability and quality. The actual health impacts that will occur in the future are strongly dependent on local environmental conditions, the socio-economic status of the area, and the range of adaptation measures put in place to reduce the threats. Another important factor that may increase the threat to human health is population displacements due to extreme weather events and sea-level rise as well as climate-related conflicts.

The vulnerability and capacity of a community or communities to adapt to health threats depends on their general health status. Key considerations in this regard include the prevalence of cardiovascular diseases, HIV and TB, malnutrition or stunting especially in young children; level of education and awareness; economic status; general demographic profile (for example gender and age profiles); migration patterns and levels; level of infrastructure development and maintenance; access to and availability of skilled medical personnel and facilities, and population density.

One major difficulty in quantifying the impacts of climate change on human health is the lack of long-term health data for a specific area or areas that can be linked to changes in the climate system. The links between human health, the natural environment and systems operating at different time and spatial scales contribute to the complexity associated with distinguishing the health effects of climate change from other global environmental changes. In addition, climate change is one of a range of factors that can affect human health.

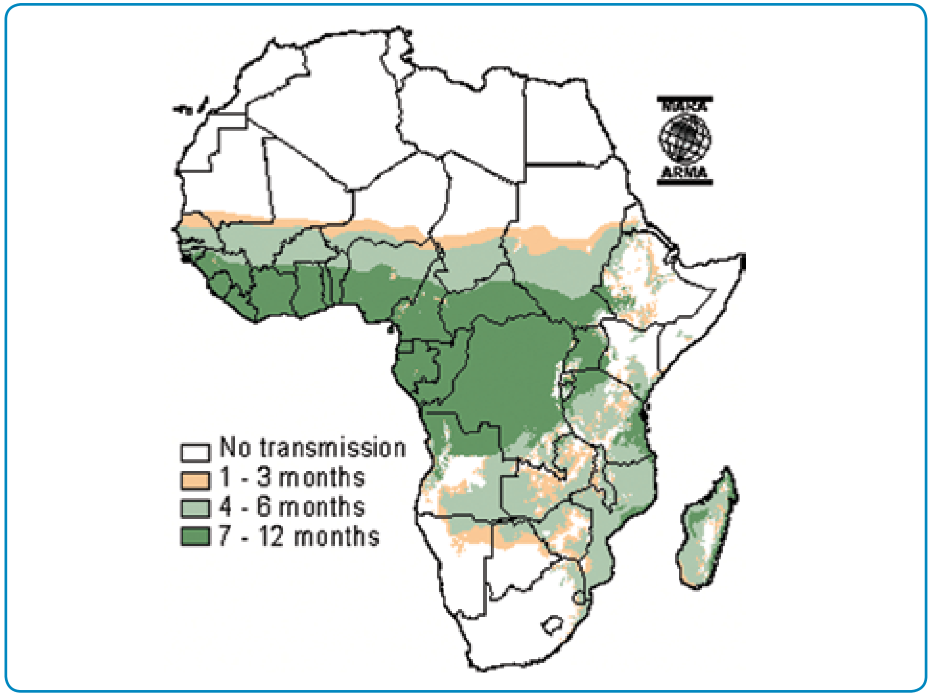


Figure 4.3: Duration of malaria transmission season under climate change. Source: Anonymous (N.D.)

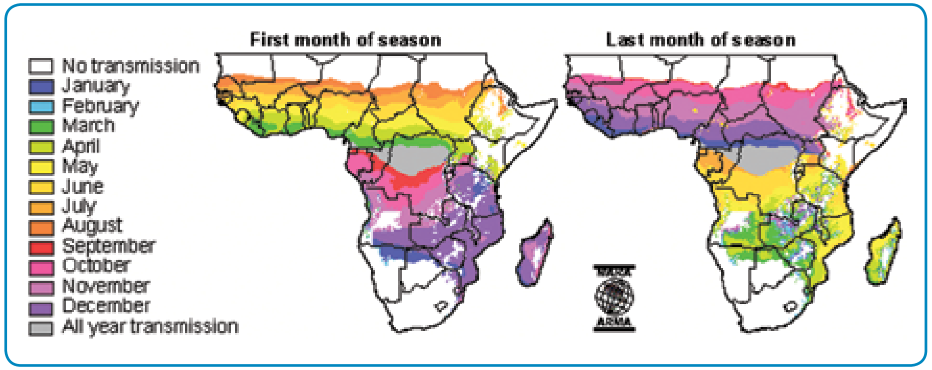


Figure 4.4: The first and last month of the malaria transmission season under climate change. Source: Anonymous (N.D.)

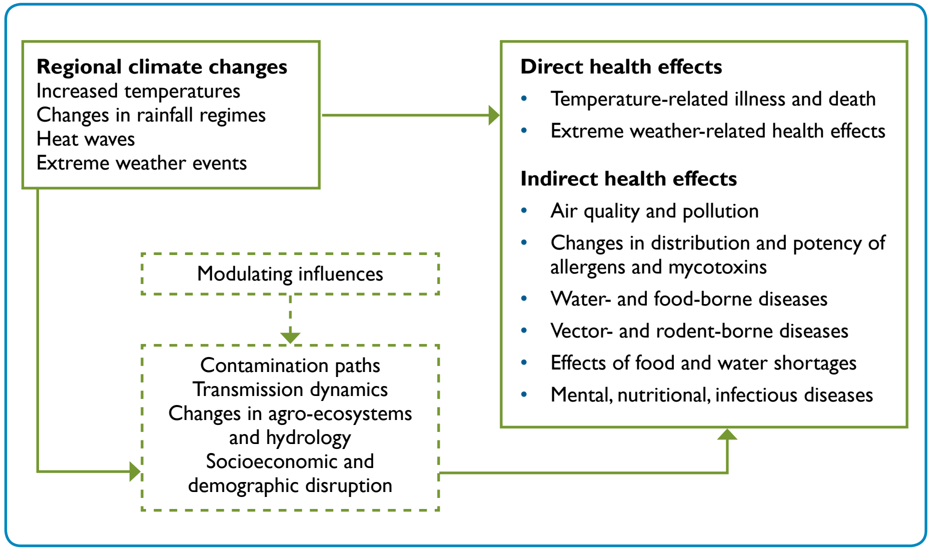


Figure 4.5: Direct and indirect health effects of climate change change
Source: Direct and indirect influences (Redrawn from World Health Organization, Online at: WHO Climate Influences)

4.4. Adaptive capacity (social vulnerability) to climate change

As previously mentioned, more recent analyses of the risks associated with climate change recognise that humans are active agents in responding to climate change and that the adaptive capacity of people will either increase or lessen their levels of risk to climate change. This adaptive capacity is influenced by their age, their socio-economic circumstances, and their access to power, to name but a few. Determining adaptive capacity in the face of climate change is highly context-specific, and thus many of the assessments of adaptive capacity take place at the local level. In this section there are two examples, one from Lesotho (on page 63), and one from South Africa (below). Both approaches develop indicators of social vulnerability for comparison.

CASE STUDY: Social vulnerability to climate change in uMkhanyakude District, KwaZulu-Natal, South Africa

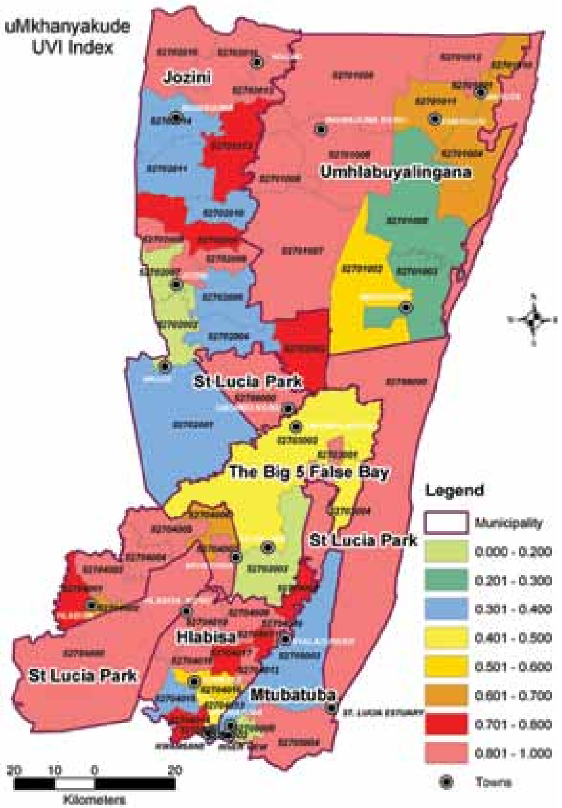
By Alison Misselhorn

Oxfam Australia commissioned a study assessing the level of social vulnerability to climate change in uMkhanyakude District, KwaZulu-Natal, South Africa. The social vulnerability of this district is thought to be high due to a number of driving forces:

- It has the highest malaria prevalence in the country
- 20-30% of adults are HIV+
- Tuberculosis is a major cause of mortality
- The population structure is such that there is a high dependency ratio (many children and the elderly relying on a smaller proportion of working age adults)
- Unemployment is very high, estimated at 66-90%
- Education levels are low, with 30% having received no formal education at all.

In order to distinguish between the relative levels of vulnerability to climate change among different wards within the district, an index was created. This index comprises several elements of social vulnerability, namely interconnectivity, economic well-being, health and security, demographic structure, and natural resource dependence. Figure 4.8 shows the results. The closer the index score to 1, the relatively more vulnerable those wards are. The least vulnerable wards are those with a score close to 0 (shown in green). The results of this vulnerability index can be used to prioritise interventions designed to support adaptation to climate change.

This case study is based on a report published by Oxfam: Misselhorn, AA, 2008: Vulnerability to Climate Change in Umkanyakude District, KwaZulu-Natal, South Africa. Oxfam Australia, Carlton, Victoria.



Location of uMkhanyakude District, KwaZulu-Natal (Misselhorn, 2008)

CASE STUDY: Social vulnerability to climate change in rural Lesotho

By Jarred Bell

Global environmental change research in Southern Africa has increasingly focused on the social vulnerability of rural livelihoods to the impacts of climate change. Social vulnerability refers to the susceptibility of households or social groupings of people to the effects of climate change and their ability to cope with, adapt to and overcome these (Adger and Kelly, 1999). Rural livelihood vulnerability is partly a function of exposure to a climatic stress and their sensitivity to the impacts. Sensitivity is determined by internal characteristics of a household, specifically its access to combinations of livelihood capitals (see DFID, 1999 for explanation of capitals). Empirical research - utilising a Vulnerability Index based on livelihood capitals - was conducted in 2010-2011 in Singalane village, northern Lesotho. The purpose was to determine the vulnerability of rural livelihoods to climate variability and change based around the five capitals in the sustainable livelihoods framework: financial, human, natural, physical and social.

The research highlighted the key vulnerabilities faced by rural households in Singalane village to the impacts of projected changes in future climate. Natural capital is one of the most vulnerable to the impacts of climate change. An inverse relationship was identified between natural capital and household vulnerability. Half of most vulnerable households in Singalane were dependent on agriculture and cultivated lower crop diversity than least vulnerable households. The former group are especially vulnerable as future impacts of climate change (specifically increased frequency of drought and temperature extremes) may decimate their monoculture crops, leading to increased food insecurity. Least vulnerable households with lower crop diversity face lower vulnerability as they rely on a wider variety of crops.

Possibly one of the greatest vulnerabilities faced by rural households is their lack of social capital. 22% of households have no membership to any community groups. 46% of vulnerable households belong to one community group (a burial society which only provides support for a death in a household), while only 21% belong to two community groups that can be relied upon for support in times of climatic stress. The geographic range of household social support networks is equally very narrow. Many vulnerable households have access to bonding social capital inside or outside the village. Least vulnerable households additionally had limited access to bridging social capital inside the village (the village headman).

Financial capital; specifically livestock assets; is another key vulnerability of households in Phelantaba village. In times of climatic stress, households can rely on livestock assets, due to their liquidity, to support the household. There is a direct relationship between the value of a household's livestock assets and its vulnerability. 45% of most vulnerable households have no livestock assets while 41% have livestock assets value under R10,000. The low value of livestock assets amongst most vulnerable households was attributed to their ownership of low valued livestock such as chickens and pigs. Moderately vulnerable households have higher valued livestock assets (average of R R11,500), while 58% of least vulnerable households in Phelantaba village have highest valued livestock assets (of cattle, sheep and goats) valued between R4,000 and R50,000.

To sum up, it is clear that rural livelihoods in Phelantaba village are characterized by same key vulnerabilities. These relate to their dependence on agriculture and poor crop diversity; meagre household social capital and the weak financial capital – specifically the lack of livestock or ownership of low-valued livestock assets – on which households can rely on when the impacts of climate change are greatest.

4.5. Conclusion

This chapter has outlined how the risks of climate change (typically seen as adverse impacts) are determined by the interaction of three factors: hazard exposure, sensitivity (or biophysical vulnerability) to that exposure, and the adaptive capacity (or social vulnerability) of people living in that environment. Since determining adaptive capacity is very context-specific, it is typically done at the small scale. As a result, when looking at regional impacts of climate change, emphasis is typically placed on sectoral impacts (biophysical vulnerability). Determining the risks of adverse impacts of climate change is important for prioritising places (and people) where adaptation interventions are required. Chapter 5 looks at opportunities for, and examples of, risk reduction and adaptation in southern Africa.

Box 4.4: Sources of information - Tools for social vulnerability assessment

CARE Climate Vulnerability and Capacity Analysis (CVCA) Handbook (http://www.careclimatechange.org).
This handbook outlines a methodology for analysing vulnerability to climate change and adaptive capacity at the local level, emphasising the integration of local knowledge in the assessment.

Provention Community Risk Assessment (http://www.proventionconsortium.org/?pageid=39)
The Community Risk Assessment Toolkit comprises a collection of methodologies and case studies to identify the most appropriate assessment method for the application.

Chapter 5: Dealing with risk

By Tracy Cull, Katharine Vincent, Claire Davis and Emma Archer van Garderen

Over the medium to longer term there is great potential to adapt to climate change through mainstreaming adaptation and risk in core development activities.

5.1. Introduction

The previous chapters have outlined the projected changes in climate conditions for the southern African region and the possible impacts of these changes on various sectors. We have also introduced the concepts of biophysical vulnerability and adaptive capacity to explain where the anticipated change in hazard exposure is likely to translate into adverse outcomes. Identifying areas and groups of people that are highly vulnerable is essential in order to prioritise interventions. This chapter is concerned with how we can respond to climate change in order to reduce its adverse impacts. Following international practice, these responses can broadly be grouped into mitigation (reduction in the causes of climate change) and adaptation (reduction of the impact of climate change), which itself has significant overlaps with disaster risk reduction. It is important to remember that, with appropriate responses, climate change need not always be detrimental, and indeed proactive responses can exploit opportunities for human development.

5.2. Mitigation

With respect to climate change, the term mitigation most commonly refers to activities to reduce the quantities of greenhouse gases in the atmosphere that drive the change in climate (for example, tax incentives for companies to reduce greenhouse gas emissions or the introduction of new technology to reduce the amount of greenhouse gas produced). The Kyoto Protocol under the United Nations Framework Convention on Climate Change is concerned with exactly that – committing parties to reduce their greenhouse gas emissions by different percentages relative to 1990 levels, with the exact percentage differing from country to country. Under the Kyoto Protocol only developed countries (otherwise known as Annex I countries) have mitigation commitments. In order to assist these countries in reducing their emissions, the Kyoto Protocol contains a number of flexible mechanisms. One of these, which is relevant to southern Africa, is the Clean Development Mechanism (CDM).

Under CDM, Annex I countries can buy carbon reductions from certified low carbon development programmes in the developing world. As the policy framework evolves, there is now also emphasis on the fact that so-called 'sinks' can remove carbon from the atmosphere. This was previously known as LULUCF – land use, land use change and forestry, but has more recently evolved into REDD+ - reducing emissions from deforestation and degradation. The + sign refers to the fact that this initiative has a corresponding environmental benefit, through conservation and sustainable forest management. This idea of co-benefits of carbon sinks has also been picked up in Africa (see Zambia and Kenya case studies below on page 67 and 68 respectively). There is, of course, a role for the private sector to play in mitigation as well, particularly in South Africa, which has made public commitments to reducing its greenhouse gas emissions in the context of ongoing negotiations for the successor to the Kyoto Protocol (see Exxaro case study on page 69). Finally, local authorities have a critical role to play in mitigation, as is increasingly recognised throughout southern Africa in local and national policy (see Ethekwini case study on page 70).

Box 5.1: Definitions

Mitigation refers to the measures taken to reduce the emission of greenhouse gases and to enhance sinks of greenhouse gases, such as growing trees which absorb carbon dioxide from the atmosphere.

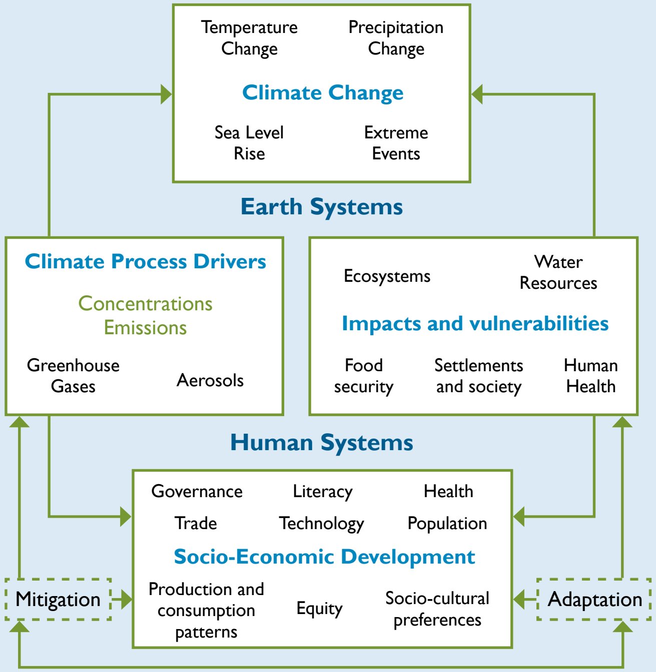
Adaptation is a means of responding to the impacts of climate change. It aims to moderate the impacts as well as to take advantage of new opportunities or to cope with the consequences of new conditions. The capacity to adapt is dependent on a region's socio-economic and environmental situation as well as the availability of information and technology. At the individual level, a person's characteristics (e.g. their age, gender, education level, etc.) will influence their ability to adapt successfully to changes in climate conditions.

There are two main types of adaptation:

- *Anticipatory adaptation* is adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- *Reactive adaptation* is adaptation that takes place after impacts of climate change have been observed.

Disaster risk reduction includes all forms of activities to avoid (prevention) or to limit (mitigation and preparedness) the adverse effects of hazards (www.unisdr.org).

Strategies that are effective and/or suitable across sectors need to be prioritised; these are termed *multi-sectoral approaches*. This would involve simultaneously addressing a range of objectives, which include climate change adaptation, carbon sequestration and greenhouse gas emissions mitigation, biodiversity conservation and sustainable livelihoods. Many existing strategies and policies may be merely supported or amended to improve adaptive capacity in the face of climate change implications for key sectors.



CASE STUDY: Reducing emissions from deforestation and forest degradation

By Catherine Traynor

Deforestation contributes between 12-20% of global greenhouse gas emissions (Gibbs and Herold, 2007; Van der Werf et al., 2009). REDD+ is designed to reduce the carbon emissions that are released into the atmosphere when trees are cut down, and has the potential to be an important mitigation action to avoid global temperature increases over 2°C (UNFCCC, 2009). The positive incentives are performance-based payments on the achievement of reduced emissions or increased removals of greenhouse gases (Wertz-Knounnikoff and Angelsen, 2009). Monitoring, reporting and verification (MRV) are used to quantify the changes in greenhouse gases, which are reported in tonnes of carbon dioxide equivalent (t CO_2e), and known as 'carbon credits'. For each carbon credit produced as a result of REDD+, financial compensation will be paid from an international fund and/or an international carbon market mechanism. REDD+ means that forest carbon now has a value, and forests are valued not just for their products and the land upon which they stand (Sunderlain and Atmadja, 2009). REDD+ activities should be implemented following 'safeguards', these include the respect for the knowledge and rights of indigenous peoples and local communities and their full and effective participation.

Zambia is developing a national REDD+ strategy with the assistance of the UN-REDD Programme, a collaborative programme which aims to contribute to the development of capacity for implementing REDD+ (UN-REDD, 2010). The UN-REDD Programme Zambia quick-start initiatives goal is to prepare institutions and stakeholders for effective nationwide implementation of the REDD+ mechanism. The programme objectives are to build institutional and stakeholder capacity to implement REDD+, develop an enabling policy environment for REDD+, develop benefit-sharing models, and develop MRV systems (MTENR/UN-REDD 2010). Local level projects will address specific deforestation and degradation (D+D) factors. Zambia will need to consider which locations have the greatest potential for REDD+ and this will require spatially differentiated data.

National level data from Zambia are used to illustrate how spatial data can assist decision-makers to identify potential REDD+ locations. To maximise the benefits, locations will need to offer opportunities to reduce D+D and also enhance multiple benefits. Two important drivers of D+D in Zambia are the conversion of forests to croplands as well as frequent fires. By asking experts, soil maps were used to identify soils with high suitability for annual cropping. Fire frequency was estimated from the MODIS burned area product (Roy et al., 2008). All the areas burnt between 2000 to 2007 were mapped and fire frequency for each grid square estimated for the eight-year period (Archibald et al., 2010). These 'driver' maps were classified into five classes and added together to give a threats layer. High carbon density areas were identified by utilising above-ground woody biomass values (Baccini et al., 2008), calculating below-ground biomass using ratios, and adding the soil organic matter carbon pool (FAO, 2007).

REDD+ 'benefits' were identified by mapping biodiversity estimates [mammals and amphibians (IUCN 2010), birds (BirdLife International 2009), and vascular plants (Barthlott et al., 2007), and also fuelwood sufficiency (Biggs et al., 2004)]. The carbon density, biodiversity and fuelwood maps were each reclassified into five classes and added together to give a 'benefits' layer. The 'benefits' layer was then multiplied by the 'threats' layer and areas of high conflict mapped. These conflict areas show where high carbon densities and the co-benefits of biodiversity and fuelwood supply are threatened by frequent fires and/or soil suitability for agriculture (see Figure 5.1). These conflict areas suggest potential priority areas for REDD+ project implementation; however, further mapping — for example integrating historical deforestation, non-wood forest products, and charcoal production — coupled with stakeholder consultation and expert elicitation would improve these preliminary findings.

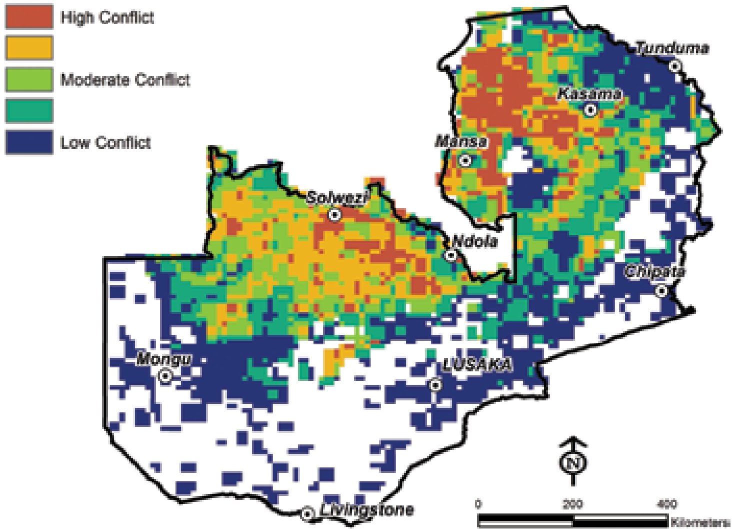


Figure 5.1: Possible priority areas for REDD+ project implementation in Zambia.

CASE STUDY: Mbirikani Carbon Project, Kenya (African Wildlife Foundation-AWF)

By Kathleen H. Fitzgerald

As part of its commitment to ensuring the sustainability of the wildlife and wildlands of Africa, AWF is currently implementing a carbon offset programme with the Mbirikani Group Ranch, southern Kenya. Mbirikani comprises approximately 320 000 acres and is owned and run communally by around 4 500 Maasai pastoralists. There are just over 15 000 people living on the ranch, along with some 60-90 000 head of livestock. Permanent water is scarce. Rainfall is erratic and averages between 350 and 500 mm per year, making it one of Kenya's driest areas. This, in turn, makes it difficult for the community to generate income from other means besides pastoralism. A carbon offset program is being tried as a way to generate income to support forest conservation and improve livelihoods, and to contribute to the protection of a wildlife linkage that enables dispersal from Amboseli National Park to Mbirikani Group Ranch.

The first step was meeting with the community, training them on REDD+ and soliciting their endorsement of the project. The training was conducted in Swahili and Kimaasai. The participants, both Group Ranch Committee and community members, gained an understanding of REDD+ and approved it enthusiastically. It was agreed that any revenue from the carbon programme would be used to support the conservation efforts, pay for annual monitoring and verification, and revenue to the community would be distributed directly to households. The community ended the meeting by stating "Karibu Carbon" ("Welcome Carbon"). After the strong endorsement, AWF initiated an assessment to identify the drivers of deforestation as an initial step to establishing a carbon offset project for the community. The main drivers of deforestation include logging and harvesting for timber, poles for construction, firewood, charcoal, carvings and 'rungus' – walking sticks; fires from honey harvesting; and overharvesting for medicinal plants.

A Project Idea Note (PIN) and Project Development Document (PDD) were completed and AWF and the community will be seeking verification from the Voluntary Carbon Standard (VCS) and Community, Climate and Biodiversity (CCB). Simultaneously, AWF has been working with partners to mitigate the threat to the forest through alternative livelihood programmes. These include alternative cookers (solar and improved jikos), range restoration, alternative building materials, and micro-enterprises, such as improved livestock markets. In addition, AWF is working with the community on reforestation, which may enable them to qualify for more carbon credits and increase forest cover.

Some of the lessons learned in this pilot project to date:

1. The cost of setting up carbon credit programmes is high. A cost-benefit analysis should be done.
2. Clear benefit-sharing mechanisms need to be agreed upon from the beginning.
3. GIS requirements are significant for the programme, both the data and expertise.
4. The project development takes time; therefore, communities need to understand the time required.

The carbon market, while still under development, potentially provides an opportunity for communities to generate income to support their livelihoods and conservation efforts. In particular, communities that live in remote areas that are not tourism destinations lack the financial incentives to protect their land. The ability of these communities to access carbon markets provides a potential source of revenue for forest conservation. There are significant challenges, not the least the need for a long-term commitment to maintaining the forest resources, and the development of the carbon market is relatively new; however, AWF hopes that some of the lessons learned from its current pilot programmes will help communities throughout Africa protect their forests from deforestation and degradation. Designing these programmes correctly, ensuring equitable distribution of benefits and engaging the community from the start are key aspects of a successful carbon programme.

CASE STUDY: Powering the possibility of a greener Earth - Exxaro Resources

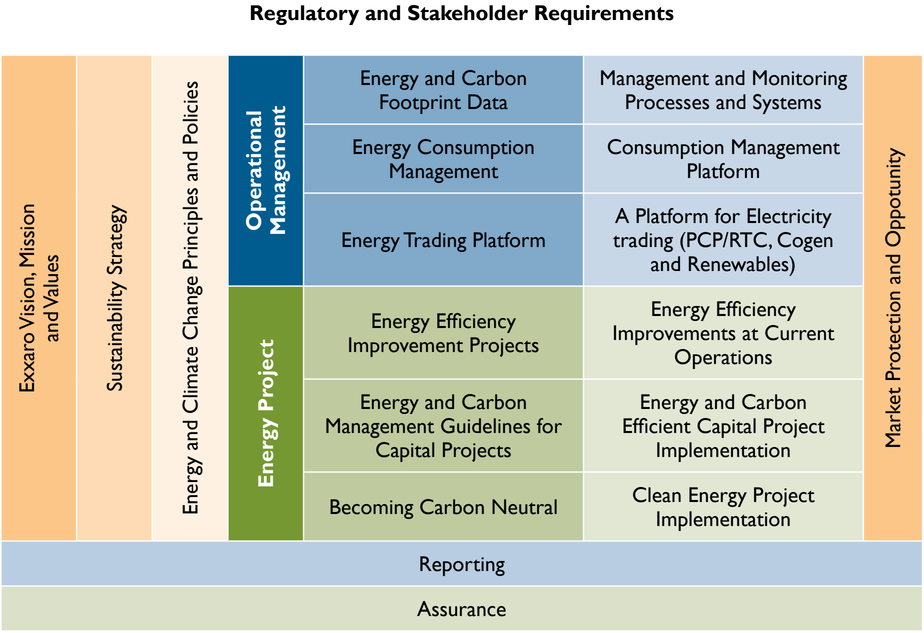
By Lizette Kohn

Exxaro Resources is a South African-based mining group that actively manages energy use in an attempt to reduce the company's carbon footprint. Exxaro took part in the Carbon Disclosure Project (CDP) and was ranked 5th out of the JSE Top 100 companies. Gathering data for the CDP highlighted some challenges related to obtaining accurate and complete energy and carbon footprint data, which sparked the creation of an Energy and Carbon Management Strategy and framework to explore energy data management and other related work streams and focus areas.

The Energy and Carbon Management Strategy is aligned with other key Exxaro policies, such as the Sustainability Strategy and Energy and Climate Change principles and policies, and is informed by iteratively updated energy and carbon data collection and management. Real-time electricity consumption management capability was created in anticipation of Eskom's Power Conservation Plan (PCP), which formed the foundation for an energy trading platform.

The rising electricity and fuel costs, carbon tax threats and the real desire to decrease the carbon footprint of the business has created a highly focused work stream in the area of energy efficiency, led by an Energy Efficiency Manager and dedicated Energy Champions at each of Exxaro's business units. This has resulted in innovative grassroots initiatives and solutions to improve energy efficiency. Solutions ranging from heat pump water heating, variable speed drive motors and various lighting solutions were researched and implemented. Tried and tested solutions were shared across business units as best practice. These energy efficiency practices are now incorporated as standard into capital projects and design criteria.

In 2010 the Exxaro Exco pledged its support for the Energy and Carbon Management Programme and reconfirmed its commitment to improve energy efficiency by 10% and reduce carbon emissions with a similar 10% by 2012. Exxaro is currently investing in co-generation capability and is about to launch a clean energy company that will focus on renewable energy.



Regulatory and Stakeholder Requirements

Exxaro Vision, Mission and Values

Sustainability Strategy

Energy and Climate Change Principles and Policies

Operational Management

Energy and Carbon Footprint Data	Management and Monitoring Processes and Systems
Energy Consumption Management	Consumption Management Platform
Energy Trading Platform	A Platform for Electricity trading (PCP/RTC, Cogen and Renewables)

Energy Project

Energy Efficiency Improvement Projects	Energy Efficiency Improvements at Current Operations
Energy and Carbon Management Guidelines for Capital Projects	Energy and Carbon Efficient Capital Project Implementation
Becoming Carbon Neutral	Clean Energy Project Implementation

Market Protection and Opportunity

Reporting

Assurance

Figure 5.2: Exxaro Energy and Carbon Management Strategy Framework.

CASE STUDY: Air quality and mitigation in Durban, South Africa

By Tirusha Thambiran

Climate change and air quality considerations share common sources of emissions, thus interventions in these areas can simultaneously affect more than one air pollutant. A measure targeted at reducing emissions of a particular pollutant might result in increases (trade-offs) or decreases (co-benefits) in the emissions of other pollutants. Air quality management policies therefore need to take cognisance of the possible impacts on greenhouse gas (GHG) mitigation efforts. The city of Durban, which is located within the province of KwaZulu-Natal on the eastern seaboard of South Africa, provides a useful example of the potential opportunities to incorporate climate change considerations into air quality management plans (AQMPs).

Durban has been characterised as consisting of numerous air pollution sources, primarily attributed to the combustion of fossil fuels at industries and in road transport. These sectors are important contributors to the city's GDP and are also significant contributors to air pollution and GHG emissions. The challenge that the city faces is to be able to reap the socio-economic benefits that these services offer, while minimising the environmental and health impacts.

Durban developed its AQMP in 2007, which serves as the foundation to ensure that measures are implemented within the road transport and industrial sectors to maintain ambient air quality levels that are acceptable for human health and ecosystems. Climate change concerns have to date been dealt with separately from the AQMP, with the majority of research focused on understanding the impacts of climate change on the city and quantifying GHG emissions. Opportunities to use air quality interventions innovatively to address GHG emissions are mostly overlooked.

For example, the city has regulated the implementation of industrial air quality action plans that consist of numerous measures with synergies and trade-offs for climate change. These include the increase in electricity consumption due to the installation of air pollution cleaning devices and decreases in GHG emissions from fuel switching. The impact on GHG emissions was not quantified or considered in the decision to implement these air quality control measures. Consequently, in instances where interventions resulted in increases of GHG emissions no measures were taken to offset the trade-offs for climate change. Furthermore, to date, industrial energy interventions have mostly focused on demand management of electricity consumption as prioritised in the city's energy strategy. Many of the large industrial consumers of electricity do not directly contribute towards air pollution and are therefore not regulated under the city's AQMP. Further to this, as grid-supplied electricity is not generated within the city's boundaries, there has been no direct co-benefit for improved air quality from reduced electricity consumption. Air quality and energy policies for the city are poorly aligned, thus opportunities for achieving co-benefits through the management of fossil fuel consumption are not being realised.

The road transport sector in Durban is considered to be a growing source of air pollution in the city. High numbers of old passenger motor vehicles and heavy-duty trucks contribute towards high levels of air pollution and fuel consumption experienced in Durban. Unlike the industrial sector, regulations for the road transport sector are not as well developed, with little incentive to ensure that motor vehicles are low contributors to air pollution in the city. There are currently no direct air pollution control measures being implemented within this sector. However, many of the measures that are proposed within the city's transport plan, such as the promotion of rail for freight transport and improving public transport systems, have the potential to simultaneously impact on air pollution, road safety and fossil fuel consumption.

Industrial fossil fuel consumption and road transportation present cross-cutting policy imperatives and the decisions taken to meet these specific challenges may determine the city's success in simultaneously achieving air quality targets and mitigating climate change. Significant co-benefits can therefore result from improved co-ordination of industrial, energy and transport plans. The AQMP can play an important role in ensuring that measures with multiple benefits are selected, by supporting and influencing interventions in the city that target energy efficiency, fuel changes and road transport management.

5.3. Adaptation

While the international policy process for addressing climate change has typically focused on mitigation, adaptation has always been a critical response in southern Africa. This is because the magnitude of projected changes in climate is so great, and the adaptive capacity typically so low, that adverse impacts are likely. Adaptation is a way of reducing the risks posed by climate change to people's lives and livelihoods (DFID, 2006).

As shown in Chapter 1, much of southern Africa is characterized by a variable climate, and people have typically used coping mechanisms to respond to this variability. The difference between coping and adaptation strategies refers to their relation to vulnerability. A coping strategy may help a person or household to maintain their wellbeing in the face of a crisis, but does not reduce their vulnerability to the same crisis happening again. An adaptation strategy does reduce vulnerability to future exposure to the same hazard. For example, if a family's mudbrick house is damaged in a flood, they may repair it using more mudbricks – this is a coping strategy. If, however, they build it again using concrete bricks which can better withstand flooding, or on stilts, that would be deemed an adaptation mechanism. Box 5.2 outlines some examples of common adaptation measures. Others are explained in greater detail in the case study boxes.

Part of the difficulty with implementing adaptation is knowing exactly what is needed in practice. While autonomous adaptation is easy to observe – in terms of responses to past climatic events – planned adaptation is much more difficult as it involves prior responses to a potential future event. Because of the link between adaptation and vulnerability, judging when adaptations are successful can only be done after the intervention, as it typically requires exposure to a hazard of similar magnitude. An appropriate response to climate change is therefore to attempt to build the adaptive capacity of populations – to ensure that hazard exposure does not translate into adverse impacts when it occurs (see DRC case study on page 73). In many cases, building adaptive capacity at the grassroots level is successful only when the socio-cultural context of the community is taken into account (see para-ecologist case study on page 74).

The capacity to adapt to climate change is dependent on a wide variety of social, political, economic, technological, and institutional factors. The specific interaction of these factors differs depending on the scale of analysis: from the level of the country down to the individual, adaptive capacity is multidimensional, it is determined by complex inter-relationships of a number of factors at different scales. At the country level it not only reflects the availability of financial resources, but, crucially, the degree of organisation and institutional capacity for targeting those resources effectively to the areas and groups of people that are most vulnerable. At the household level, whether or not a person can adapt to climate change depends on such factors as their knowledge base, which may enable them to anticipate change and identify new or modified livelihood opportunities, and their access to further resources required to achieve this (Vincent, 2007).

Arguably one of the most appropriate ways of adapting to climate change is through mainstreaming consideration of adaptation into core development activities. This makes sense for several reasons – if development initiatives disregard climate change, meeting their aims and objectives may be impeded by climate change, or the intervention may inadvertently increase vulnerability to climate change (for example by encouraging dependence on a natural resource whose availability is projected to change) (Klein, 2001). This approach has been embraced by a number of bilateral and multilateral donors, who now consider "climate proofing" or climate risk assessment of their development projects to be imperative (Klein et al., 2007). Many other development actors, including non-governmental organisations (NGOs), support this approach of mainstreaming climate into development activities (Vincent et al., 2010).

[Picture: Kathleen H. Fitzgerald]

Box 5.2: Examples of common adaptation measures (adapted from Vincent et al., 2008)

Adaptation measure	*Opportunities*	*Challenges*
Disaster risk reduction measures.	There is an established history of disaster risk reduction in a number of southern African countries, in particular Madagascar and Mozambique.	The institutional set up is not always conducive to integrating climate change adaptation and disaster risk reduction: they are often housed in different ministries, for example.
Social protection for people vulnerable to climate change.	A number of southern African countries (e.g. Botswana, Lesotho, Mauritius, Namibia, South Africa, Swaziland) now have national level social protection schemes, including cash transfers, so the systems are in place to make transfers related to climate variability.	Social protection schemes are typically viewed as expensive by governments, not least because once introduced, they are long term.
Provision of climate information and early warning, so that farmers are able to make decisions that are appropriate to the upcoming conditions.	Seasonal forecasts are commonly produced by national meteorological services, which model a range of climate parameters and provide probabilistic short-term forecasts of the likelihood of rainfall being less than the average, average, or higher than average over the coming season.	Importance of the process of transferring information from national to local level, which must be timely and take into account the farmers' preferences in information channels and timing (Patt and Gwata, 2002). One piece of research showed that women prefer to hear seasonal forecasts from extension officers, while men prefer to hear these on the radio (Archer, 2003).
Agricultural technology: new crop varieties, conservation agriculture practices.	Small-scale farmers (and those requiring minimal inputs) have more flexibility on what they grow from year to year.	Access to resources (inputs such as seed and fertiliser, and physical capital such as land and tools) may be too expensive for small-scale farmers. Tree crop farmers have a longer lag time to implement changes in the production system.
Improved water management: efficiency measures and demand-side management.	Since water is a scarce resource in southern Africa, encouraging resource conservation and efficiency of use ensures better availability of resources.	Policy structures often have to be changed to encourage efficiency through the implementation of pricing mechanisms. There are also costs to efficiency, for example through ensuring that infrastructure is well maintained to minimise loss due to leakage.
Risk-sharing mechanisms, such as index-linked insurance.	Index-linked insurance can make a financial mechanism available without moral hazard – as the payout is linked to the weather conditions and not to the crop harvest. It has been successfully trialled in Malawi, Kenya and Ethiopia.	Relies on the availability of weather information. Can be costly for poor farmers to access. Risk that such options actually increase susceptibility by providing a cushioning layer which prevents farmers from taking decisions to link their farming activities with the weather conditions (McLeman and Smit, 2006).
Livelihood diversification out of more climate-sensitive activities.	Diversification is a commonly practiced strategy to deal with multiple stresses.	Encouraging livelihood diversification at grassroots level through national level policy is notoriously difficult, due to the location-specific context of many livelihoods.
Facilitating the movement of people out of areas where their livelihoods are at risk.	Climate change will not bring disadvantages to all areas – to some it will bring opportunities, and (optional) redistribution of population to take advantage of resource shifts is a good strategy to adapt.	Migration brings political and humanitarian challenges, particularly where national borders are crossed, for example xenophobic attacks in South Africa.

CASE STUDY: Lessons learned for enhancing the adaptive capacity of forest communities in the Democratic Republic of Congo

By Youssoufa Bele

People living in forests are highly dependent on forest goods and services, and are vulnerable to forest changes, both socially and economically.

In the Democratic Republic of Congo (DRC), like in many other Central African countries, pressures such as forest fragmentation, reduction in habitat, loss of biodiversity and the resulting adverse effects on forest-based communities are already proving difficult to manage. Climate variation and change constitute an additional burden that constrains national development for realising major global targets like the Millennium Development Goals. However, the adaptive capacity of the rural poor who are likely to be the most vulnerable to climate change is still not well understood.

In the DRC, more than 80% of the population is dependent on climate-sensitive sectors for their livelihoods, such as agriculture, fisheries, pastoral practices, and forests for household energy, food security, water supply, herbs, and tree bark as first line of health care products. In this case, indigenous peoples and local communities, through their extensive traditional ecological knowledge and know-how, could play a determining role as "sentinels" by providing first-hand and accurate observations and supplying databases on climate change adaptation. These populations have, however, a very low capacity to cope with the impacts of climate variability and change or to take advantage of opportunities. Incidentally, climate change is not currently considered in decisions and long-term forest management plans in this country.

With this perspective, the Centre for International Forestry Research (CIFOR) launched a three-year project titled 'Congo Basin forests and climate change adaptation in Central Africa' (CoFCCA) in 2008, funded by Canada's International Development Research Centre (IDRC) and the UK Department for International Development (DFID). Within the framework of this project, participatory action research (PAR) has been used in the Kisangani and Mambasa forest communities in DRC to help indigenous and local communities enhance their adaptive capacity to climate variation and change.

As a major finding, adaptation is not new to the local communities studied, as they have always had to develop and implement individual and collective strategies to adapt to climate variability and environmental change. Some households have successfully avoided animal morbidity in prolonged periods of drought by planting and watering around their houses some grass species animals can eat or by placing vessels filled with water under shade for them to drink. Collectively, the community created firebreaks to protect their forests and farms from forest fires. The studied communities have taken advantage of opportunities provided by climate variability and change. These communities take advantage of occasional rainfall during the dry season to boost production of certain foodstuffs. Such rainfall has had positive effects on the growth of banana-plantain and cassava in Mambasa. Local communities in Kisangani take advantage of the drying of swampy areas to develop the culture of maize in the off season.

Strategies used so far may, however, be jeopardised by future climate change; thus the need to develop new adaptation strategies. Such strategies include training in apiculture, farming of *Gnetum* trees and production of plant species for caterpillar cultivation, important food sources when climate change affects harvest. Many obstacles hamper the implementation of new strategies – limited access to scientific innovation and information on climate change; socio-economic stresses; weak education and preparedness for disasters; low or insufficient financial resources that impedes collective action; and lack of appropriate agricultural outreach relevant to climate change adaptation.

Climate change is thus not just an environmental problem in the DRC but a development problem as well. It has the potential to exacerbate poverty. The responses developed so far by local communities may be less appropriate in the near future because of climate change. Participatory action research has helped these communities develop new adaptation options whose implementation necessitates the support of partners such as international organisations, national and regional authorities and NGOs. This support must, however, be coordinated and action oriented.

CASE STUDY: Para-ecologists can support adaptation to climate change

By Ute Schmiedel

Stakeholder participation plays an increasingly important role in applied climate change research that aims at adaptation of land use management. The reason for this is the understanding that the outcome of applied research will only achieve the envisaged impact and is likely to result in implementation if the target group of the research activities has been part of the solution-finding process. However, true stakeholder participation in an academic research context may be a challenge for the academic researcher. Typical academic research projects have to meet milestones and research goals as well as have to deliver peer-reviewed scientific publications that often require a focus on a rather narrow academic research scope. These requirements hamper the participatory process that calls for an open-ended, flexible approach that allows for adjustment of project means and goals as the project progresses.

BIOTA Southern Africa, an international, interdisciplinary biodiversity research project, which monitored and analysed the impact of land use and climate change on biodiversity in southern Africa (Namibia and South Africa), experienced this challenge. In order to be able to engage with land users in the context of an academic research approach, BIOTA employed and trained eight members of local land user communities to become members of the research team. These "para"-ecologists were trained over a period of almost six years on the job and during annual training courses in the field of biodiversity monitoring and related socio-economic research (for more details on the para-ecologist programme see Schmiedel et al., 2009, 2010). The aim of the para-ecologist initiative was to empower members of local communities to get involved in research activities and to intensify the exchange and collaboration with the local land users. Para-ecologists facilitated the sharing of research aims, activities, results and their possible implications on land management with the land users. Last but not least, para-ecologists also supported the researchers with their time-consuming biodiversity monitoring activities, including those tasks that require data observations during the absence of the researchers.

The experiences showed that the involvement of para-ecologists in the project helped to better understand the land users' perspective of the natural and social environment as well as the constraints, challenges and incentives for their land management decisions under global change conditions. Also, the para-ecologists became instrumental in knowledge exchange between scientists and land users as well as in awareness raising and environmental education among local communities. Thus, the para-ecologist programme contributed towards the empowerment of the local land user communities in the field of adaptation and sustainable land use management. It helped to expand their knowledge as referring to observational data aided their management decisions.

Learning to collect and identify plants and animals is part of the para-ecologist training workshops. [Picture: Ute Schmiedel]

The para-ecologist programme can be one step to empower members of land user communities to share, evaluate (in terms of their own experiences) and utilise scientific insights for their strategies to adapt to the changing environment. This is in line with the understanding that adaptation to climate change as a dynamic process requires the enhancement of adaptive capacity now instead of targeting adaption to a changed state in the future (Tschakert and Dietrich, 2010).

The employment and training of para-ecologists requires strong personal commitment from the scientists and para-ecologists. Problems which arise might differ depending on the social, economic, and political environment of such a programme. Due to differences in culture and codes between scientists and para-ecologists, difficulties that are caused by miscommunication and differences in perception will almost certainly arise. These structural, intellectual or social challenges might even cause personal crises among the trainees, and they need to be overcome with efforts from all parties, i.e. para-ecologists, supervisors and scientists. However, if the group is willing and able to face the challenges, and if the para-ecologists are empowered to grow with their tasks and responsibilities, this close collaboration between land users and scientists in applied, biodiversity or land use-focused research can be very fruitful, productive, and highly rewarding for both sides.

5.4. Disaster risk reduction

Adaptation shares much in common with disaster risk reduction in preventing harmful impacts from extreme events. One of the manifestations of climate change is a projected increase in the frequency and intensity of extreme weather events which, without reductions in vulnerability, will increase the risk of disasters (Vincent et al., 2008).

The Centre for Research on the Epidemiology of Disasters defines a disaster as "a situation or event which overwhelms local capacity, necessitating a request to national or international level for external existence, an unforeseen and often sudden event that causes great damage, destruction and human suffering (www.emdat.be)". Similarly, using the definitions outlined in the previous chapter, a disaster is a negative outcome brought about by high vulnerability (or low adaptive capacity) in the face of exposure to an extreme weather event, such as a drought, flood or cyclone. It is for this reason that an event of similar magnitude in one place may translate into a disaster, but in another may not, depending on the capacity of the population to cope.

Fields of action in the disaster risk reduction framework (UN/ISDR, 2004)

- Risk awareness and assessment, including hazard analysis and vulnerability/ capacity analysis;
- Knowledge development, including education, training, research and information;
- Public commitment and institutional frameworks, including organisational, policy, legislation and community action;
- Application of measures including environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, partnership and networking, and financial instruments;
- Early warning systems, including forecasting, dissemination of warnings, preparedness measures and reaction capacities.

5.5. Policy development — what makes for a good strategy for responding to climate change?

As stated earlier, over the medium to longer term there is great potential to *adapt to climate change through mainstreaming adaptation and risk in core development activities*, relative to financing of adaptation through the climate regime (Agrawala, 2004 and Box 5.3). If the risks of climate change are not considered when planning development projects and programmes, there is a chance that the effects of climate change may negate the positive effects of the initiatives (Vincent et al., 2008). The case study on page 76, for example, outlines some policy responses that Namibia has adopted to adapt to climate change.

Vulnerability reduction and mainstreaming adaptation and risk into development activities are thus important policy goals for responding to the risks of climate change. But implementing these changes often requires fairly radical shifts in thinking and new institutional architecture (O'Brien et al., 2006). Typically with extreme weather events the focus in developing countries in particular, is on the recovery from a disaster rather than vulnerability reduction before the event, and this system is reinforced by the investment policies of donors. The more incremental changes projected under climate change are often not a priority to address relative to emergency response. This system is beginning to change with integrated disaster risk reduction and recognition of the need for climate change adaptation. New institutions and coordination mechanisms will, however, be required to ensure their success. There will also be a critical need for these to be mechanisms for information sharing and knowledge management. Regional networks and partnerships are becoming increasingly important in this regard (see water case study on page 77).

As well as including administrative structures, it is also important to create institutional frameworks that allow for participation of other relevant stakeholders. NGOs, for example, have a long history of providing emergency humanitarian assistance after disasters, and longer-term reconstruction. They are arguably suited, and indeed often have a comparable advantage in this role, due to their location on the ground and understanding of local context and conditions (Vincent et al., 2008).

Box 5.3: Sources of information – climate finance

There are a number of international finance sources open to the countries of southern Africa. Many of these fall under the international policy process, the United Nations Framework Convention on Climate Change, and include the Special Climate Change Fund, Least Developed Countries Fund, and Adaptation Fund, as well as a number of so-called fast start finance mechanisms announced since COP-15 in Copenhagen in December 2009.

Climate Funds Update is an independent website that provides information on the growing number of international climate finance initiatives designed to help developing countries address the challenges of climate change: www.climatefundsupdate.org

Glemarec, Yannick (2011). *Catalysing Climate Finance: A Guidebook on Policy and Financing Options to Support Green, Low-Emission and Climate-Resilient Development.* United Nations Development Programme, New York, NY, USA. Available online at http://www.undp.org/climatestrategies/docs/lecrds/catalysing_climate_finance.pdf

CASE STUDY: Adapting to climate change in Namibia - from scientific data to information for decision-making

By Raúl Iván Alfaro Pelico

In order to reduce the risks of higher temperatures, drier conditions, and more extreme weather events, Namibia is currently embracing a suite of responses aimed at developing the adaptive capacity of the Namibian population. These responses have been designed to take into account the challenges of linguistic/cultural diversity, vast distances, and the legacy of apartheid.

Namibia has been implementing a pilot project promoting the use of climate resilient crops and livestock in its northern Omusati region. Further, a community-based adaptation (CBA) programme is currently in place. At an upstream policy level, the Namibian Government has strengthened national responses to disasters, such as the recent floods, by guiding the development of a new Disaster Risk Management Policy. In addition, Namibia has been assessing the flows of investments and financial flows (I&FFs) that would be required to both adapt and mitigate the impacts of climate change in two selected sectors — respectively, the land use, land use change and forestry (LULUCF) sectors, as well as the energy sectors.

These and other ongoing adaptation responses are helping prepare the country for increased climate risk and variability, for instance illustrated by the recurring flooding seasons of recent years. While initiatives are underway, it is difficult to gauge how integrated and coordinated these measures are at a national level. This provided the entry point in 2009 for the launch of another government-led initiative to build the foundation for a national approach to climate change adaptation (CCA).

The Namibia component of the regional Africa Adaptation Programme is helping to ensure that the country has the institutional, individual and systematic capacity to address climate change risks and opportunities.

So far efforts have focused on building capacity in Namibia to generate data, and to assess specific risk and vulnerability interventions, including improved early-warning systems. In order to ensure that scientifically-grounded data is of use to climate change practitioners and leaders, efforts are underway by Namibia's Ministry of Environment and Tourism, with technical guidance from the Namibian Climate Change Committee (NCCC), and support by the United Nations Development Programme (UNDP), to ensure this data is turned into information for decision-making.

To this effect, the Africa Adaptation Project-Namibia (http://www.undp-aap.org/countries/namibia) is looking at long-term planning mechanisms to measure climate-inherent uncertainty; leadership and institutional frameworks to deal with climate risks; climate-resilient policy implementation in priority sectors; expansion of financing options to meet adaptation costs; and knowledge management, generation and sharing.

CASE STUDY: Transboundary water security - water scarcity in the Limpopo and Incomáti River basins

By Jenny Clover and Peter J. Ashton

Concerns around water availability are growing in the semi-arid portions of southern Africa and water resources are already over allocated in many parts of this region. Mozambique and South Africa are two such countries facing the high probability of limitations to their future economic growth potential as the result of localised water deficits.

Agreements and treaties are in place as the basis for good transboundary water governance in the river basins shared by South Africa and Mozambique, and levels of inter-state cooperation and collaboration have improved. Nevertheless, there are limits to traditional models of transboundary basin management and the mere presence of agreements and treaties cannot guarantee that their intended outcomes will be met (Kistin, 2007). The traditional approach takes a territorialised view of nature, focusing on water as stock and has a preference for a negotiated regime as the foundation for an institutional arrangement to manage shared waters. Although it is usual for agreements to take into consideration seasonal variability, they are in principle mostly too rigid to take into account significant variability in rainfall that leads to droughts and floods, and often overlook the consequences of climate change (McCaffrey, 2003; Fischhendler, 2004). Such is the case for these two countries which are facing growing concerns around climate change and unforeseen events such as floods and droughts in addition to facing increased exploitation of the scarce water resources in the Limpopo and Incomáti basins that will further complicate the national aspirations for sustainable development in Mozambique and South Africa. The combination of hydrological variability and extreme events is the most critical challenge for achieving basic water security (Grey and Sadoff, 2007).

New insights are called for which will emphasise the need to re-examine the current water sharing and co-operation agreements and treaties. Most important is to give priority to the regulatory agreements of shared river basins in a way that does not lock Mozambique into the current status quo. Both parties jointly need to re-examine the structure and details of existing water-sharing agreements, consider the degree to which these agreements have been implemented successfully, and determine whether or not these agreements meet their current and future needs. Benefit sharing principles that view water as a flux, promote a shift in focus from sharing water to sharing the wider suite of benefits derived from its use (Sadoff et al., 2002; Turton, 2008). Such benefits include water transfers, virtual water trade agreements, direct payments for loss of benefits, granting of rights to use water, financing of investments, or the provision of unrelated goods and services (Sadoff et al., 2002). These benefits are then shared in a manner that is agreed as fair. Some of the key elements of the benefit sharing approach are that it requires strong institutions; embraces a wider range of institutional architectures; is more regional in its orientation and involves human security as its focus; seeks to optimise scarce water resources at a level of scale above that of the sovereign nation state; requires an enabling environment that is conducive to the harmonisation of regional laws and policies; and is based on institutionalised knowledge with learning emerging as an inherent property of the basin management organisation (Turton, 2008).

Greater cooperation is needed horizontally between government departments and state-supported institutions (such as water management authorities), as well as vertically between all spheres of government (national, provincial and local) and civil society organisations such as water user groups (MacKay and Ashton, 2004). There is a need for more prudent oversight to address concerns over insufficient capacity to implement and enforce laws and policies. A clear institutional process needs to be in place to review and re-evaluate agreements and, where necessary, resolve disputes. Most agreements do not provide detailed dispute resolution mechanisms and where such mechanisms are included, they are often non-binding on the parties. Initiatives to achieve water security in transboundary river basins require a long and repetitive process of continuing to seek consensual management approaches to resolving water supply and demand problems.

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The Climate Risk and Vulnerability Handbook for Southern Africa was conceived and designed with the intent to provide decision-makers with up to date information, appropriate for country planning, on impact and risk of climate change and variability. It presents a selection of information, translated to communicate climate change processes, key existing and emerging trends, impacts and the possible measures that could be taken to reduce these impacts.

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