



Regional Climate Messages for Southern Africa



CARIAA
*Collaborative Adaptation Research
Initiative in Africa and Asia*



ASSAR
Adaptation at Scale in Semi-Arid Regions

About ASSAR Working Papers

This series is based on work funded by Canada's International Development Research Centre (IDRC) and the UK's Department for International Development (DFID) through the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA). CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The program supports collaborative research to inform adaptation policy and practice.

Titles in this series are intended to share initial findings and lessons from research and background studies commissioned by the program. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the CARIAA program, they have not undergone an external review process. Opinions stated are those of the author(s) and do not necessarily reflect the policies or opinions of IDRC, DFID, or partners. Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

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SUMMARY MESSAGES

The climate across southern Africa varies from arid to humid subtropical conditions.

It is mainly influenced by large scale seasonal atmospheric patterns as well as the cool South Atlantic Ocean and warm Indian Ocean. Most of the region receives the majority of its rainfall in the summer months with the exception of southwest South Africa.

Temperature and rainfall vary on annual, decadal and multi-decadal timescales.

Over the past fifty years there has been substantial multi-decadal variability in rainfall, with large parts of the region experiencing wetter than average conditions in the 1970s and drier than average conditions in the 1990s.

Temperatures across the region have increased by 1 to 1.5°C on average over the past 50 years.

The increases were greatest (up to 2°C) in the interior regions of southern Africa and there is evidence suggesting the increases were higher during the dry season.

Future projections of temperature change show significant increases across the region.

Temperatures in the Kalahari region and central Namibia are projected to have the largest increases with lower increases projected along the coastline. Though model projections are subject to uncertainties, the projected increases in average annual temperatures range from 1 to 4°C by 2050. Relatively high/low increases are more likely under a higher/lower greenhouse gas emissions scenario.

Rainfall trends over the past 50 years are less evident than for temperature, and there are large variations in the direction and magnitude of changes across the region.

There is evidence of an increase in summer rainfall across much of Lesotho, Namibia and South Africa, particularly in the region south of Lesotho. A decrease in summer rainfall is observed in other regions, particularly in the border region of Botswana, Namibia, Zimbabwe and Zambia, corresponding to part of the upper Zambezi river catchment.

Future projections of rainfall change show both potential increases and decreases.

In South Africa, many model projections show a tendency for wetting in the summer rainfall region (north and east) and drying in the winter rainfall region (southwest). The magnitudes of such changes are highly uncertain.

The impacts of future climate change on different sectors are complicated by the spread of model projections and the complexity of natural and societal systems.

The impacts of climate change on water availability are unclear but the increased evaporation that is likely to occur with increased temperatures may place additional stress on vulnerable systems. Many studies suggest that crops will be adversely affected by climate change but the precise impacts vary across regions and cropping systems, and some regions may be positively influenced by climate change.

CHAPTER 1

Historical Climate

Historical Climate

This report provides a general overview of the regional climate in southern Africa. A follow-up report that provides a specific focus on the climate of the semi-arid regions of southern Africa is currently under development.

1.1 General overview

The climate across southern Africa varies from arid conditions in the west to humid subtropical conditions in the north and east, while much of the central part of southern Africa is classified as semi-arid. The primary factors affecting the climates experienced in southern Africa include altitude, the warm Indian and cool South Atlantic Oceans, the migration of the Inter-Tropical Convergence Zone (ITCZ) and the location of dominant atmospheric high and low pressure systems. Not forgetting the important role of the mid-latitudes and transient mid-latitude waves, not just for frontal rainfall in the south but for TTTs which can extend quite far north.

Most of the region, with the exception of southwest South Africa, receives the majority of its rainfall in the summer months, between November and March. However, there is a large difference in the amount of rainfall experienced in the eastern and western parts of southern Africa, primarily due to the influence of the ocean on the atmosphere and the direction of prevailing winds. The warm Agulhas Current in the Indian Ocean provides a source of additional moisture, which leads to higher rainfall in eastern parts of the region, while the cool waters of the Benguela Current in the South Atlantic Ocean corresponds to much lower rainfall in the west.

The highest temperatures are experienced in the Kalahari Desert which spans southwest Botswana, southeast Namibia and northwest South Africa. Here the diurnal cycle can be large ($>20^{\circ}\text{C}$), with extremely high daytime maximum temperatures ($>40^{\circ}\text{C}$) and much lower temperatures at night. In addition, some of the highest average temperatures are experienced in coastal regions, such as Mozambique where the warm Indian Ocean maintains warm temperatures at night. The lowest temperatures are found in the high altitude regions of Lesotho, South Africa and Zimbabwe.

1.2 Seasonal and annual variability

Throughout the year, the timing and magnitude of the summer rains is largely dictated by the seasonal migration of the ITCZ. This large-scale atmospheric feature represents an area of intense convective activity associated with low pressure. The ITCZ is found near the equator during late March and late September (the equinoxes) but moves south during the southern hemisphere summer bringing rains to much of the region. However, each year the amount of summer rainfall experienced varies as the ITCZ interacts with other dominant global and regional atmospheric patterns.

The best studied and arguably most important of these patterns is the El Niño Southern Oscillation (ENSO) – a cyclical variation in the surface temperature of the tropical eastern Pacific Ocean. When the ocean surface in this region is warmer than average an El Niño

event occurs and when the ocean surface is cooler than average a La Niña event occurs. The timing between ENSO events varies but typically an El Niño or La Niña occurs once every few years. El Niño is associated with drier and warmer than normal conditions in Southern Africa from December to February while La Niña is associated with wetter and cooler conditions. However, these associations vary at finer scales and they are not always apparent. The mechanisms that link ENSO and the southern African climate are still not fully understood.

Year-to-year variability in the weather is a result of variability in these large scale processes and variability in regional and local scale processes, such as the location of storm tracks (particularly relevant for rainfall associated with tropical cyclones in the east of the region) and feedbacks between the atmosphere and land surface.

Figure 1.1

Summer (December to February) and winter (June to August) mean, maximum and minimum temperatures at each grid cell over the period 1963 to 2012; adjacent grid cells may display warmest/coolest temperatures from different years. Data taken from the CRU TS3.22 dataset - see technical reference document.

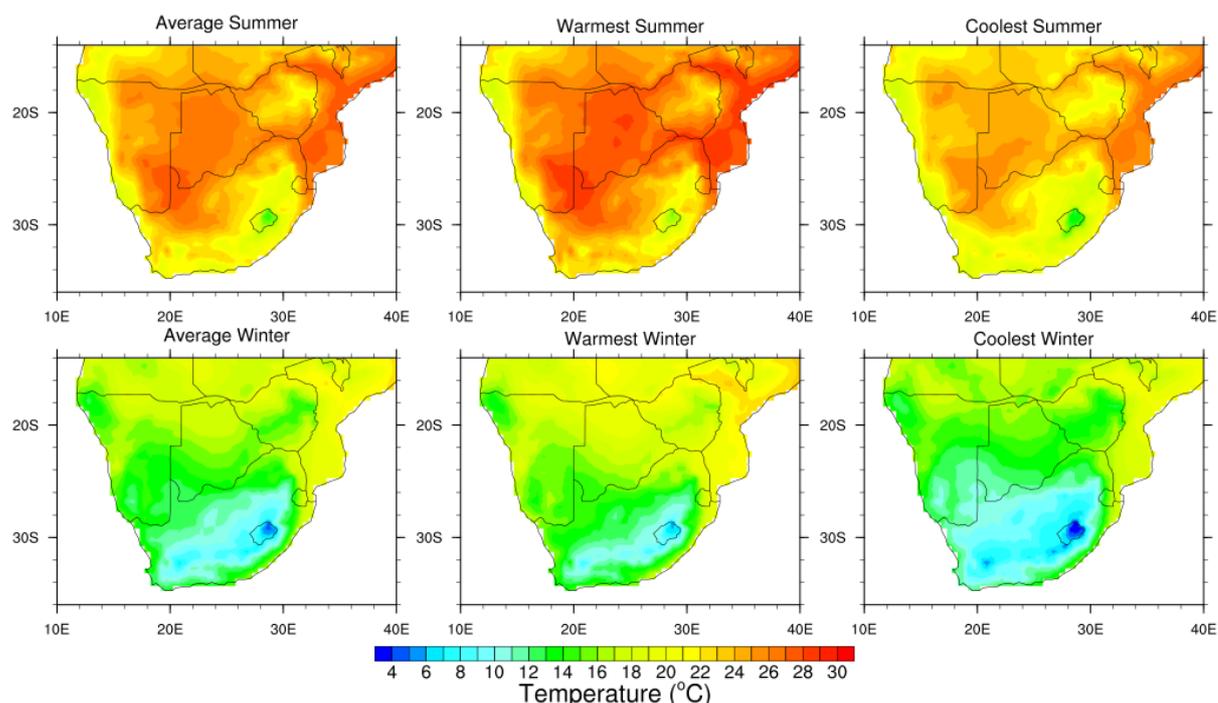


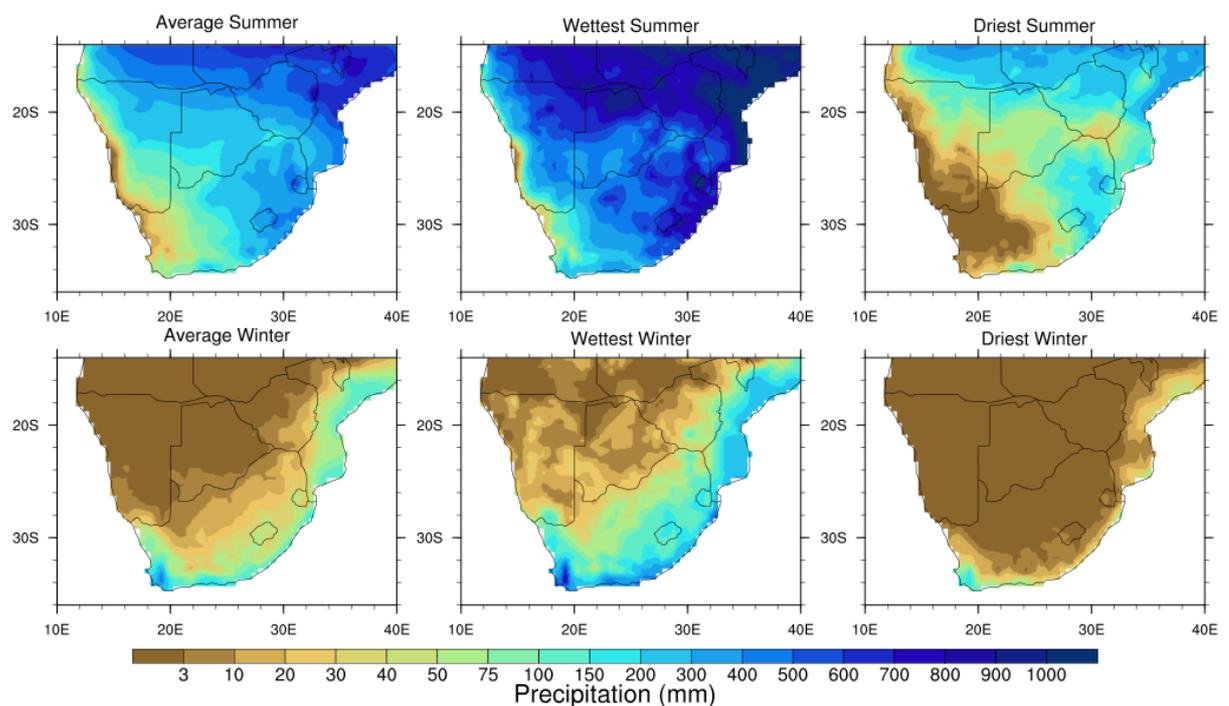
Figure 1.1 shows the average summer and winter temperatures across the region (left column), as well as the warmest (middle column) and coolest (right column) years over the 50 year period from 1963 to 2012 for a particular location; the year of the warmest summer in one grid cell may differ for an adjacent grid cell. The figure shows that the oceans moderate temperatures along much of the coastline, except in Mozambique where the warm waters of the Mozambique Channel maintain high temperatures throughout the year. High summer temperatures are experienced in Mozambique as well as in the Kalahari and throughout Botswana. The coolest winter temperatures occur in the interior regions of South Africa, and especially in the high altitude regions of Lesotho. The greatest differences

between the average summer and winter temperatures in the warmest and coolest years are also found in the interior of the region.

Rainfall is more variable than temperature, both in space and time. Figure 1.2 shows the average summer and winter rainfall as well as the wettest and driest years at each grid cell. In summer there is a clear east-to-west gradient, with very dry conditions experienced on the Namibian coast and western parts of South Africa while there is much higher rainfall in the north and east. The difference between the wettest and driest summers is substantial in many locations. In the arid and semi-arid regions of central and southeastern Botswana the summer rainfall varies from less than 100 mm to more than 300 mm between the driest and wettest year. In winter, a northwest-to-southeast gradient is observed with Namibia and Botswana typically receiving little to no rainfall. The coast of South Africa and Mozambique receives some winter rainfall, particularly in the winter rainfall region of southwest South Africa. There is also a very large difference between the wettest and driest winters. Some regions experience no rainfall in the driest year and received hundreds of millimeters of rainfall in the wettest year.

Figure 1.2

Summer (December to February) and winter (June to August) mean, maximum and minimum total rainfall at each grid cell over the period 1963 to 2012; adjacent grid cells may display wettest/driest conditions from different years. Data taken from the CRU TS3.22 dataset – see technical reference document.



1.3 Decadal and longer term variability

The climate of southern Africa also varies on much longer time scales. Tyson et al (2002) state, “multi-decadal variability has long been known to be a feature of the southern African climate system”. The study uses tree ring proxy climate data to demonstrate the existence of cyclical patterns of variability on time scales of approximately 18 and 80 years. Decadal and longer term variability in the climate system results from natural processes both internal and external to the climate system. On decadal, multi-decadal and centennial time scales, major modes of variability are found in the Pacific, Atlantic, Indian and Southern Oceans, and they can have substantial influences on global and regional atmospheric circulation patterns. These large scale modes of natural variability mean that one decade can be warmer or cooler, and drier or wetter than the previous decade without any changes in the external influences on the climate system. However, factors such as solar cycles, volcanic eruptions, biosphere processes, and more recently human emissions of greenhouse gases (GHGs) and aerosols (particulates in the atmosphere), exert external forcings on the climate system that can also cause variability and change on long time scales.

Figure 1.3 shows the difference between the mean decadal (ten year) temperature and the mean temperature over the 1963 to 2012 period at each grid cell. We can clearly detect a warming signal as all locations in southern Africa were warmer, on average, in the 2000s than in the 1970s. However, it is also apparent that in some locations more recent decades are cooler than preceding decades; for example, the northeast of Namibia was warmer in the 1990s than the 2000s, and the southern coast of South Africa was warmer in the 1980s than in the 1990s.

Figure 1.3

Difference between decadal mean temperatures and 1963 to 2012 mean temperatures at each grid cell. Data taken from the CRU TS3.22 dataset – see technical reference document.

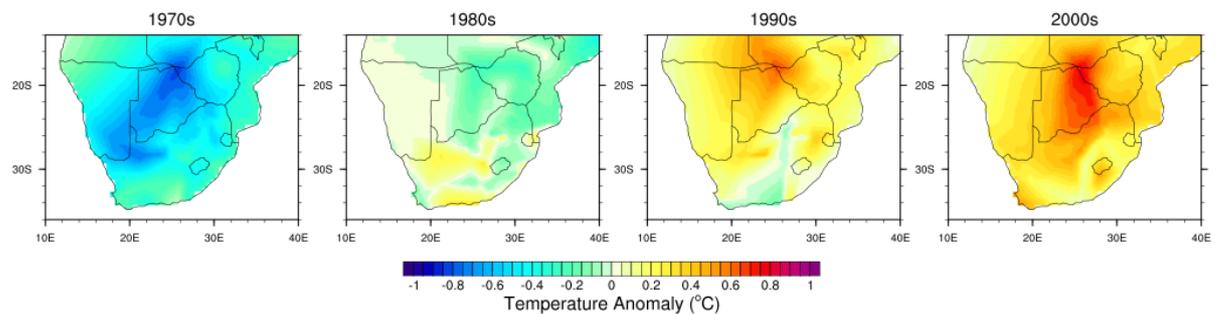
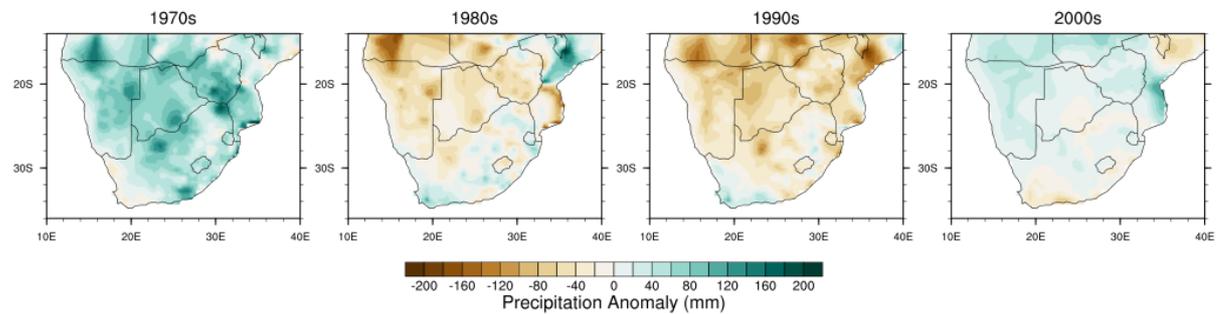


Figure 1.4 shows the difference between the mean annual rainfall total for each decade and the mean annual rainfall total over the 1963 to 2012 period at each grid cell, illustrating considerable variability in rainfall on multi-decadal time scales. The 1970s were, in most locations across southern Africa, much wetter than average, while the 1990s were much drier. The CRU rainfall data is consistent with a number of related recent studies, such as the Mmopelwa (2011) study that identifies a significant difference between the wet 1970s and the dry 1990s in the Okavango and Boteti basins in Botswana.

Figure 1.4

Difference between decadal mean annual rainfall totals and 1963 to 2012 mean annual rainfall totals for each grid cell. Data taken from the CRU TS3.22 dataset – see technical reference document.



On much longer time scales, the climate can vary dramatically due to external influences on the climate system. Over time scales of thousands of years, it is well established that the glacial-interglacial cycle is primarily driven by variations in the orbit, tilt and precession of the Earth and the resultant impact on incoming solar radiation.

1.4 Climate trends

To determine whether or not, and by how much, the climate has changed in the recent past, trends in temperature and rainfall are calculated from the available observed data. Figures 1.5 and 1.6 show the seasonally averaged spatial and temporal changes in temperature over southern Africa during the period 1963 to 2012. Despite annual and decadal variability, across all seasons and locations temperatures have increased over this period; the region west of Lesotho in summer is an exception. Temperature increases were generally higher (approximately 1.6 to 2°C) in the interior regions, particularly in northeastern and central parts of Botswana, and lower (approximately 0.4 to 1.4°C) along the coasts and parts of central and southern South Africa. Whilst there has been an increase in temperatures in all seasons, the lowest increases are found in the summer months, with the exception of southwest South Africa. This implies that, in general, temperature increases have been more pronounced in the dry season. In addition, the IPCC AR5 reports “it is likely that the number of cold days and nights has decreased and the number of warm days and nights has increased in southern Africa (high confidence)”.

Figure 1.5

The change in temperature between 1963 and 2012 at each grid cell, according to a linear trend, for the four seasons: Summer (DJF), Autumn (MAM), Winter (JJA) and Spring (SON). Data taken from the CRU TS3.22 dataset – see technical reference document.

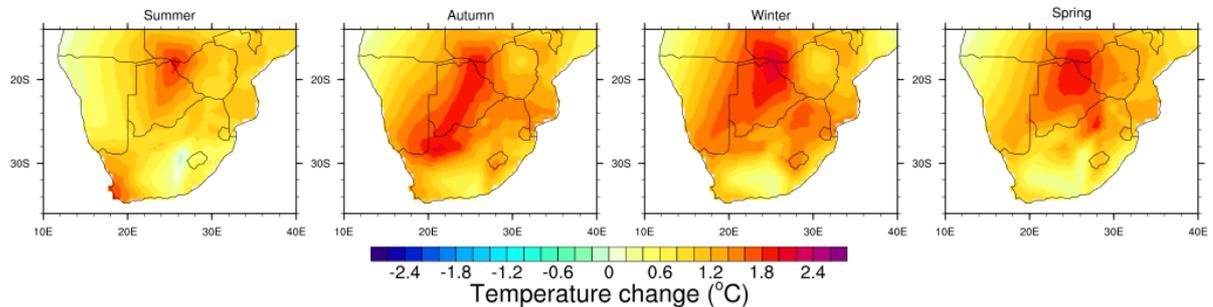
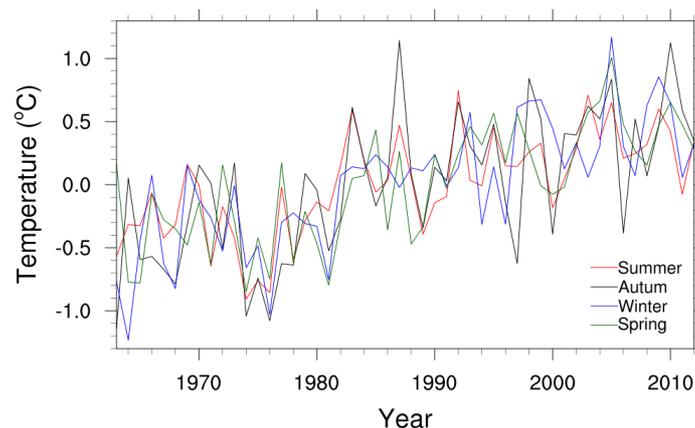


Figure 1.6

Time series of the land area averaged seasonal temperature changes between 1963 and 2012, corresponding to figure 5. Data taken from the CRU TS3.22 dataset – see technical reference document.



Figures 1.7 shows how the total rainfall has changed for each season from 1963 to 2012. In winter and spring the observed trends over much of the region are close to zero across the region, meaning that there has not been any substantial drying or wetting over this period. In the summer and autumn, however, we observe larger magnitude trends. In autumn, there has been a decrease in rainfall (in the order of tens of millimeters) across much of the region, with the exception of southwest South Africa (small increase, < 20 mm) and in northern central regions where rainfall has increased by up to 60 or 70 mm. The changes in summer are more dramatic, which might be expected given that the region receives most of its rainfall in the summer months. The spatial pattern of change is almost the exact opposite of the pattern observed in autumn. Much of South Africa and Namibia has become wetter, especially in the region near Lesotho, while elsewhere we observe decreases in summer rainfall, particularly in the border between Botswana, Namibia, Zimbabwe and Zambia, corresponding to part of the upper Zambezi river catchment. The increase in summer rainfall may be linked to an intensification of rainfall associated with the seasonally migrating ITCZ (see section 1.1). However, the patterns of change are not consistent everywhere and

rainfall in southern Africa, as described in prior sections, is highly variable so any signals of systematic change are weak.

Observations of rainfall are subject to substantial uncertainty – see technical reference document. Therefore the evidence presented here must be treated cautiously and the conclusions must be interrogated in the context of additional regional and local scale information and observed datasets. In particular, linear trends in rainfall are not entirely reliable as an indicator of change, especially in semi-arid regions where year to year variability is very high. Figure 1.8 shows the variation in annual rainfall at two locations in southern and northern Botswana. The year to year variability is very high, with some years receiving three times more rainfall than others. The northern station (Fig 8a) is in a semi-arid location while the southern station (Fig 8b) is in an arid location, and the evidence supports a general observation that drier average conditions are associated with higher year-to-year rainfall variability.

Figure 1.7

The change in rainfall between 1963 and 2012 at each grid cell, according to a linear trend, for the four seasons: Summer (DJF), Autumn (MAM), Winter (JJA) and Spring (SON). Data taken from the CRU TS3.22 dataset – see technical reference document.

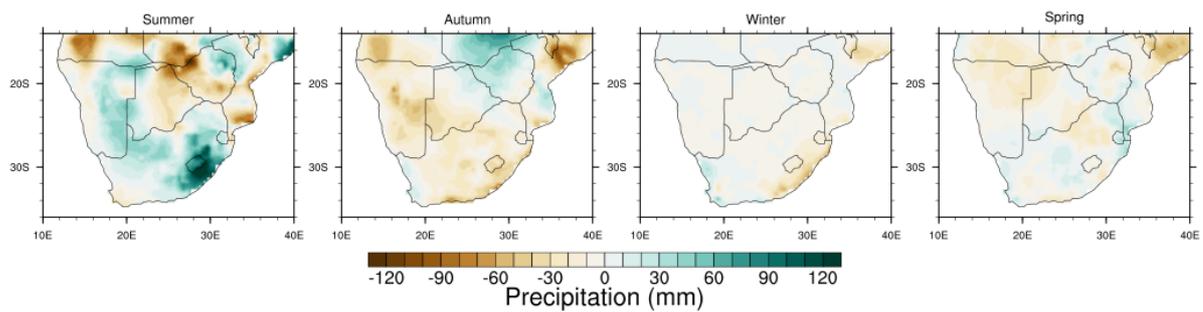
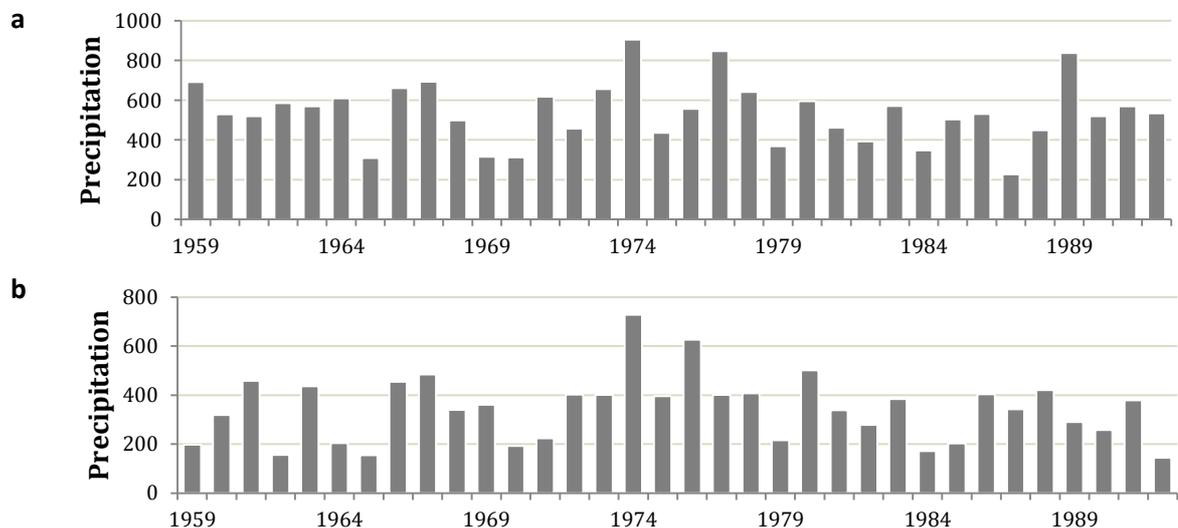


Figure 1.8

Station observed annual rainfall (mm) at: a) Shakawe, northern Botswana, and b) Tshane, southern Botswana. Data extracted from the CSAG Climate Information Platform; 1959 to 1992 represents the longest period of concurrent, uninterrupted observations.



In relating any observed climate trend to underlying changes in the climate, we must first account for the different time scales of climatic variability. In southern Africa, and particularly across the central regions of Botswana, Namibia and northern South Africa, the climate is subject to decadal and longer term climate variability (see section 1.3). Moreover, even if we detect a significant trend, that we are confident is not merely a result of long time scale variability, we must first rule out other external drivers before we can attribute such changes to increasing GHG concentrations – see technical reference document for more explanation. But lack of attribution does not mean lack of experience of change over societally/ecosystem relevant time periods – see technical reference document for more explanation.

1.5 Trends in extreme rainfall and temperature

To better understand the impacts of historical climate variability and future climate change on communities and ecosystems, it is often more relevant to focus on the less frequent but more severe weather and climate events that influence exposure and vulnerability.

A report by Climate Development Knowledge Network (CDKN 2012) summarizes the findings of the Intergovernmental Panel on Climate Change (IPCC) special report on managing extreme events (SREX, IPCC 2012). Changes to temperature and precipitation extremes in southern Africa observed since the 1950s, with the period 1961-1990 used as a baseline, are reported (see Box 3.1 in Chapter 3 of SREX for more information):

- Increase in warm days (decrease in cold days) – *medium confidence*
- Increase in warm nights (decrease in cold nights) – *medium confidence*
- Increase in warm spell duration – *medium confidence*
- No spatially coherent patterns of trends in precipitation extremes – *low confidence*
- General increase in dryness – *medium confidence*

Because of sparse observations in some parts of southern Africa, and given statistical issues associated with deriving trends in extremes for short sampling periods, none of the findings are stated with high confidence. However, there is medium confidence in the observed trends associated with temperature extremes. The low confidence associated with any trends in extreme precipitation is consistent with the findings for mean annual rainfall where the variability over the last 50 years confounds any trends.

An earlier study by New et al (2006) analyzed daily temperature (maximum and minimum) and precipitation data from 14 south and west African countries over the period 1961–2000. The findings of the study are largely consistent with the SREX results but the study also showed evidence of increase in dry spell durations and rainfall intensity. However, the observed trends in temperature extremes were more apparent than for precipitation. Furthermore, the authors provided evidence that the frequency of hot extreme events had been increasing at a faster rate than the decrease in cold extreme events, resulting in the conclusion:

“Hot extremes generally have trends of greater magnitude than their cold counterparts, suggesting that the warm tails of the daily temperature distributions are changing faster than the cold tails.” (New et al 2006)

CHAPTER 2

Future Climate Projections

Future Climate Projections

2.1 Key results in the IPCC AR5

Climate change projections span a range of possible future climates. This range results from substantial uncertainty in key climate processes as well as different future GHG emissions scenarios. The projections shown in this section are taken from the available output of the latest generation of Global Climate Model (GCM) experiments. It is possible that the “true” uncertainty range is wider than the range of model projections. Further information on the issues associated with climate prediction is provided in the supporting reference document.

The IPCC fifth assessment report (AR5) provides a synthesis of the output from approximately 40 GCMs developed at institutions across the world. The model simulations were conducted as part of the fifth phase of the Coupled Model Intercomparison Project (CMIP5)¹ to generate a set of climate projections for the coming century. This section presents some of the model results relevant for southern Africa.

Globally, average annual temperatures are projected to rise by 0.3 to 2.5°C by 2050, relative to the 1985 to 2005 average, but projected changes are higher for land areas. Figure 2.1 shows that in southern Africa temperature projections range from no change to 3.5°C (winter) and 4°C (summer) warmer conditions by 2050. Lower temperature increases are more likely under a low emissions scenario and higher temperature increases are more likely under a high emissions scenario.

¹ <http://cmip-pcmdi.llnl.gov/cmip5/>

Figure 2.1

Time series of temperature change relative to 1986–2005 averaged over land grid points in Southern Africa in December to February (left) and June to August (right). Thin lines denote one model simulation and thick lines are the multi-model mean. On the right the 5th, 25th, 50th, 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 for the four RCP scenarios. Source: IPCC (2013).

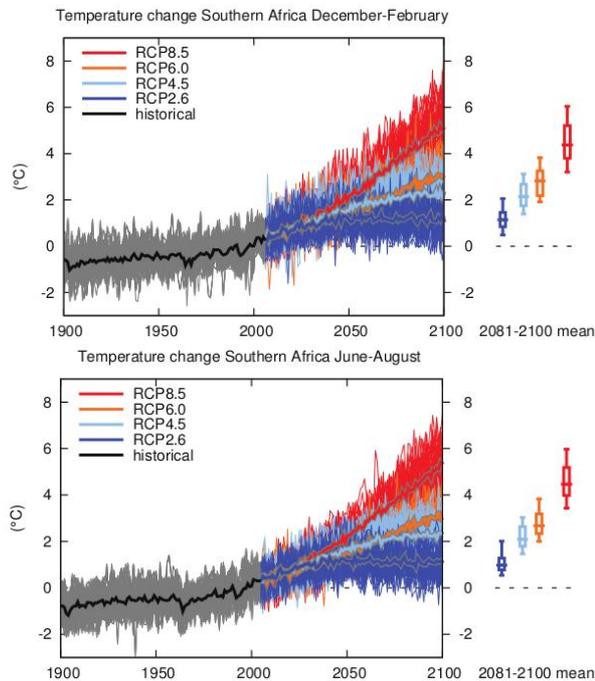
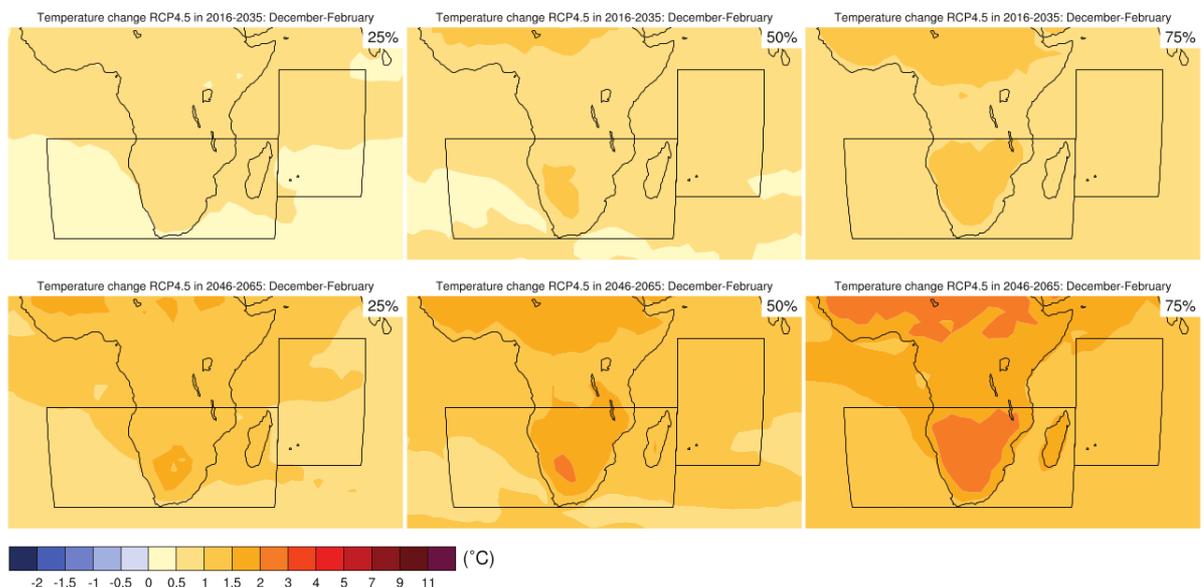


Figure 2.2

Maps of temperature change in Southern Africa in December to February for 2016–2035 and 2046–2065 with respect to 1986–2005 according to the RCP4.5 scenario. The left column show the 25th percentile (i.e. a quarter of models are below these values), the middle column shows the median and the right columns shows the 75th percentile (i.e. a quarter of models are above these values). Source: IPCC (2013).

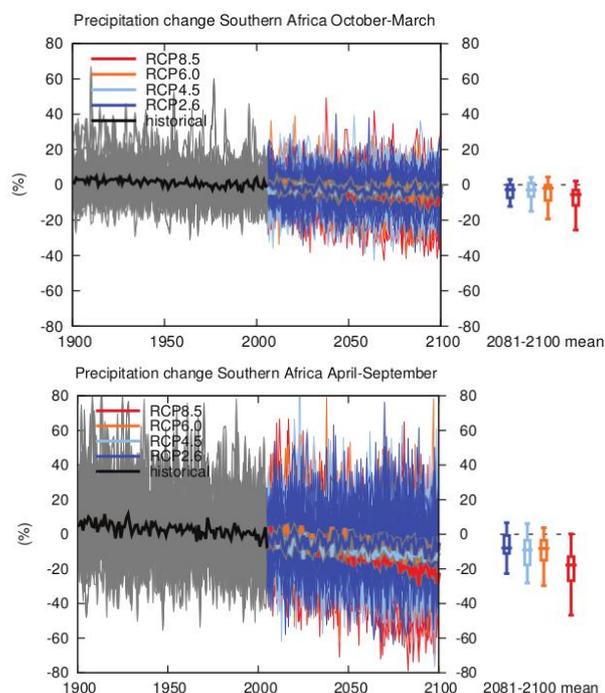


Projected changes in temperature vary spatially. Figure 2.2 shows that, for the RCP4.5 emissions scenario, central regions are projected to warm more than coastal regions, continuing the observed trends shown in section 1.4. The figure shows that in December to February half of all model simulations project a warming across southern Africa of between 1°C and 3°C by mid-century, with a quarter of models projecting an increase of less than 1°C and a quarter of models projecting an increase greater than 3°C; similar magnitudes and spatial patterns of change are projected for other seasons. Beyond increases in average temperatures, the IPCC report states “it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase”.

Future projections of rainfall change are subject to substantial uncertainties and model simulations disagree on the likely direction and magnitude of change. In southern Africa, variability on interannual, decadal and multi-decadal time scales, as experienced in the past, is expected to continue to be the dominant influence on future rainfall. However, towards the end of the 21st century the majority of model simulations do suggest a shift to slightly drier conditions on average over southern Africa, especially for the high RCP8.5 emissions scenario, with a minority projecting wetter average conditions. Figure 2.4 shows that the drying is likely to be greater in April to September, coinciding with the time of year when rainfall is already more variable, with some models predicting an average decrease across the region of up to 40% under the RCP8.5 emissions scenario. However, for the next few decades up to 2050 the drying signal across the model ensemble remains weak.

Figure 2.4

Time series of precipitation change relative to 1986–2005 averaged over land grid points in southern Africa in October to March (left) and April to September (right). Source: IPCC (2013).



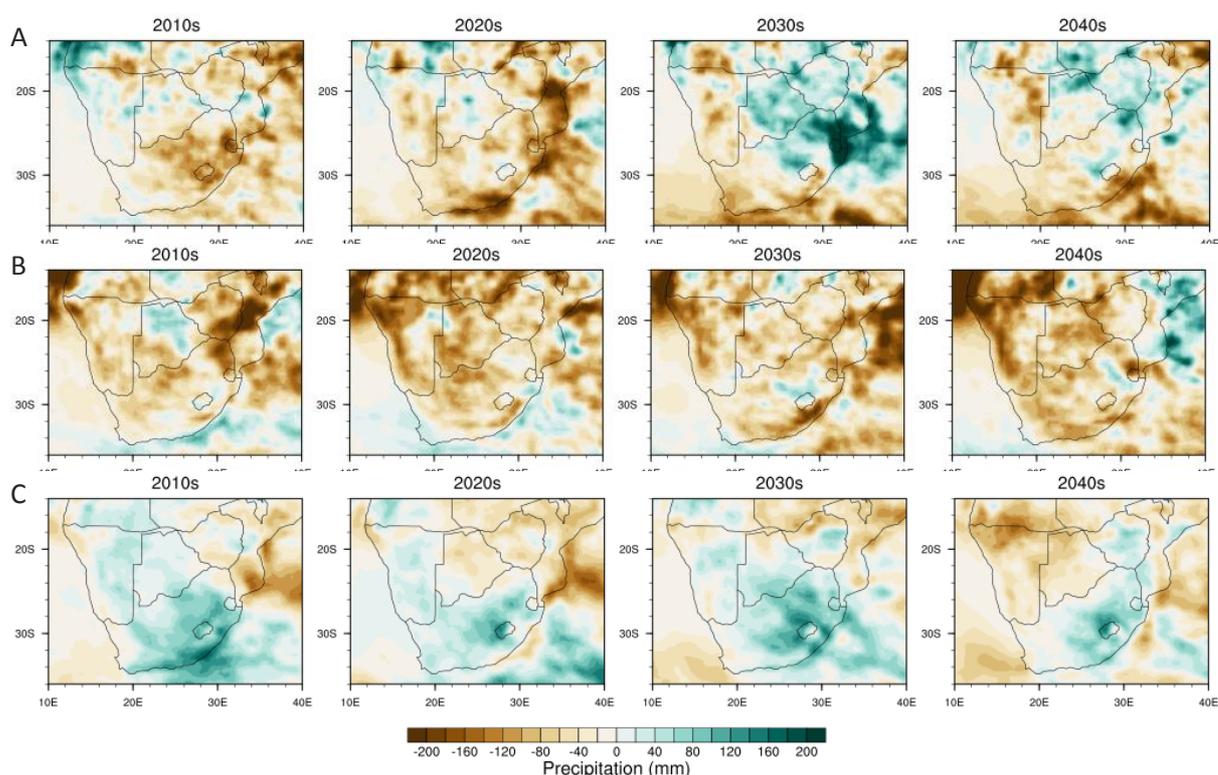
2.2 CORDEX Projections

The Coordinated Regional Downscaling Experiment (CORDEX) uses the latest generation of regional climate models (RCMs) to provide 50 km resolution projections of climate change up to the year 2100 for regions across the world. The models are driven by GCMs used in the IPCC AR5 report. Here, some example CORDEX model projections are presented showing possible future regional climate change scenarios for southern Africa. It should be noted that all projections shown are for the same GHG forcing scenario, RCP8.5; this scenario is often categorized as “business as usual” with respect to GHG emissions.

Regional climate projections are subject to significant uncertainties (Hawkins and Sutton 2009). The output of a single model simulation should be treated with caution and even an ensemble of regional model projections cannot be expected to provide reliable quantitative “predictions” (Daron et al 2014). Rather, the projections show possible scenarios of future change. Further explanation of the issues in projecting the future climate at regional scales is provided in the supporting technical reference document.

Figure 2.5

Difference between decadal mean annual rainfall totals and the 1950 to 2000 mean annual rainfall totals, at each grid cell, for three CORDEX models under the RCP8.5 scenario: A = HadGem2-CCLM4; B = ICHEC-CCLM4; and C = ICHEC-KNMI.



The model projections shown in figure 2.5 are taken from combinations of two GCMs (HadGem2 and ICHEC) and two RCMs (KNMI and CCLM4), all driven by the RCP8.5 scenario. A more rigorous exploration of future climate scenarios would involve analyzing many more GCM-RCM combinations that are being made available in the CORDEX project. However, for demonstrative purposes it is useful to look at some of the available data to examine the

nature of future climate output. Figure 2.5 shows model projections of future rainfall change for four decades. The average annual rainfall change for a particular decade is calculated by subtracting the decadal average from the average annual rainfall over the period 1950 to 2000 in the model.

In general, all projections show that for most of the domain substantial multi-decadal variability in rainfall patterns will continue with most locations experiencing dry decades and wet decades in the future. However, there are some large differences between the model projections. Model A shows a broad pattern of drying in the 2010s and 2020s with wetter conditions for some regions (e.g. east South Africa) in later decades. Model B also shows a general pattern of drying with a particularly strong drying signal in northwest Namibia and southern Angola. The changes projected by model C are much lower in magnitude but there is a general pattern of wetting across South Africa and a variable signal further north. Both model B and model C are driven by the same GCM so the large differences in magnitude clearly demonstrate that selecting a different RCM can result in qualitatively different estimates of future climate change.

Whilst there is no consensus on the direction of change in rainfall for the future, even amongst a small selection of three model simulations, there is much better agreement that temperatures are likely to increase. Figure 2.6 shows decadal changes in temperature for the same set of GCM-RCM combinations under the RCP8.5 scenario. In all model simulations, temperatures across the region are projected to rise. Model A projects the greatest magnitude increase by the 2040s with some regions (e.g. central Namibia) expected to have an increase in average annual temperatures of up to 4°C. The changes are less dramatic in model B and C; all regions are expected to warm by less than 3°C by the 2040s in model C. In general, there is less warming in coastal regions, which corroborates with the CMIP5 GCM projections and the observed warming experienced in the last 50 years (see section 1.4).

Figure 2.6

Difference between decadal mean temperatures and the 1950 to 2000 mean temperatures, at each grid cell, for three CORDEX models under the RCP8.5 scenario: A = HadGem2-CCLM4; B = ICHEC-CCLM4; and C = ICHEC-KNMI.

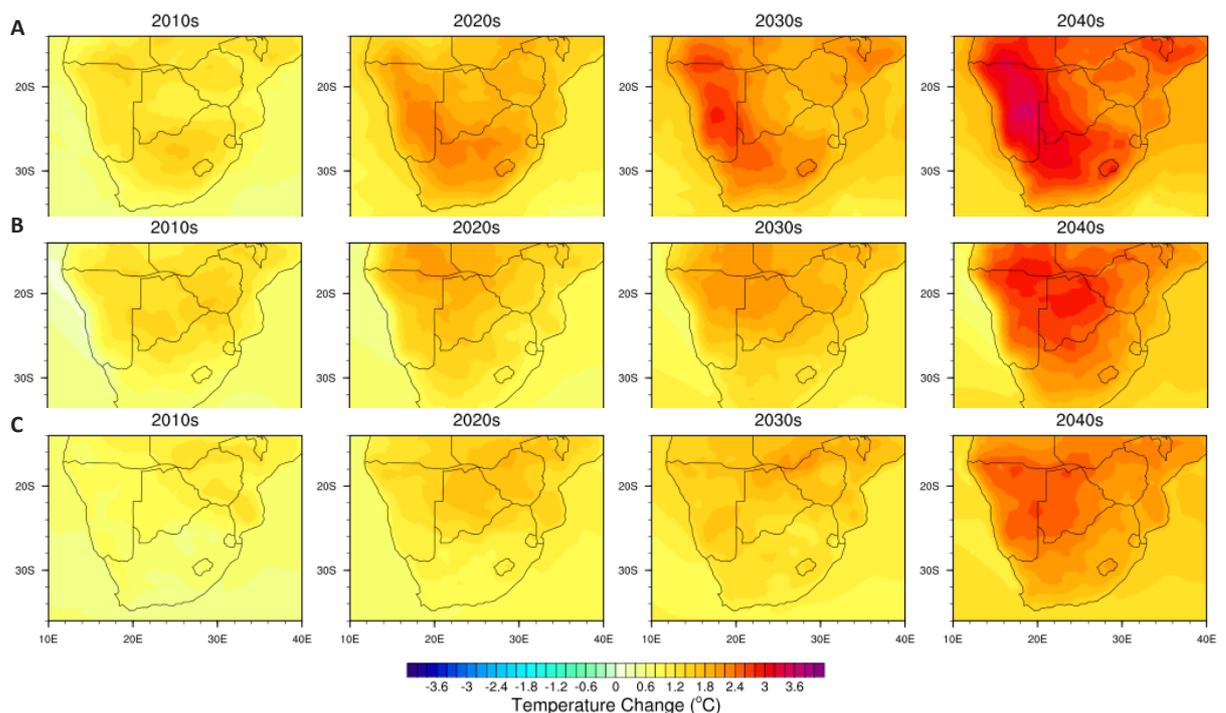
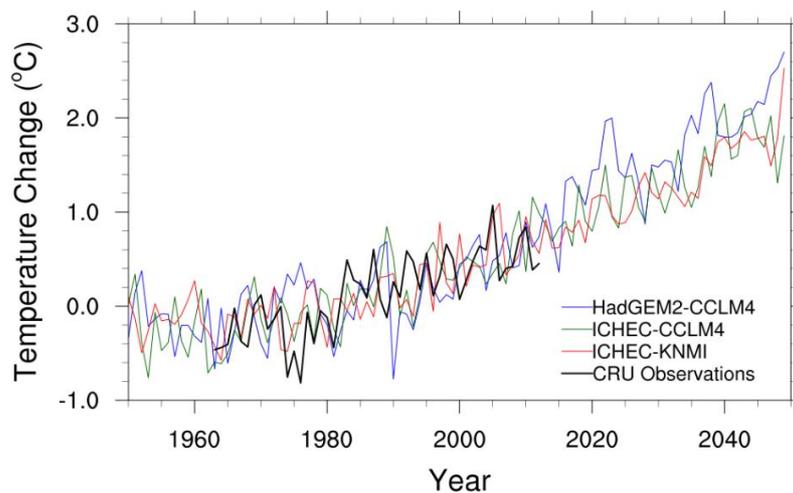


Figure 2.7

Time series of the change in southern Africa annual average temperatures from the three CORDEX models analysed (see key). The model changes are relative to the average of the models in the respective domains from 1963 to 2000, while the CRU TS3.22 observational data (from 1963 to 2012) are relative to the observed 1963 to 2000 average.



Unlike rainfall, changes to temperature on the decadal time scale appear to be dominated by a systematic warming signal as opposed to multi-decadal variability. This can also be seen clearly when aggregating temperature changes over the region and analysing the time series' of model projections. Figure 2.7 shows the change in annual average temperature for the three model simulations, as well as the observed changes from the CRU dataset. All model simulations appear to capture the emergence of a warming trend over the past 50 years and this trend is projected to continue into the future. By 2050, there is some uncertainty in the projected temperature change – even from a very small sample of simulations all driven with the same GHG forcing scenario – with the three simulations projecting a 1.9°C to 2.6°C warming by 2050. The divergence of models would likely be much larger if additional simulations and forcing scenarios were included.

CHAPTER 3

Literature Review: Key Findings

Literature Review: Key Findings

3.1 Historical climate and impacts

The past climate in southern Africa has been studied by a number of scientists using a variety of different methods. While there are relatively few studies specifically looking at changes to the observed climate in the southern African region, a number of studies (mostly analysing trends in South Africa) show that warming has been observed in the region but that, in general, rainfall trends are less apparent.

Using rainfall data for eight stations across Botswana, Batisani and Yarnal (2010) show a trend towards decreased rainfall throughout Botswana over the period 1975 to 2005, especially during the latter part of the rainy season (January to March). The decrease was found to be associated with a decrease in the number of rainy days, though only two stations show statistically significant drying trends (Gantsi and Tsabong). In South Africa, Archer et al (2009) find no detectable trends in annual mean rainfall since 1900, but they do find an increase in the annual mean temperature of 1°C. In addition to increasing average temperatures, a study by the UK Met Office (2011) finds that between 1960 and 2003 warm days and nights became more frequent while cool days and nights became less frequent. An increase in temperature is also reported in the DEA (2013) study based on findings in the recent literature combined with some additional analysis of recent data; however, they report that an increase of 1°C has been observed in South Africa in the last 50 years alone. The DEA (2013) study also agrees that rainfall trends are weak or not detectable, but the report emphasises the decadal variability stating that rainfall was above average in the 1970s, the late 1980s, and mid to late 1990s, and below average in the 1960s and in the early 2000s, reverting to mean towards 2010. Their findings are not entirely consistent with the historical analysis presented in section showing CRU data (section 1.3), where the data shows drier than normal conditions for many regions of South Africa in the 1990s and near-normal or wetter conditions in the 2000s. This illustrates the necessity to consult other sources of observed data – see supporting reference document.

Some studies focus explicitly on understanding the climate system of southern Africa. Cook et al (2004) use gridded rainfall and moisture data to show that seasonal modulations in the intensity of the heat low over Angola and Namibia are important for influencing summer rainfall over South Africa. They find that wetter seasons tend to have longer or more intense wet spells rather than a greater frequency of wet spells.

There are very few studies analyzing change specifically in semi-arid regions but a recent study by Masubelele et al (2014) examined historical observations of climate and linked these to observed changes in land cover in semi-arid regions of South Africa. The authors report that long-term annual rainfall has not changed significantly over the 20th century at the grassland or Nama-Karoo biome sites investigated in the study. They find that for most sites grass cover has increased and dwarf shrub cover has decreased over time and that understanding the key drivers of change is complex.

3.2 Future climate and impacts

Future projections of climate in southern Africa are uncertain and model projections provide contrasting evidence with regards to future impacts in the region. A range of crop models, hydrological models and other impacts models are used to determine the impact of climate change on agriculture, water resources, biodiversity and other key sectors in the region, but most studies require climate model projections that span a wide range of possible futures.

Much of the available literature focuses on the future climate and impacts in South Africa, with relatively few studies analysing trends in Botswana, Namibia and Mozambique. A study by Moise and Hudson (2008) compares scenarios of the late 21st century to model output from the late 20th century for the whole of southern African. They find that a large proportion of southern Africa (virtually all of the region south of 15°S) shows warming greater than 4.0°C, with a regional maximum warming of greater than 5°C in southwest Botswana. They also find a drying pattern in the summer months for the region south of 15°S, particularly over the west (southern Angola, Namibia and Botswana), while wetter conditions are found north of 15°S.

In a recent evaluation of multi-model climate projections to inform South Africa's long-term adaptation strategies (DEA 2013), projections showed very significant warming, as high as 5 to 8°C, over the South African interior by the end of this century, with reduced warming over coastal areas. Projections of rainfall change in South Africa show both potential increases and decreases but with a tendency for wetting in the summer rainfall region (southwest) and drying in the winter rainfall region (north and east). This corresponds to the findings of Hewitson and Crane (2006) who find a similar pattern of change. A study by the UK Met Office in 2011 analysed the response of models to the A1B emissions scenario and found a slightly stronger drying signal across the country, particularly in the far west with decreases of up to 20% (UK Met Office 2011). Lumsden et al (2009) also find that less rainfall is projected along the west coast and the adjacent interior but they also assert that in the east of the region more rainfall is projected in the form of both more rain days and more intense rainfall events. The authors link such changes to a projected decrease in river flows and an increase in flow variability in the west, with increased runoff in the east. The DEA (2013) study noted that many of the projected changes are within the range of historical natural variability, and uncertainty in the projections is high.

It was noted by Ziervogel et al (2014) that because of the spread of precipitation projections, coupled with high natural variability, the potential climate impacts on water in South African cities is unclear. The study, which uses output from the DEA (2013) report, states that changes to runoff range from a 20% decrease to a 60% increase by as early as 2050 under an unmitigated emissions pathway, while the range reduces under a constrained emissions scenario projection; between a 5% decrease and a 20% increase. The UK Met Office (2011) report refers to simulations from the AVOID project and shows that climate change could have a minor impact on water stress beyond 2030 in South Africa, but that there could be a relatively small increase in the percentage of the population exposed to increased water stress towards the end of the century.

Studies by Chipanshi et al (2003) and Archer et al (2009) focus on downscaled projections for the semi-arid sandveld region of central northern South Africa. Both studies show that

minimum, average and maximum temperatures are projected to rise, with Chipanshi et al (2003) showing a rise of average temperatures between 2.2 and 4.3°C by the end of the century. Both studies also show that downscaled projections display a decrease in rainfall in the summer months in the region. Archer et al (2009) state that all model projections show reduced groundwater recharge under climate change, at least in the coming decades, with some evidence of increased recharge by the end of the century in eastern parts. Chipanshi et al (2003) show that through a reduced growing season and changes to temperature and rainfall during the growing season, climate change may cause substantial reductions in crop yields (36% for maize and 31% for sorghum) in the sandveld region. Ziervogel et al (2014) also find that climate change is likely to have largely negative impacts for key cereal crops across South Africa. However, the UK Met Office (2011) study comments that despite projections of adverse impacts of climate change on some crops, several global-scale studies project a generally positive outlook for the impact of climate change on food security in South Africa.

In considering the impacts on biodiversity, Ziervogel et al (2014) note that the wettest and coolest climate scenarios for 2050 will have only minor impacts on biodiversity in South Africa and that the grassland biome is most under threat of significant structural change, independent of which climate scenario is used.

CHAPTER 4

References

References

- Archer et al (2009) Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa. *Journal of Integrative Environmental Sciences* **6**(2), 139–155.
- Batisani and Yarnal (2010) Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. *Applied Geography* **30**, 483–489.
- Chipanshi et al (2003) Vulnerability Assessment of the Maize and Sorghum Crops to Climate Change in Botswana. *Climatic Change* **61**(3), 339–3360.
- CDKN (2012) Managing climate extremes and disasters in Africa: Lessons from the SREX report. Climate and Development Knowledge Network, available online at www.cdkn.org/srex
- Cooke et al (2004) Wet and dry spells within particularly wet and dry summers in the South African summer rainfall region. *Climate Research* **26**, 17–31.
- Daron et al (2014) The role of regional climate projections in managing complex socio-ecological systems. *Regional Environmental Change* doi: 10.1007/s10113-014-0631-y
- DEA (2013) Long term adaptation scenarios: climate trends and scenarios. LTAS Phase 1: DEA – South African Department of Environmental Affairs.
- Hawkins and Sutton (2009) The potential to narrow uncertainty in regional climate projections. *Bulletin of the American Meteorological Society* **90**(8), 1095–1107.
- Hewitson and Crane (2006) Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. *International Journal of Climatology* **26**(10), 1315–1337.
- IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B. et al. (eds), Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.
- IPCC (2013) Climate Change 2013: The Physical Science Basis. Stocker T et al. (eds). In: IPCC Fifth Assessment Report (AR5), Cambridge University Press, Cambridge, UK, and New York, NY, USA,
- Lumsden et al (2009) Evaluation of potential changes in hydrologically relevant statistics of rainfall in Southern Africa under conditions of climate change. *Water SA* **35**(5), 649–656.
- Masubelele et al (2014) A 50 year study shows grass cover has increased in shrublands of semi-arid South Africa. *Journal of Arid Environments* **104**, 43–51.
- Mmopelwa et al (2011) The impact of environmental change on ecosystem services supporting human livelihoods: the case of the Okavango and Boteti basins, Botswana. Technical Report by the Okavango Research Institute, University of Botswana.
- Moise and Hudson (2008) Probabilistic predictions of climate change for Australia and southern Africa using the reliability ensemble average of IPCC CMIP3 model simulations. *Journal of Geophysical Research* **113**, D15113.

New et al (2006) Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research* **111**, D14102.

Tyson et al (2002) Millennial to multi-decadal variability in the climate of southern Africa. *International Journal of Climatology* **22**, 1105–1117.

UK Met Office (2011) Climate: Observations, projections and impacts – South Africa. Report commissioned by the Department for Energy and Climate Change.

Ziervogel et al (2014) Climate change impacts and adaptation in South Africa. *WIREs Climate Change* doi: 10.1002/wcc.295.



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