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CHAPTER 2:
PROJECTED CLIMATE CHANGE FUTURES FOR SOUTHERN AFRICA

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Warmer conditions associated with more frequent very hot days (> 35 °C) are likely over most of the interior of southern Africa in the future. A decrease in rainfall is projected over central southern Africa (e.g. Northern Botswana, Namibia, southern Zambia and Zimbabwe), while an increase in rainfall is projected over northern Mozambique and Tanzania.

2.1. Introduction

Observed changes in climate presented in the previous chapter are projected to increase into the future. Global Climate Models analysed in IPCC AR5 project that mean annual global temperatures will increase by 0.3 to 2.5 °C by 2050, relative to the 1985-2005 climatological average (Stocker et al., 2013b). Over Africa temperatures are expected to rise at a faster rate than the global mean increase.

Since the first edition of the *Climate Risk and Vulnerability Handbook for Southern Africa*, significant progress has been made in projecting and understanding climate change for the region, providing an increasingly robust basis for strategy and policy in various countries as well as in the subregion.

The focus of this chapter is:

To communicate the latest climate change projections for the region and to summarise the areas of agreement between the different sources in order to provide a storyline of climate change that can be used in decision-making.

Key messages are drawn from recent subsets of future climate projections for the southern Africa region. Material in this chapter is drawn from the latest IPCC Assessment Report (Stocker et al., 2013b), the latest dynamically downscaled projections from the CSIR (NRE)[4], using the conformal-cubic atmospheric model (CCAM) (McGregor, 2005), as well as recently released studies comparing multiple GCMs, dynamical and statistically downscaled models (Hewitson et al., 2014). A multi-model ensemble approach[5] is taken in this chapter to describe the range of uncertainty (see Box 2.1) associated with climate change projections.

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[4] A set of six climate simulations has been performed by the Climate Studies, Modelling and Environmental Health Research Group of the Council for Scientific and Industrial Research (CSIR) in South Africa. In these experiments, a variable-resolution atmospheric global circulation model, CCAM, was applied as a regional climate model (RCM) to simulate both present-day and future climate over southern Africa and its surrounding oceans.

[5] An ensemble of models is used to project different (but equally plausible) climate futures.

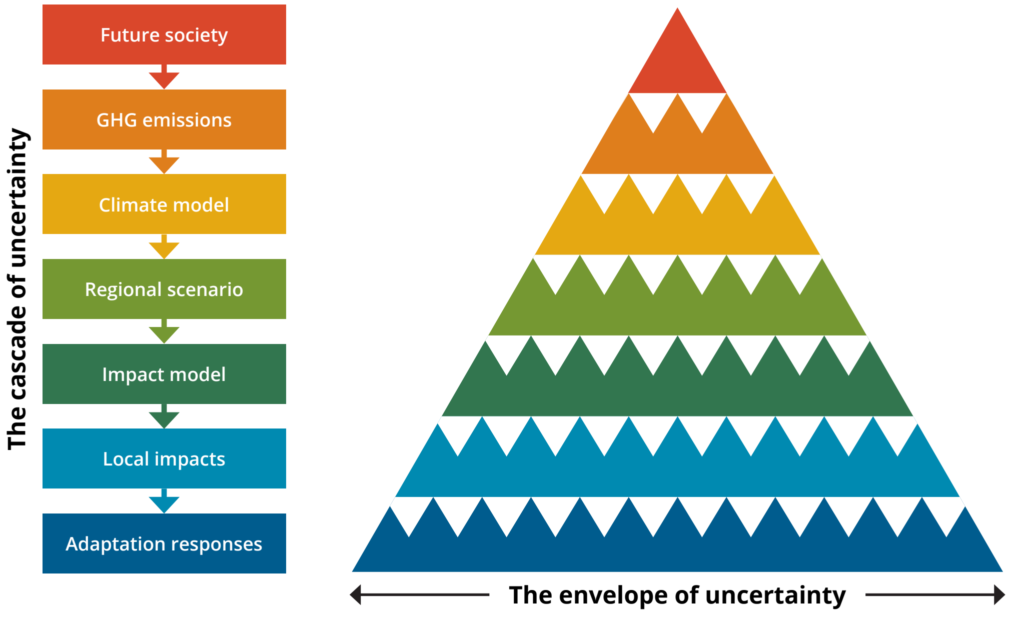
Box 2.1: A note on (un)certainty

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.

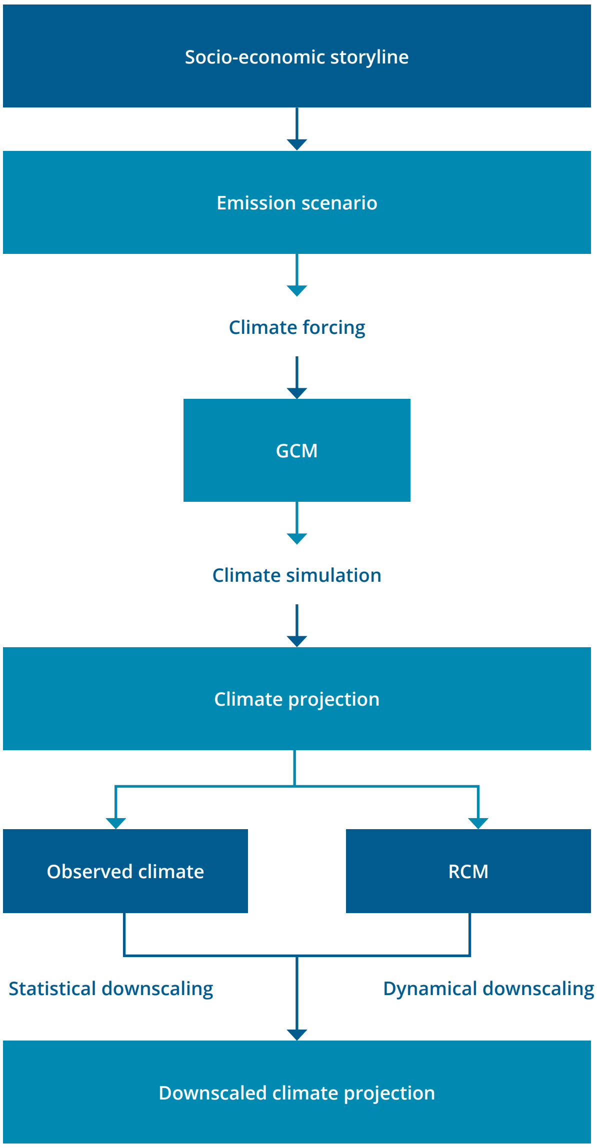
Uncertainty does not mean that there is no confidence in the projections of future climate. Rather, it implies there is a probability or level of confidence associated with a particular outcome. Indeed, all climate projections (and even short-range and seasonal forecasts), are couched in terms of the 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.

The degree of certainty in each finding presented in this chapter is based on the consistency of evidence such as observed climate, mechanistic understanding of how the climate works, models of the climate, expert judgement and the degree of agreement between the different models and approaches to downscaling. Simply stated, there is a greater confidence in the direction (rainfall) and magnitude (temperature) of future change in instances where all sources of information agree.

The cascade of uncertainty in projecting future climate change illustrating the increasing envelope of uncertainty from different socio-economic and demographic scenarios to local impacts and adaptation responses (Source: Wilby & Dessai, 2010).



2.2. Determining future climate



Global climate models (GCMs) comprise the fundamental tools used for assessing the causes of past change and to project long-term future change. These complex computer models represent interactions between the different components of the climate system, such as the land surface, the atmosphere and the oceans. Projections[6] of future climate change by GCMs may provide insight into potential broad-scale changes in the atmosphere and ocean, such as shifts in the major circulation zones and the magnitude of sea-level rise.

Projected changes in climate are dependent on the future levels of greenhouse gas emissions in the atmosphere, which in turn are crucially dependent on society's behaviour and policy choices, whether we continue to depend on fossil fuels or switch to renewable energy sources, for example. GCMs simulate climate under a range of emission scenarios, each representing a possible future.

The IPCC Special Report on Emissions Scenarios (SRES) described four possible 'storylines' (A1, B1, A2 and B2), each assuming different paths of development for the world. Each scenario has an associated future emissions pathway which describes the amount of greenhouse gases emitted through human activity (Nakicenovic et al., 2000). This is largely why the IPCC reports project future global average temperature change to be within a certain range. The lower estimate is based on an emissions scenario where behaviour and policy translate into lower emissions of greenhouse gases. The higher estimate comprises a 'worst case' scenario, where emissions continue to increase at a rapid rate. It is very important to clearly understand that there are a range of future possibilities, as it follows that we can only suggest futures that may be more likely than others (Tadross et al., 2011:28).

In the IPCC AR5 (Stocker et al., 2013b), Representative Concentration Pathways (RCPs) replaced the SRES emission scenarios and were used as the basis of the climate projections presented in AR5. The RCPs are named according to their 2100 radiative forcing level[7].

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[6] The term 'projection' refers to estimates of future climate possibilities decades into the future.

[7] Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere.

There are four pathways – RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP 2.6 describes a scenario of very low greenhouse gas concentration levels, RCP 4.5 and 6.0 describe a future with relatively ambitious emission reductions, whereas RCP 8.5 describes a future with no reductions in emissions. Emissions in RCP 2.6 peak between 2010 and 2020; RCP 4.5 emissions peak around 2040, then decline; in RCP 8.5 emissions continue to rise throughout the 21st century (Meinshausen et al., 2011; Stocker et al., 2013a; Stocker et al., 2013b). While RCPs have replaced the SRES emission scenarios in current assessments, the outputs of older SRES GCM simulations and associated downscaled models remain valid[8] as they describe a different subset of possible future climates.

2.3. Determining regional climate change

Global climate models (GCMs) can reliably project changes in temperature, since the warming response is widespread and the physical processes responsible for warming are well-captured by these models. These models are, however, often less-skilled in translating the gathered information into changes in rainfall and other parameters at the local scale. This is because GCMs are applied at spatial scales of 200-300 km, and they often cannot capture the physical processes and features of the landscape which are important determinants of local and regional climates. For example, thunderstorms occur on spatial scales which are too small or localised for GCMs to resolve. It thus follows that GCMs tend to be unreliable estimators of rainfall in regions where convection (the physical process which produces rainfall in thunderstorms) is important. This limits the application of GCM projections for assessments of change at the local scale. For this reason, **'downscaling'** techniques, which translate changes in the 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 (Tadross et al., 2011, p.28). Two main types of downscaling methodologies may be employed, namely statistical (empirical) and dynamical downscaling.

Statistical downscaling refers to the process where large-scale climate features are statistically related to the local climate of a region – historical observations are utilised. **Dynamical downscaling** refers to the process where a dynamic climate model (either a higher resolution limited-area model or variable resolution global model) is nested/nudged within a GCM. For further explanations of these methodologies, refer to page 30 of the first edition of the handbook.

Downscaled projections are increasingly being used in studies of regional impacts and adaptation, and it is thus critical that the limitations of these data sets are well understood. Firstly, a common misconception is that high-resolution or downscaled projections are better than the coarser projections from GCMs. 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. This is as the performance of downscaling techniques are highly dependent on the quality of the input data and this means that downscaled data may inherit assumptions and errors in the GCM simulations.

Secondly, choosing the single 'best' GCM is problematic as 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. A better approach in any impact and adaptation assessment is to use the largest number of possible 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. percentiles) of the distribution of projected changes, with some measure or recognition of the spread of possible future climates also provided.

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[8] Since there is no current method of validating the different future climate change projections, there is no reason to assume that the more recent projections based on RCPs are more trustworthy than the previous estimates.

2.4. Regional climate projections

2.4.1. Comparisons between GCMs, statistically and dynamically downscaled projections for different RCPs

This section presents key messages drawn from recently released studies comparing multiple GCMs, dynamical and statistically downscaled models (Hewitson et al., 2014). The simulated climates are taken from an ensemble of 16 GCMs, an ensemble of statistical downscaling of 10 of these GCMs, and an ensemble of a single RCM downscaling of 8 GCMs generated through the Coordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme (WCRP). All simulations utilised both the RCP 4.5 and 8.5 scenarios and whilst some of the RCM downscaling used GCMs not included in the GCM ensemble, these model future climates are still plausible and help to address a wider range of possible future climates.

Before discussing projected changes in climate over southern Africa, it is important to recognise that both the magnitude and spatial distribution of simulated changes are dependent on which future period is interrogated in the GCM ensemble. Simply stated, changes in rainfall will vary across the region and over time; short- to medium-term versus long-term projections are dependent on decadal variability in the models and choice of future period in which to calculate the average change.

Given multi-decadal variability, it is important to recognise when in the future a model's mean state significantly deviates from its mean state during the baseline period. Without this measure it is unclear as to what degree any differences are due to variability on shorter timescales. Figure 2.1 shows the 20-year moving average rainfall in 14 GCM simulations (using RCP8.5), with simulated mean differences (with the base period 1985-2005) significant at the 95% confidence coloured orange (insignificant differences coloured blue). It is clear from the figure that significant negative differences in rainfall only become apparent in three models around 2016, with 10 models indicating mean drying by 2050. No models indicate mean wetter futures throughout the simulated period.

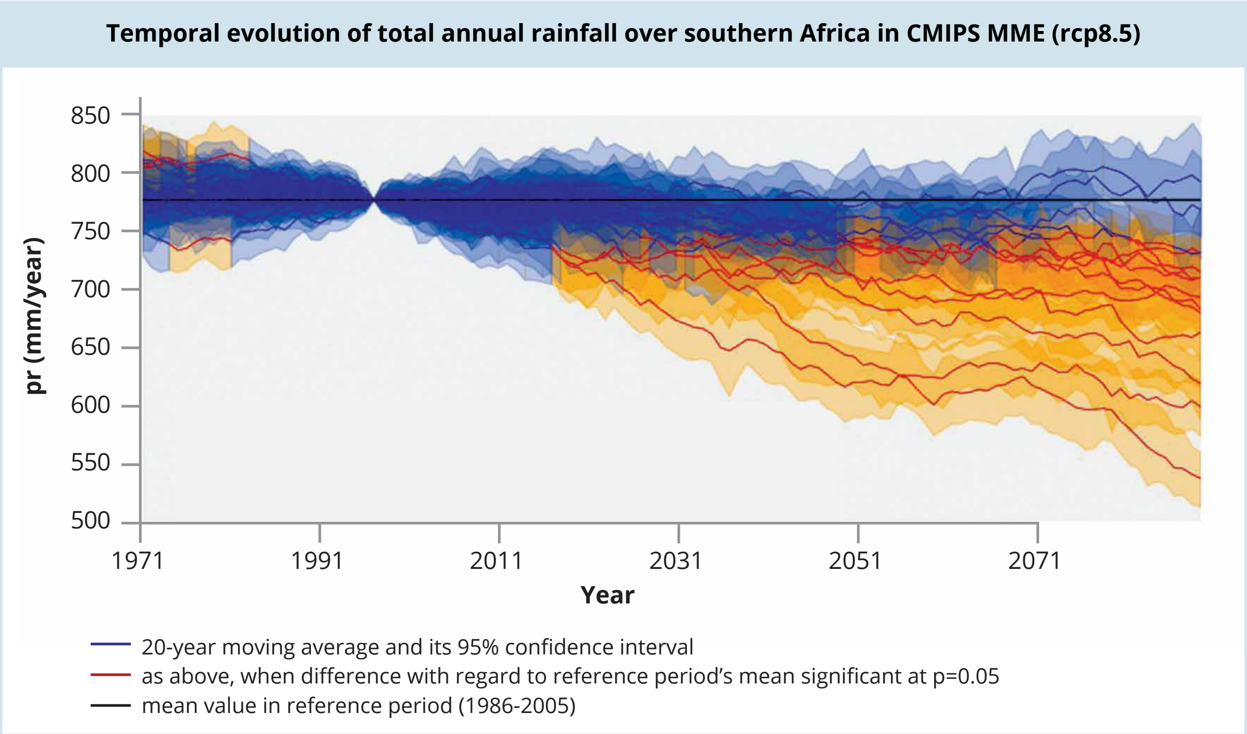

Temporal evolution of total annual rainfall over southern Africa in CMIPS MME (rcp8.5)

Figure 2.1: 20-year moving average rainfall, simulated by 14 GCMs (RCP8.5), averaged over a domain covering the land body of southern Africa (35°-20°S, 10°-40°E). Mean model (solid line) differences with the 1985-2005 period significant at the 95% confidence level (shaded plumes) are coloured orange; insignificant differences coloured blue.

Figure 2.2 indicates the future changes (2041-2070 period relative to 1976-2005 period) in DJF rainfall and temperature simulated by the different ensembles, the RCP scenario as a whole, and the individual ensemble members, averaged over southern Africa. For rainfall, the medians for each ensemble and scenario indicate a reduction in rainfall, but it is evident that some of the individual ensemble members (particularly in the GCM ensemble) simulate an increase in rainfall. Without further information on how these models simulate the current climate, it is difficult to assess how representative they may be and we must assume they are equally plausible representations of the future climate. However, taking the interquartile range (central 50% of model simulations) as an indication of what may be the most likely future would suggest a reduction in rainfall.

For maximum temperatures all scenarios, ensemble medians and individual models suggest an increase in the future (Figure 2.2). The GCM ensemble again encompasses the range of simulations in the statistical and dynamically downscaled ensembles, with the exception of two dynamical downscalings of the RCP 4.5 scenario. Nevertheless, taking the inter-quartile ranges, the hyper ensemble suggests increases in maximum temperatures of between 1 and 3 °C. Projections based on CCAM downscalings show that for the period 2040-2060 temperatures are projected to increase by 2 to 4 °C. By the end of the century (2080-2100), temperatures are projected to increase up to 8.5 °C over interior arid regions under RCP 8.5 (refer to Figures S.7 and S.8 in the Supplementary information).

Figure 2.3 shows maps of median simulated changes in seasonal (DJF) rainfall in each of the three ensembles for the RCP 8.5 scenario. The GCM ensemble change is shown for the same 10 GCMs used for the statistical downscaling. While there are some regional differences in simulated rainfall between the different ensembles, there are clearly also areas of convergence. The median of the GCM ensemble indicates drying over much of the region south of 15 °S, with mostly wetting further north. The statistical downscaling ensemble indicates a similar drying region (mostly concentrated in a band across central southern Africa extending further north), whereas the dynamical downscaling ensemble has a tendency for more extreme drying over central and south-eastern southern Africa, with wetting towards the southwest. Central southern Africa (e.g. northern Botswana/Namibia, southern Zambia and Zimbabwe) is consistently projected to be drier in all three ensembles, with Tanzania and parts of northern Mozambique projected to be wetter in the future. It is notable that these regions of consistent drier/wetter modelled changes are also consistent with the results simulated for DJF by CCAM downscalings under an assumed A2 scenario as well as RCP4.5 and 8.5 (refer to Figure S.9 in the Supplementary information), suggesting the simulated changes are robust under a wide range of modelling approaches. Differences between the three ensembles below, however, serve as a reminder that simulated changes in some regions may be dependent on both the GCMs used to make an assessment, as well as the method for producing the rainfall estimates, and additionally, might reflect transient effects associated with multi-decadal natural variability as illustrated in Figure 2.3.

CMIP5 data, southern African domain (2041-2070 vs. 1976-2005)

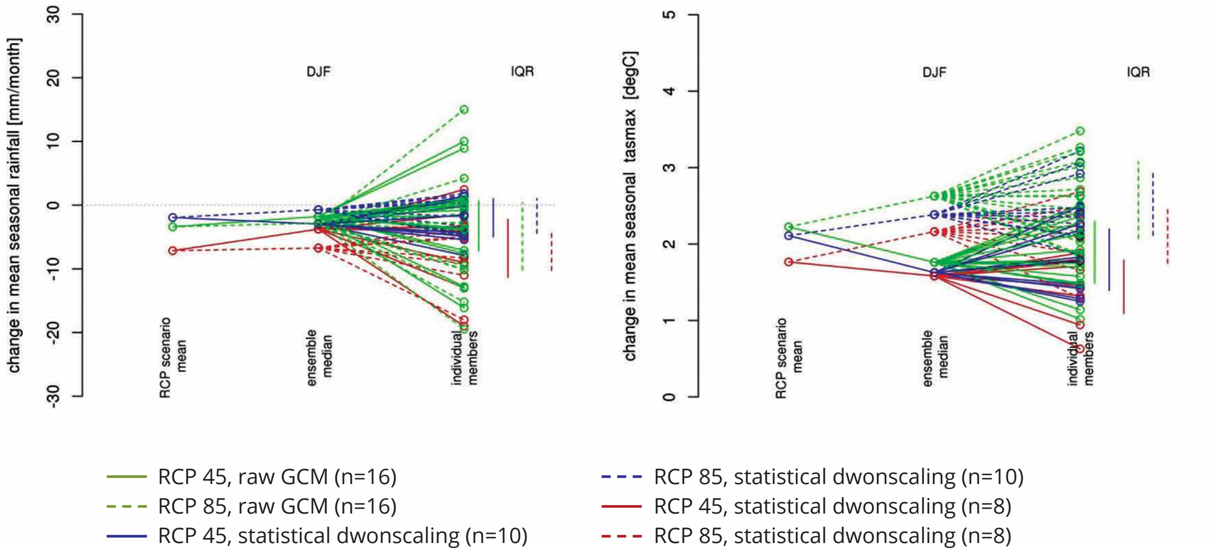
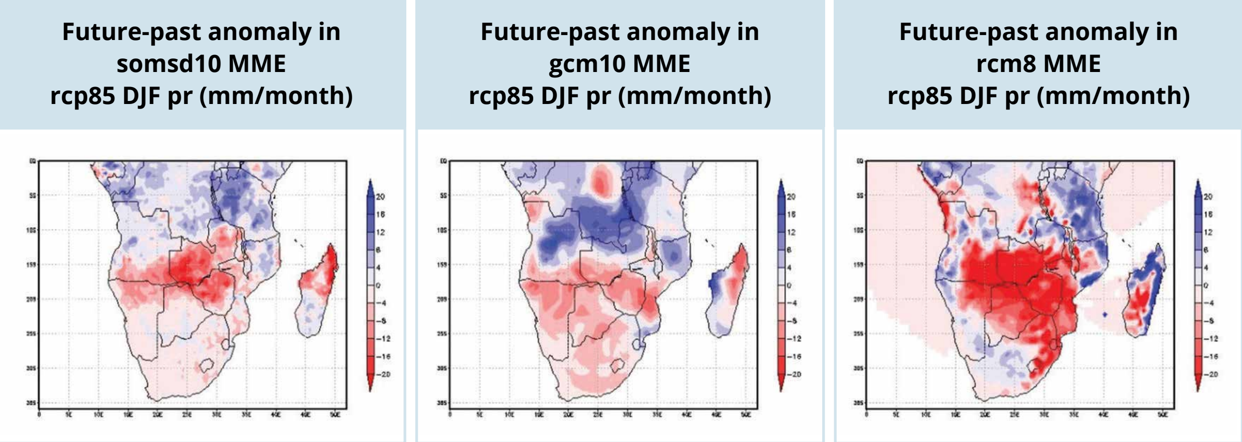


Figure 2.2: Change in mean monthly rainfall (left) and maximum temperature (right) for DJF for two RCP scenarios: 16 GCMs, 10 statistical downscaling realisations and 8 regional climate model realisations averaged over the domain covering the land body of southern Africa (35°-20°S, 10°-40°E). Bars on the right-hand side of the graphs mark the inter-quartile range for each ensemble/RCP combination.


Future-past anomaly in somsd10 MME rcp85 DJF pr (mm/month)

Future-past anomaly in gcm10 MME rcp85 DJF pr (mm/month)

Future-past anomaly in rcm8 MME rcp85 DJF pr (mm/month)

Figure 2.3: Maps of ensemble median of change in rainfall (2041-2070 period relative to 1976-2005 period), in statistically downscaled ensemble (left), GCM ensemble (middle) and dynamically downscaled ensemble (right), for DJF, under RCP 4.5.

2.4.2. Projected changes in climate extremes

Changes in many extreme weather events have been observed since 1950 and there is mounting evidence suggesting that the frequency and intensity of some events will change in the future.

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (Field, 2012; Seneviratne et al., 2012) provides a comprehensive assessment of climate extremes. For southern Africa, there is:

- High confidence that heat waves and warm spell durations will increase and that the number of cold extremes will decrease;
- Medium confidence that droughts will intensify in some seasons due to a reduction in rainfall and/or an increase in evapotranspiration; and
- There is some evidence to suggest that heavy rainfall events will increase, but there is low confidence in this finding.

Extreme temperatures

Projections, based on CCAM downscalings, suggest that the annual frequency of very hot days (number of days when the maximum temperature exceeds 35 °C) will increase into the future. Even under the more conservative RCP4.5 scenario, increases as high as 80 days per year by the end of the century are projected by some models. For sectors currently sensitive to extreme temperatures, exposure to such events will almost certainly pose an increased risk in the future.

Heavy rainfall events

Projections, based on CCAM downscalings, suggest that an increase in the frequency of extreme rainfall events (20 mm of rain falling within 24 hours) will occur over the eastern parts of southern Africa including Mozambique, Tanzania, parts of Zambia and Zimbabwe, north-east corner of South Africa, and west coast of Madagascar. The increase in extreme wet days over the eastern region is driven by modelled changes in the landfall of tropical cyclones originating in the Indian Ocean (Malherbe et al., 2013).

Whilst changes in thunderstorms (including hail and lightning) are difficult to project as they occur at resolutions finer than those of the GCM (IPCC, 2012; Stocker et al., 2013a), some studies suggest that an increase in the frequency of more intense thunderstorms is possible over tropical and subtropical Africa in a warmer climate (e.g. Engelbrecht et al., 2013). This is in keeping with a global trend towards more heavy rainfall events, which are expected in a warmer atmosphere that can hold more water vapour (Stocker et al., 2013a).

Tropical cyclones

Future changes in tropical cyclones (intensity, frequency, and duration) are highly uncertain (Field, 2012). Tropical cyclones are very difficult to simulate even under current climatic conditions and there are large uncertainties on projected changes (Stocker et al., 2013). The general increase in temperature and water vapour however suggests an increase in heavy precipitation associated with tropical storms and cyclones. Further research is needed in order to better understand changes in the characteristics of tropical cyclones occurring over the southwest Indian Ocean (Malherbe et al., 2013; Tadross et al., 2011).

Coastal storm surges

Coastal storm surges are expected to increase globally due to sea-level rise and an increase in the frequency and intensity of sea storms, accompanied by increases in wave heights (IPCC, 2012; Stocker et al., 2013). These storm events and associated surge events are region-specific and at this stage the region-specific projections are made with a relatively low confidence level (Stocker et al., 2013). Even if the intensity of sea storms remains unchanged, higher sea levels will mean that smaller storms are likely to have an increased impact on the coastline (Theron, 2011).

Droughts
Since droughts in southern Africa are often linked to strong El Niño conditions, an important question is whether a warmer climate will result in more frequent and more intense ENSO events. Researchers across the region are conducting ongoing research into climate dynamics and extreme events including ENSO in order to understand the mechanisms and consequences of climate dynamics in the region on short- to long-term time scales (CSIR, 2015). The SREX report states that there is low confidence in projections of changes in the behaviour of ENSO because of insufficient agreement between different model projections (Field, 2012).

Fires
The occurrence of fires is closely linked with climate and increases in temperature combined with an increase in dry spells may result in wildfires affecting larger areas, and fires of increased intensity and severity (IPCC, 2012). The frequency of high-fire danger days is projected to increase across southern Africa and is consistent with the increases in heat-wave days (Engelbrecht et al., 2015).

2.5. Key messages

Box 2.2 provides a summary of the climate projections for the region. Assuming that emissions of anthropogenic greenhouse gases continue rising at current or higher levels, central southern Africa is likely to be drier in the future during mid-summer, with parts of Tanzania and northern Mozambique likely to be wetter. As demonstrated in the first edition of the handbook, winter rainfall in the Western Cape of South Africa is expected to decline in future. Temperatures are projected to continue to increase into the 21st century. Warming is likely to be greatest towards the interior, and less in coastal areas, a finding consistent with earlier results for the region.

As stated earlier, projected changes in rainfall for the long term presented in this chapter may on occasion disagree (for example, rainfall) or be consistent (for example, temperature), depending on the downscaling or model used. The difference in rainfall projections may be attributed to the way in which surface rainfall is related to the physical processes which produce rainfall, as well as the choice of GCMs used in the downscaling ensemble. Even so, here we find greater consistency between projections using different modelling approaches than was found in earlier work (Tadross et al., 2011), suggesting that convergence may be enhanced through the use of more GCMs and through refinement/development of modelling approaches and downscaling tools.

Box 2.2: Summary of the climate projections for the region

	GCM	Statistical downscalings	Dynamical downscalings
Temperature	⬆	⬆	⬆
	Increase in mean, maximum and minimum temperatures		
Rainfall	⇧ Increase in rainfall over Tanzania and parts of northern Mozambique		
	⇧ Decrease over central southern Africa (e.g. northern Botswana, Namibia, southern Zambia and Zimbabwe) and southwestern Cape of South Africa.		
Extreme temperatures	⬆ Increase in very hot days and heat waves	Not available	⬆ Increase in very hot days – above 35 °C
Heavy rainfall	Low confidence that heavy rainfall events will increase	Not available	⇧ Increase in the frequency of extreme rainfall events (20 mm of rain falling within 24 hours) over eastern parts of southern Africa
Droughts	⇧ Medium confidence that droughts will intensify	Not available	Not available

The black arrows (⬆) indicate high confidence in projected change, with all model ensembles indicating the same directional change (e.g. increase in temperature). The grey arrows (⇧) indicate some agreement between models, but there is less confidence in those projections.