2025 Climate Change Distillation Report for Southern Africa

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September 2025

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Preface

Thirty-five years have passed since the Intergovernmental Panel on Climate Change (IPCC) published its First Assessment Report (FAR) in 1990. It was a pivotal report, providing clear evidence that human activities were increasing greenhouse gas concentrations in the atmosphere, and that this had the potential to result in global warming. The report was also clear that fossil fuel burning was the main cause of increasing greenhouse gas concentrations, with deforestation and agriculture being other important sources.

Another important feature of the FAR was that it made use of global climate models to project future levels of global warming as a function of increases in atmospheric greenhouse gas concentrations. The FAR climate models were relatively simplistic, not being able to simulate coupled ocean-atmosphere processes, cloud feedbacks or the details of regional climate change. Yet the overall evidence that the FAR provided in terms of potential future climate change and environmental risks was sufficiently strong for the United Nations Framework Convention on Climate Change (UNFCCC) to be established in 1992.

The evidence for anthropogenically-induced climate change has strengthened considerably since the FAR, to the extent that the IPCC in its Assessment Report Six (AR6) published in 2021 stated that it is 'unequivocal that human influence has warmed the atmosphere, ocean and land'. Climate models have also become much more sophisticated, nowadays being able to simulate the coupled ocean-atmosphere-land system, various feedback processes and the global carbon cycle. Increasingly, it is becoming possible to project the regional details of climate change, thereby enabling climate action in the form of adaptation at local scales.

Yet within these advances of climate science lies a conundrum. Decision makers, specifically those with the responsibility to build resilience to climate change impacts, are increasingly confronted with a growing body of evidence of current and future climate change, including from observations, global climate models, regional climate models, the peer-reviewed literature, key international assessments such as those from the IPCC, and various national assessments. For the layperson, it is certainly challenging to make sense of these multiple lines of evidence, towards distilling these into actionable messages for adaptation.

It is against this background that the Wits-Nedbank Chair in climate modelling will, on an annual basis, publish s 'Climate Change Distillation Report' for southern Africa, of which this is the first issue. The report aims to, in accessible language, convey the main insights into current and future climate change in southern Africa, within the context of the continuous advances being made in our understanding of global warming and global climate change. The report in particular lists the main risks that climate change poses to the southern African region, as per the assessment of the Chair. That is, the report aims to 'distil' the growing body of evidence of climate change into key messages that can aid adaptation in the southern African region.

In my experience, the South African government is embracing climate science and is actively pursuing climate change adaptation. This is not to be taken for granted, since in other countries we've seen in recent years an erosion of respect for the scientific evidence base. Moreover, in South Africa, the private sector is also increasingly becoming aware of climate change risks, thereby opening more doors for climate change action. As I am writing this preface to the first distillation report in my office in Braamfontein, Johannesburg, in September 2025, I am thus very hopeful that South Africa will increasingly make use of climate science to inform the climate change adaptation action the country so dearly needs.

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1. Dawn of the era of 1.5 °C of global warming

The year 2024 was the first calendar year to exceed the 1.5 °C level of global warming (Figure 1). Technically, this means that the average near-surface atmospheric temperature of Earth was more than 1.5 °C higher than the corresponding temperature of the pre-industrial climate (Lee et al., 2021). This does not mean that the 1.5 °C level of global warming has been permanently exceeded, however. During 2025, due to the presence of La Niña events at the beginning and end of the year, the level of global temperature will likely be slightly below 1.5 °C. La Niña is the naturally cool state of the planet, when sea-surface temperatures in the tropical Pacific Ocean are cooler than normal. The year 2025 may nevertheless turn out to be the 3rd warmest year on record, behind 2024 and 2023.

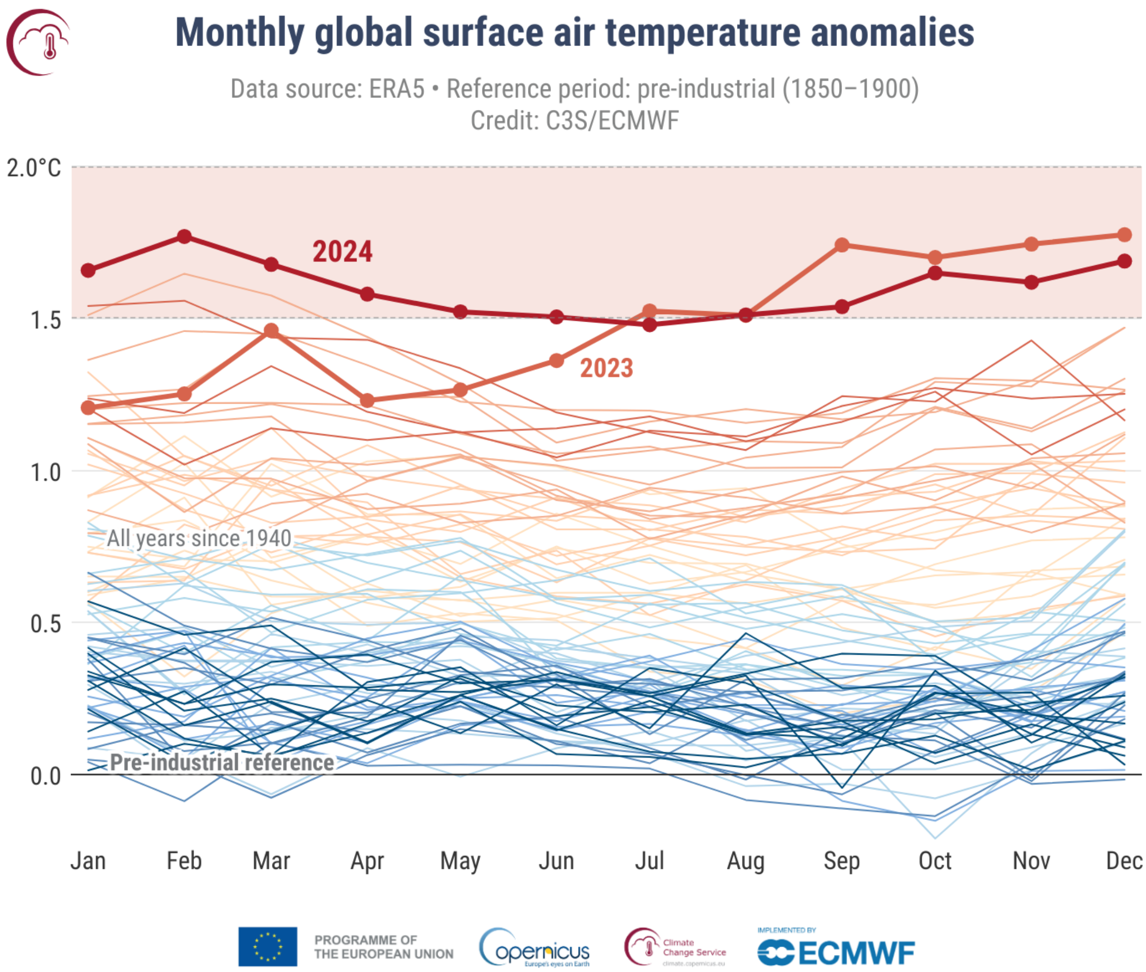

Figure 1: Global surface air temperature increase (°C) above the average for the pre-industrial reference period (1850–1900) for each month from January 1940 to December 2024, plotted as a time series for each year. 2024 is shown as a thick red line and 2023 as a thick pink line, while other years are shown with thin lines and shaded according to the decade, from blue (1940s) to red (2020s). Data source: ERA5. Credit for graphic and Figure text: C3S/ECMWF.

The Intergovernmental Panel on Climate Change (IPCC) defines the permanent exceedance of the 1.5 °C level of global warming as a twenty-year period for which the time-averaged global average near-surface atmospheric temperature exceeds the 1.5 °C threshold (Lee et al., 2021). The mid-point of this twenty-year period defines the year that signifies permanent exceedance of the threshold. A recent paper by Forster et al. (2025) estimates that the remaining carbon budget that could have avoided permanent exceedance 1.5 °C level will, at the current rate of emissions, be burnt over the next three years. It follows that the permanent exceedance of the 1.5 °C level of global warming will likely occur in the late 2020s, somewhat earlier than the IPCC 2021 best estimate of the early 2030s (Lee et al., 2021).

Why is the 1.5 °C level of global warming so important? The Paris Agreement on Climate Change states that global warming should be kept to well below 2 °C, preferably below 1.5 °C. These thresholds (1.5 and 2 °C) are important, since they signify levels of global warming where global tipping points with far-reaching consequences may be reached. The most well-known of these is the tipping point at which the Greenland ice sheet may become unstable and melt irreversibly. The 2018 IPCC Special Report on Global Warming of 1.5 °C (SR1.5) estimated this threshold to likely be reached somewhere between 1.5 and 2 °C of global warming (Hoegh-Guldberg et al., 2018). SR1.5 also projected a tipping point around 1.5 °C of global warming at which warmer ocean temperatures, marine heat waves and associated coral reef bleaching will lead to a loss of about 90% of the world's coral reefs. There is clear evidence that this tipping point has been reached, with massive die-offs of coral reefs being recorded worldwide (Lenton et al., 2025).

More generally, a 1.5 °C world will be a more dangerous world for humans to live in. This is due to the increases in extreme weather events such as heat waves, droughts, heavy falls of rain and floods that are projected to occur at this level of global warming (Seneviratne et al., 2021). In fact, the world has already become more dangerous in this respect, with increases in extreme weather events already detectable in every region of the world (Seneviratne et al., 2021).

2. Climate models and the Wits-Nedbank Chair in Climate Modelling

Global climate models (GCMs) have become the main tools to project future climate change. Based on the Laws of Physics, GCMs are used to simulate how the coupled ocean-atmosphere-land system will respond to increasing greenhouse gas concentrations. GCM projections are comprehensive, providing simulations of how aspects such as rainfall patterns, temperature and heat waves, wind patterns and ocean currents will respond to the strengthening anthropogenic forcing. More than forty different GCMs developed from countries across the world participated in the Coupled Model Intercomparison Project Phase Six (CMIP6), forming the cornerstone of the IPCC's Assessment Report Six (AR6).

GCMs do have a shortcoming, however. They are computationally expensive and consequently can only be integrated at resolutions of 100 – 200 km in the horizontal. Their ability to represent a range of extreme weather events, including heavy falls of rain, is consequently limited. This, in turn, limits the usefulness of GCM projections in terms of informing on the regional to local details of climate change adaptation. Regional climate models (RCMs) are used to obtain higher resolution climate simulations over limited areas through the process of downscaling GCM projections. The highest resolution multi-model ensemble of projections obtained to date for Africa is the CORDEX-CORE experiment, in which the simulations have a resolution of about 25 km in the horizontal. The CORDEX-CORE ensemble consists of the simulations of 3 RCMs that each downscaled 3 GCMs that participated in the second-last global model intercomparison, CMIP5. GCM and RCM projections are undertaken for various greenhouse gas mitigation scenarios.

The Wits Global Change Institute, via the Wits-Nedbank Chair in climate modelling, generates even higher resolution projections of regional climate change for southern Africa (Figure 2). Using the computational resources of South Africa's Centre for High Performance Computing, the Chair is able to generate simulations at resolutions as high as 4 km in the horizontal (Engelbrecht et al., 2025). At such spatial resolutions, important atmospheric processes such as convection and small-scale weather systems, such as thunderstorms and the rainfall they cause, can be simulated far more realistically than in GCMs or traditional RCMs.

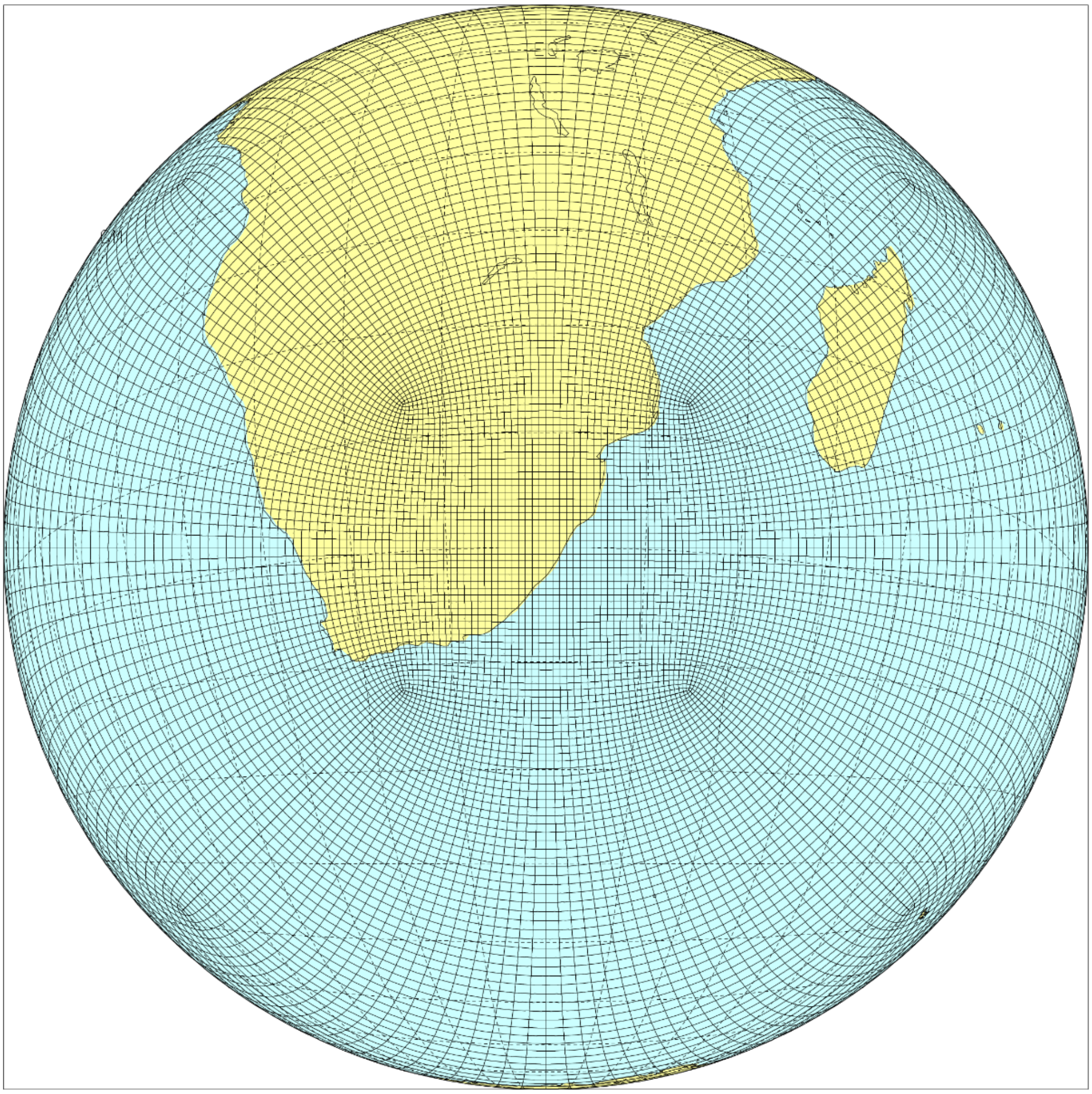

Figure 2: The Wits-Nedbank Chair in climate modelling is undertaking km-scale projections of future climate change in southern Africa, to inform on climate-smart Disaster Risk Reduction and climate change adaptation in the form of unprecedented future extremes.

In this way, the regional details of climate change can be more realistically represented, and there is the possibility that some of the structural uncertainties associated with GCI simulations can be removed. The new generation of climate models being developed internationally, running at spatial resolution sufficiently high for convective processes to be partially or fully resolved, are referred to as ‘km-scale’ or ‘convection-permitting’ models.

The Wits-Nedbank Chair in Climate Modelling has commenced with the systematic generation of km-scale climate simulations for the southern African region. A first paper on the application of these technologies in South Africa has been published (Engelbrecht et al., 2025). This study established that climate change doubled rainfall totals during the Durban floods of April 2022. Future distillation reports of the Chai will report in more detail on km-scale projections of future climate change for the southern African region. The main purpose of this research is to anticipate the possible occurrence of unprecedented extreme weather events in southern Africa, specifically heavy rainfall events inducing flood hazards, towards climate-smart Disaster Risk Reduction (DRR) and the development of climate change adaptation options.

3. What do we know about southern Africa's climate change future?

In what follows, the multiple lines of evidence available in terms of future climate change in southern Africa, including observed trends, climate model projections, peer-reviewed literature and IPCC Assessment Reports are considered to arrive at a confidence assessment (or distillation) of what we know about projected climate change futures in southern Africa.

The most prominent feature of climate change in southern Africa that can already be detected is the drastic rate of warming (that is, strong positive trends in near-surface temperatures). Over the western and central interior regions of southern Africa, the observed rate of warming is in the order of twice the global rate of warming (Engelbrecht et al., 2015). In South Africa specifically, there are several weather stations with multi-decadal, homogeneous time-series records, and these stations consistently report substantial increases in annual average temperatures (Kruger and Nxumalo, 2017). Clear increases have also been detected in the occurrence of warm extremes (e.g. heat-wave days) in South Africa, with corresponding decreases in cold extremes (e.g. frost days) (Kruger and Nxumalo, 2017). These and a substantial number of additional studies provide strong and consistent evidence that temperatures and warm extremes have been increasing over the last several decades in southern Africa (*virtually certain*), and that these increases are unequivocally the regional consequence of anthropogenically-induced global warming.

When considering climate model projections of future temperatures across southern Africa, all climate models agree that under low-mitigation climate change futures temperatures will continue to increase in the near-, mid- and far-future (Figure 3), consistent with the observed trends. Here, the near-future refers to the period 2021-2040, the mid-future to 2041-2060 and the far-future to 2081-2099. The changes shown in Figure 3 are relative to the 1981-2000 baseline period. Several studies have documented projections of drastically rising temperatures across southern Africa under low mitigation futures, and these changes can consequently be assessed to be '*virtually certain*' (Engelbrecht et al., 2015; Ranasinge et al., 2021). Warm temperature extremes such as heat-waves, very hot days and high fire-danger days are similarly projected to increase across southern Africa in all GCM and RCM projections (Figure 4; Engelbrecht et al., 2015; Mbokodo et al., 2020; Ranasinghe et al., 2021). Further increases in warm extremes in southern Africa are thus *virtually certain*, already for the near future, and provide a clear and actionable message for climate change adaptation. For example, millions of people in southern Africa live in informal housing and are exposed to oppressive temperatures during heat-waves, which impacts human comfort, health and mortality (Garland et al., 2015). It is clear that heat-health adaptation plans need to be implemented across southern African cities and municipalities to build resilience and help protect the most vulnerable communities and people against the increasing impacts of warm temperature extremes.

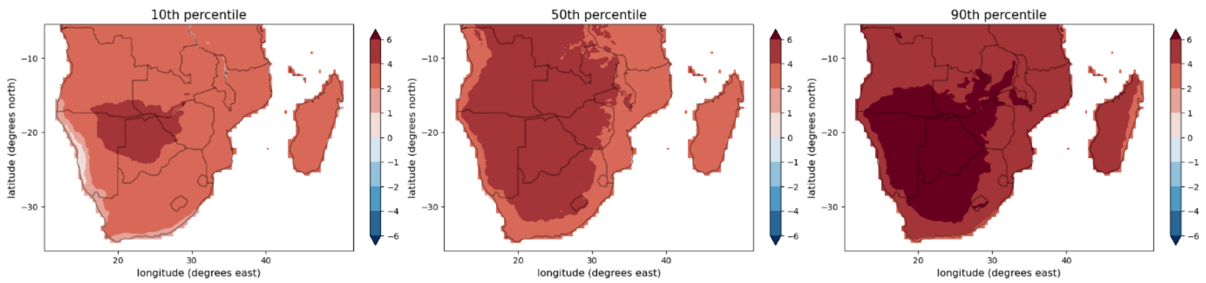

Figure 3: Projected changes in annual average temperature (°C) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

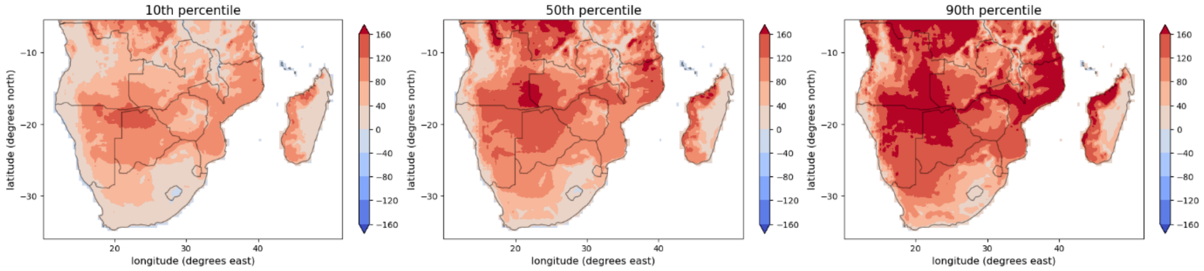

Figure 4: Projected changes in the annual number of very hot days across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

The IPCC in AR6 has assessed that decreasing trends in annual rainfall can already be detected across the two regional domains of 'Western Southern Africa' and 'East Southern Africa', with associated increases in agricultural and hydrological drought (Ranasinge et al., 2015). Over the summer rainfall region of southern Africa, these decreasing trends in rainfall are particularly prominent in spring (Abubakar et al., 2025). Observed increases in extreme rainfall events have also been observed in recent decades across the southern African region (Ranasinge et al., 2021). When considering observed trends in extreme rainfall for South Africa specifically, most weather stations in eastern and central southern Africa are reporting general increases in extreme precipitation (McBride et al., 2022), consistent with the AR6 assessment. There is *high confidence* in this trend and that it is of anthropogenic origin, given the well-known thermodynamic fact that a warmer atmosphere can hold more moisture and potentially produce more intense storm systems. When considering observed trends in annual rainfall totals across South Africa, a more nuanced picture emerges (MacKellar et al., 2014). Pronounced multi-decadal variability may well still be obscuring the anthropogenic signal in terms of systematic rainfall changes, with a large portion of stations reporting trends that are without local statistical significance. There is *low confidence* that general decreases in rainfall can be detected in both South Africa's winter and summer rainfall regions, with associated increases in meteorological and agricultural drought.

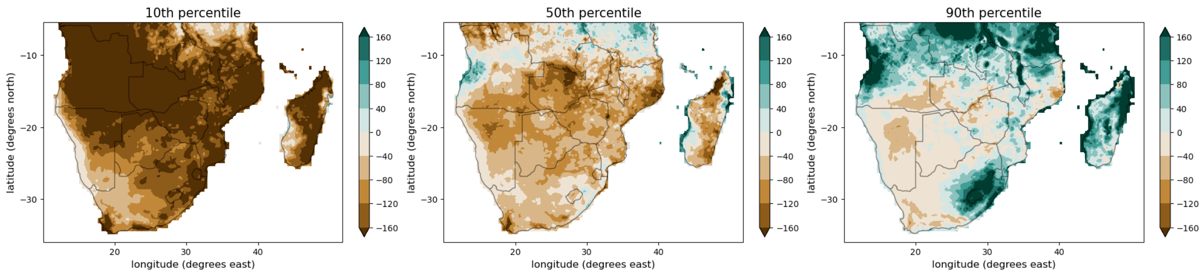

Figure 5: Projected changes in annual average rainfall totals (mm) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

Most climate models projected general decreases in rainfall over southern Africa in a warmer world, with associated increases in meteorological and agricultural drought (Engelbrecht et al., 2015; Ranasinge et al., 2021). This is a signal that strengthens over time, and for the far-future under low mitigation scenarios, general rainfall decreases over southern Africa are *likely* (Figure 5). As far as inter-annual variability is concerned, there is strong evidence that the El Niño Southern Oscillation teleconnection to southern and East Africa will persist in a future warmer world (Steinkopf and Engelbrecht, 2025). The eastern escarpment region of South Africa is the one region in Africa south of 10 °S where there is a lack of congruency between climate model projections of future changes in rainfall. Over this part of South Africa, future decreases in rainfall are *about as likely as not*. It is a clear example of model uncertainty, which may be related to the statistical treatment (parameterisation) of convective rainfall in climate models. That is, the GCMs and RCMs applied in the IPCC's AR6 were integrated at horizontal resolutions too low for the dynamic circulation processes working within thunderstorms to be resolved, which forced the need for these effects to be statistically estimated. It is hoped that a new generation of higher resolution 'km-scale climate models', which can, to some extent, resolve thunderstorm dynamics, will remove some of these structural uncertainties from climate change projections for South Africa's eastern escarpment. Extreme rainfall events are projected to occur more frequently over eastern South Africa in a warmer world by most climate models (Figure 6). It is a signal that can already be detected (McBride et al., 2022), and there is *high confidence* that it will strengthen in the near future.

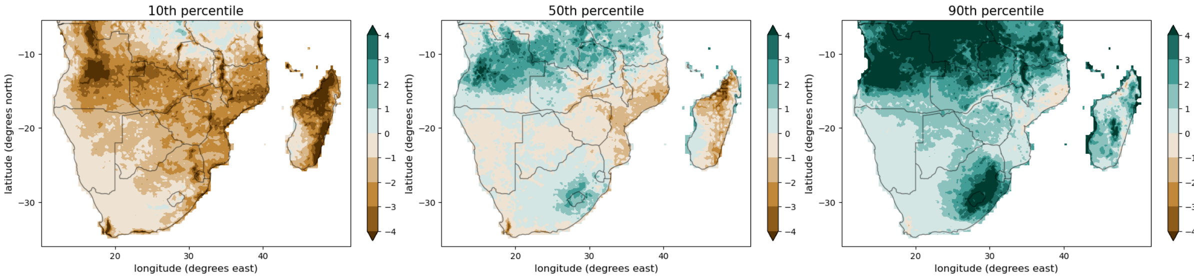

Figure 6: Projected changes in extreme rainfall events (mm) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

Summary of changes

In light of the above discussion and the broader peer-reviewed literature, we can summarise what is known about southern Africa's climate change futures as follows:

- Southern Africa is warming drastically – over the interior regions, the rate of warming is in the order of twice the global rate of warming.
- Warm extremes, such as very hot days, heat wave days and high fire-danger days, are similarly observed to be increasing with further drastic increases under low mitigation futures.
- The region is likely to become generally drier, but rainfall futures over the eastern escarpment areas are uncertain.
- When a water-stressed, dry and warm region becomes warmer and drier, the options for adaptation are limited
- Over eastern southern Africa, the number of extreme rainfall events are projected to increase in frequency of occurrence.
- Strong evidence of rainfall onset occurring later across the summer rainfall region.
- The ENSO (El Niño – La Niña) cycle and teleconnection to Africa are projected to persist in a warmer world.

4. Climate change fact sheets for South Africa's Provinces and District Municipalities

The detailed projections of future climate change generated by RCMs, including new km-scale projections, when grounded in the larger ensembles of GCM projections, make possible climate change risk assessments at regional and even local scales. Decision makers in South Africa's Municipalities and Provinces are indeed in need of actionable messages for adaptation action at local scales. The Wits-Nedbank Chair in Climate Modelling at the GCI, in collaboration with the South African National Biodiversity Institute (SANBI), have collaborated to distil the assessment of climate change risks for southern Africa (see section 3) into actionable messages for climate change adaptation all the way through to the District Municipality level. We refer to this distillation as 'climate change fact sheets' for South Africa's District Municipalities and Provinces (Engelbrecht et al., 2025b). It is hoped that the fact sheets will guide decision makers in the District Municipalities, Provinces, national government and across a range of sectors, in terms of the adaptation actions they may decide to take. Such actions should always be informed by the expert understanding of the risks and vulnerabilities of the specific communities or sectors where adaptation action needs to take place.

5. Regional tipping points

Southern Africa was classified as a climate change hotspot in the IPCC's 2018 SR1.5 (Hoegh-Guldberg et al., 2018). Our assessment of the region's climate change futures under low mitigation (section 3) reveals why: southern Africa is projected to become drastically warmer, and likely also drier. For a region that is already water-stressed, this means that options for adaptation will be limited. It is against this background that some of the biggest climate change risks for southern Africa, related to regional tipping points being reached, can be identified (Engelbrecht and Monteiro, 2021; Engelbrecht et al., 2024):

- A Gauteng day-zero drought – this is probably South Africa's biggest economic risk in the near-term. The risk of a next day-zero drought also continues to loom in Cape Town.
- More frequent and intense multi-year droughts and heat waves impacting on the maize crop and cattle industry. Considering only biophysical heat stress, the tipping point (collapse of these sectors) has been estimated to be at ~ 3 ºC of global warming (Hoegh-Guldberg et al., 2018). Socio-economics likely imply, however, that the tipping point will be reached earlier (at a lower level of global warming).
- More frequent and intense heat-waves impacting on human health and mortality. This is a pronounced risk in southern Africa, given the vulnerability of millions of people living in informal housing and without easy access to cool water.
- Wildlife is fenced in across southern Africa. There is the potential of extensive die-offs during unprecedented multi-year droughts, occurring in association with intense heat waves and runaway veldfires.

In the eastern parts of southern Africa, following our assessment in section 3, an additional set of tipping-point related risks can be identified:

- The possibility of an intense tropical cyclone (category 3-5 hurricane) reaching Maputo, Richards Bay or even Durban, or moving westwards into the Mpumalanga Lowveld or Limpopo River valley.
- Mega-flooding in the KwaZulu-Natal and Eastern Cape Provinces, due to cut-off low-pressure systems causing heavy falls of rain, intensified by increased moisture availability above the warmer Indian Ocean and Agulhas current.

More research is needed to improve our understanding of the probabilities of all these high-impact events occurring, which is a key focus of the Wits-Nedbank Chair in Climate Modelling at the GCI. At the same time, climate-smart DRR plans and adaptation options need to be developed to build resilience to these events. The Wits-Nedbank Chair in Climate Modelling is working with research partners and stakeholders across southern Africa to this effect.

6. Reasons for hope

Despite the pronounced risks that climate change poses to the southern African region, there remains hope that future impacts can be limited (Figure 7). There are three reasons for this statement:

- Strong international collaboration on climate change mitigation (i.e. drastically reducing greenhouse gas emissions) can still keep global warming to well below 2 °C. This means that at least some of the tipping points described in section 5 can be avoided.
- The science of climate modelling is well developed and continues to be improved. That is, climate change projections give us the ability to anticipate risks and prepare for them to the fullest extent possible, thereby reducing impacts.
- In South Africa, and more broadly in southern Africa, governments respect climate science and are willing to incorporate climate science in decision-making, including in adaptation strategies. The private sector is also becoming increasingly aware of climate change risks and is taking proactive steps to build resilience.

Southern African countries thus need to move forward with a two-prong approach, contributing fairly to climate change mitigation, whilst focusing strongly on adapting to an increasingly warmer and more dangerous regional climate system.

Figure 8: When the IPCC launched SR1.5 in October 2018, it was under the banner of ‘Reasons for Hope’. This referred to the hope of keeping the level of global warming below 1.5 °C, thereby avoiding a range of climate change impacts. Climate change mitigation was too weak to achieve this aspiration, but there will still be substantial benefits in terms of avoided impacts if global warming can be restricted to well below 2 °C. Photo by Kristie Ebi.

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