Climate risk report for the Southern Africa region: Technical Reference Document

Authors: Katy Richardson, Roger Calow, Leigh Mayhew, Guy Jobbins, Gabrielle Daoust, Amy Waterson, Hannah Griffith, Cathryn Fox, Rosanna Amato, Emma Dyer, Rebecca Osborne and Laura Burgin

Reviewers: Richard Jones, Jane Strachan

Recommended citation: Richardson et al (2022) Climate risk report for the Southern Africa region: Technical Reference Document. Met Office, ODI, FCDO.

Image location: Gaborone, Botswana

Contents

A: Methods and Data

Climate in context methodological approach

The key stages in the methodology and division of responsibilities across the project team are presented in a schematic in Figure A1 and described in more detail below.

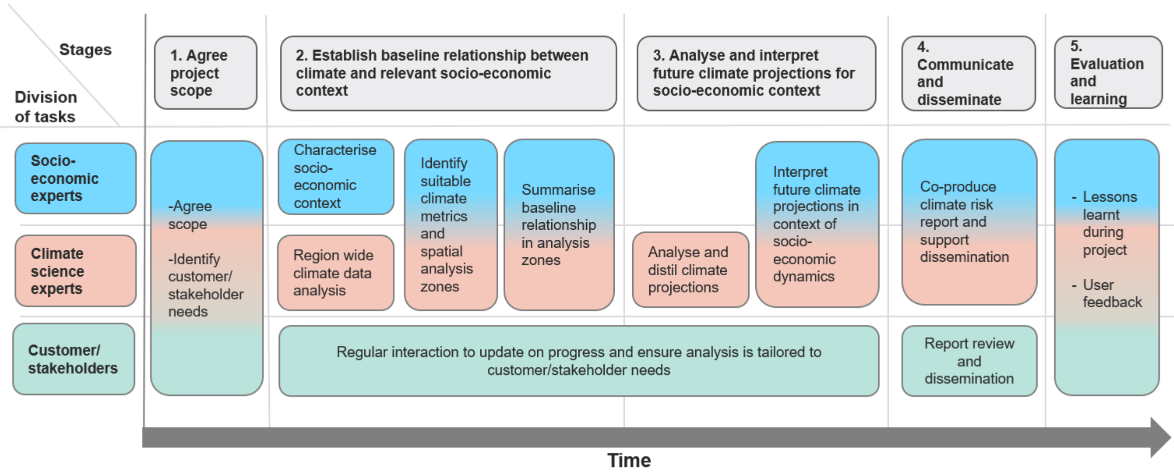

Figure A1 – Schematic diagram of the key stages of the methodology and division of tasks between the socio-economic experts (ODI), climate science experts (Met Office) and customer (FCDO) roles of the project team (Richardson et al. 2022).

Stage 1 involves agreement on the scope of the work and the format of the outputs through iterative discussions across the project team. Consultations with the customer (FCDO) are conducted to identify the socio-economic themes relevant to their decision context.

Stage 2 involves establishing the baseline relationship between climate and the key socio-economic themes identified in Stage 1. This includes:

- Preliminary analysis is conducted to characterise the regional socio-economic context and regional climate through a combination of literature review and processing climate reanalysis data by the relevant experts.
- Identification of suitable climate metrics and spatial analysis zones via an iterative process between the experts, drawing on the outcomes of the preliminary analysis.
- Characterisation of the baseline climate, the key climate-related vulnerabilities and exposure to climate-related hazards in each of the spatial analysis zones.

Stage 3 involves analysis of future climate projections and interpretation in the context of the key vulnerabilities and baseline assessments developed in Stage 2. This includes:

- Selection of appropriate climate model simulations for the region and quantitative analysis of projected changes in relevant climate variables in each of the spatial analysis zones.
- Distillation of the future climate projections into narrative summaries for the relevant climate metrics in each spatial analysis zone.
- Translation of the future climate summaries into climate risk impacts with a focus on the key socio-economic themes.

Stage 4 involves the co-production of a report summarising the analysis and outcomes, tailored to the needs of the customer.
Finally, **Stage 5** involves evaluation and learning of the process to support future applications of the methodology.

Climate data and analysis methods

This report makes use of bespoke climate data analysis in the selected spatial analysis zones (see Section 3.2) and relevant scientific literature. The bespoke data analysis involved processing gridded reanalysis[1] data to characterise the current climate over the 1981-2010 baseline period, and climate model projections to assess the projected trends in average temperature and precipitation for the 2050s (using the 2041-2070 future period compared to the baseline period).

To characterise the baseline climate, we processed temperature from ERA5[2] (Hersbach et al., 2020) and precipitation data from WFDE5 (Cucchi et al., 2020) over the 1981-2010 baseline period. Using this dataset and time period keeps this report consistent with FCDO climatology briefing notes provided to FCDO offices for many of the countries in the Southern Africa region.

For the future climate projections, we used global and regional climate model simulations to assess the projected change in temperature and precipitation for the 2050s under different scenarios of future greenhouse gas emissions. The results presented in this report show projected changes for the 2050s under the RCP8.5[3,4] scenario (van Vurren et al., 2011). This future time-period and scenario combination represents an increase in global average temperature of around 2.5˚C compared to pre-industrial levels. This is higher than the target of limiting warming to well below 2˚C set by the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement. The baseline period of 1981-2010 considered in this report represents an observed increase of around 1°C in global average temperature compared to pre-industrial levels.

---

[1] A gridded dataset that blends climate observations and model data to present the current climate for use as a baseline in future climate assessments.

[2] All observational and reanalysis datasets have associated uncertainties and limitations. For example, reanalysis datasets may underestimate observed extremes, and cannot fully represent localised features such as intense precipitation caused by complex topography, partly due to their limited resolution in space and time. Additionally, ERA5 precipitation fields are derived from 'forecast' output and are therefore more affected by imperfections within the underlying model. The benefit, however, of using reanalyses is that they provide a systematic approach to producing gridded, dynamically consistent datasets for climate monitoring, particularly over data-scarce regions. However, the use of these data to characterise climatological means for the purpose of this analysis is largely uninfluenced by these biases, and the benefits of using a dataset that is globally consistent and consistent with other climate information products outweighs this.

[3] The RCP8.5 Representative Concentration Pathway represents a worse-case future pathway of on-going and substantial increases in future global greenhouse gas concentrations. Other pathways represent stabilisation or eventual reduction of greenhouse gas concentrations with the lowest projecting less additional climate change in the 2050s compared to RCP8.5. Analysis of the RCP4.5 scenario was also conducted, and results were broadly consistent with those presented here for RCP8.5.

[4] The SSP5-8.5 scenario was used for the CMIP6 generation of climate models.

The climate projections in this report comprise an 80-member ensemble; 30 World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) global climate model simulations (see Table A1), 20 WCRP CMIP Phase 6 (CMIP6; Eyring et al., 2016) global climate model simulations, and 20 regional climate model simulations from the WCRP CoOrdinated Regional climate modelling Downscaling EXperiment (CORDEX; Giorgi & Gutowski, 2015) project (see Tables A2 and A3).

CMIP5 models were used to inform the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5; IPCC, 2013), with horizontal model resolution ranging from 100-300 km. CMIP6 models informed the latest Assessment Report (AR6; IPCC, 2021). Like CMIP5, the horizontal resolution of the CMIP6 models varies by model. The range is large; many models are higher resolution compared to those in CMIP5, whereas some are unchanged. The regional climate models are downscaled CMIP5 simulations over the CORDEX Africa domain (AFR-44) at a resolution of 50km.

The models selected are those that were available to access at the time of analysis. Model simulations were assessed for their suitability in simulating the climate of the region by comparing the baseline periods from the model simulations with the reanalysis. The results from this assessment were taken into consideration when interpreting the future projections from the model simulations. More detail on evaluation of these model simulations and known biases is available in IPCC (2013).

The climate data analysis focuses on quantifying projected changes in annual, seasonal and monthly means in the spatial analysis zones. Information on the projected changes in other relevant climate variables and indicators – such as Sea Surface Temperatures (SSTs), Sea Level Rise (SLR) and relevant climate extremes – is drawn from appropriate scientific literature and from the IPCC Interactive Atlas (2021).

Table A1 – GCM simulations from CMIP5 used in the climate data analysis, from https://pcmdi.llnl.gov/mips/cmip5/availability.html.

Modelling Centre	**Model**	**Institution**
BCC	BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration
	BCC-CSM1-1	
CSIRO-BOM	ACCESS1-0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
	ACCESS1-3-m	
CCCma	CanESM2	Canadian Centre for Climate Modelling and Analysis
CMCC	CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici
	CMCC-CMS	
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-QCCCE	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
EC-EARTH	EC-EARTH	EC-EARTH consortium

GCESS	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University
INM	INMCM4	Institute for Numerical Mathematics
IPSL	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
	IPSL-CM5A-MR	
	IPSL-CM5B-LR	
MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
	MIROC-ESM	
	MIROC-ESM-CHEM	
MOHC	HadGEM2-CC	Met Office Hadley Centre
	HadGEM2-ES	
MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology
	MPI-ESM-MR	
MRI	MRI-CGCM3	Meteorological Research Institute
NCAR	CCSM4	National Center for Atmospheric Research
NCC	NorESM1-M	Norwegian Climate Centre
NIMR/KMA	HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration
NOAA-GFDL	GFDL-CM3	NASA Goddard Institute for Space Studies
	GFDL-ESM2G	
	GFDL-ESM2M	
NSF-DOE-NCAR	CESM1-CAM5	National Science Foundation, Department of Energy, National Center for Atmospheric Research

Table A2 – GCM simulations from CMIP6 used in the climate data analysis, from https://pcmdi.llnl.gov/mips/cmip5/availability.html.

Modelling Centre	**Model**	**Institution**
BCC	BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration
CCCma	CanESM5	Canadian Centre for Climate Modelling and Analysis
CNRM-CERFACS	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
	CNRM-CM6-1-HR	
	CNRM-ESM2-1	
CSIRO	ACCESS-ESM1-5	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia)
EC-EARTH consortium	EC-Earth3	EC-EARTH consortium
	EC-Earth3-Veg	
INM	INM-CM4-8	Institute for Numerical Mathematics
	INM-CM5-0	
	INM-CM6A-LR	
MIROC	MIROC6	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MOHC	HadGEM3-GC31-LL	Met Office Hadley Centre
MOHC	UKESM1-0-LL	
MPI-M	MPI-ESM1-2-LR	Max Planck Institute for Meteorology

MRI	MRI-ESM2-0	Meteorological Research Institute
NCC	NorESM2-MM	Norwegian Climate Centre
NOAA-GFDL	GFDL-ESM4	NASA Goddard Institute for Space Studies
	GFDL-CM4	
NUIST	NESM3	Nanjing University of Information Science and Technology

Table A3 – RCM simulations from CORDEX AFR-44 used in the climate data analysis. These are downscaled simulations of a subset of the CMIP5 models in Table A1 at ~50km resolution.

Modelling centre	**Institution**	**RCM**	**Driving GCM**
CLMcom	Climate Limited-area Modelling Community (CLM-Community)	CCLM4-8-17	CNRM-CM5
			MPI-ESM-LR
			EC-EARTH
			HadGEM2-ES
DMI	Danish Meteorological Institute	HIRHAM5	EC-EARTH
GERICS	Helmholtz-Zentrum Geesthacht, Climate Service Center Germany	REMO2009	IPSL-CM5A-LR
			MIROC5
			HadGEM2-ES
MPI-CSC	Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology	REMO2009	EC-EARTH
			MPI-ESM-LR
SMHI	Swedish Meteorological and Hydrological Institute	RCA4	CNRM-CM5
			CSIRO-Mk3-6-0
			CanESM2
			HadGEM2-ES
			EC-EARTH
			MPI-ESM-LR
			IPSL-CM5A-MR
			NorESM1-M
			MIROC5
			GFDL-ESM2M

B: Vulnerability and climate resilience in Southern Africa

Southern Africa has witnessed strong economic growth over the last 20 years or so, buoyed by economic reforms and, in some countries, rising commodity prices. Precious metals and minerals are the region's biggest exports, including gold and diamonds from South Africa (the region's largest economy), diamonds from Namibia, copper from Zambia and platinum from Zimbabwe. Wealth is very unevenly distributed between and within countries, however, and the region still experiences persistent poverty and food insecurity (USAID, 2016a, 2016b, 2016c, 2016c, 2017). Zambia, Malawi, Mozambique, Madagascar and Lesotho all fall into the low-income category defined by the World Bank[5], and have a combined population of 99 million – roughly 55% of the regional total (World Bank data for 2020 – see Section E). In Mozambique, state fragility is an ongoing concern. Here, a combination of natural disasters, insurgent attacks and contested elections have led to growing mistrust in government, illustrating how climate-related shocks can contribute to state fragility (World Bank Mozambique Country Overview, 2022).

Across the region, the direct and indirect impacts of Covid-19 pushed most countries into recession in 2020-21, with Africa as a whole experiencing its first economic contraction in 25 years (World Bank, 2022). Even though health impacts were less severe than expected, the economic and social fallout has been severe. In Madagascar, the economic shock on exposed sectors shrunk the economy by over 7%, income per capita fell by almost 10%, and an additional 1.8 million people were pushed below the international poverty line (World Bank Madagascar Economic Update, 2022). Following a 2–3-year period in which progress on poverty reduction was reversed, regional economies are now rebounding, albeit patchily, with rising food prices now threatening those countries most heavily dependent on cereal imports – Lesotho, Namibia, Botswana, Eswatini, Mauritius, Seychelles and Comoros (Raga and Pettinotti, 2022; Wiggins, 2022).[6]

Climate-related shocks have also had devastating consequences, with floods and droughts a recurring (and growing) risk throughout the region. In March 2019, Cyclone Idai swept across southern Africa causing catastrophic damage and a humanitarian crisis in Mozambique, Zimbabwe and Malawi. Over 1000 people were killed, and 2.6 million left needing emergency assistance. The country was hit again in 2022 by storm Ana causing widespread flooding and population displacement (see Section 3.4, main report). In South Africa, flash floods and landslides in the eastern coast provinces of KwaZulu Natal and Eastern Cape killed over 400 people, destroyed 12,000 homes and forced 40,000 people from their homes (PreventionWeb, 2022).

Droughts have also decimated lives and livelihoods, with impacts that have rippled across sectors. Droughts in 2015-16, 2018-19 and 2021-22 have caused widespread food insecurity

[5]Low income (<USD1085/person/year); lower-middle (USD1086-4255); upper-middle (USD4256-13,205); high-income (>USD13,205). In Southern Africa, no countries are in the high-income category (World Bank: https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2022-2023

[6] Botswana, Lesotho, Mauritius Comoros and Seychelles all have cereal import dependency ratios of over 75% based on a 2016-18 average. Namibia (69%) and Eswatini (67%) are also heavily dependent on food imports (FAOSTAT, 2022 – see Section E).

in Malawi, Zambia, Mozambique, Zimbabwe and Eswatini. In middle-income Namibia, the 2018-19 drought killed 60,000 head of cattle, led to widespread crop failure and left one-third of the population without adequate food (World Bank and Relief Web, various). Drought has also disrupted hydropower generation. Low-flow conditions during the 2015-16 El Niño led to concurrent power outages in Malawi, Tanzania, Zambia and Zimbabwe (Conway et al, 2017; Siderius et al, 2021).

While it is not yet routine, attributing the change in magnitude or frequency of specific events to climate change is straightforward in many cases. Often climate change can be shown to increase the magnitude of damaging extremes or make such events m*ore likely.* And recent global analyses demonstrate how such climate 'shocks' keep people in poverty and push people back into poverty (Hallegatte et al, 2017; World Bank 2020). Poorer people are typically more exposed and more vulnerable to the hazards that destroy assets and income streams; to waterborne diseases and pests that become more prevalent during heat waves, floods or droughts; to crop failure and livestock mortality caused by drought; and to the spikes in food prices that often follow local production failures or, at present, shocks to international trade. Evidence from Madagascar also suggests that rates of forest clearance increase after a poor harvest as farmers attempt to cultivate more land (Hallegatte, 2019). Similarly, those who may have escaped poverty in a good year can be dragged back down again when a flood destroys a tea shop, or a drought decimates a herd or crop.

Longer term changes in climate conditions may have less obvious impacts but threaten lives and livelihoods nonetheless, particularly in poorer countries and locations. Southern Africa is characterised by varied topography, from the Maloti mountains of Lesotho to the savannah plains of Botswana and Namibia. These diverse conditions support important rangelands for livestock and pastoralists, and important agricultural lands for farmers. All are susceptible to shocks but are also vulnerable to slower onset changes in temperature and rainfall that affect the productivity and viability of different production systems and the spread of pests and diseases. Those 'systems' also include freshwater fisheries affected by (amongst other things) rising temperatures, and the coastal-marine environment impacted by sea level rise, ocean acidification and warmer water.

The link between increasingly erratic rainfall and poverty remains a key source of vulnerability, especially in the low/lower-middle income countries of Zambia, Malawi, Mozambique, Zimbabwe, Lesotho and Madagascar (69% rural – World Bank data for 2020, Section E). Those engaged in low intensity, low input rainfed farming, disconnected from markets, and with few opportunities to adapt cropping patterns or diversify in rural or urban economies are among the most vulnerable to climate change, particularly to rising temperatures and rainfall variability (Ellis, 2013; Hallegatte, 2016). For rural smallholders, the climate determines the harvest, and the harvest determines the ability to meet most staple food needs (Devereux, 2009). Pastoral and agro-pastoral livelihoods, significant across the more arid lowlands, are similarly climate-sensitive, as rains (and heat) affect forage and water availability, as well as livestock health (IPCC, 2022).

Rapid urbanisation is changing the exposure and vulnerability landscape, however. The region has the highest urbanisation rate in sub-Saharan Africa, and infrastructure provision (safe water and sanitation, drainage, housing) typically lags behind urban expansion. In low income

Zambia, Malawi, Mozambique, Lesotho and Madagascar, over 65% of urban residents live in poorly served informal settlements, and new migrants often have little choice but to settle in riskier places exposed to multiple hazards (World Bank data for 2018-202 – see Section E).

People and businesses in informal settlements, especially, are exposed to multiple threats, including power cuts, heat stress, communication outages, damage to housing and the destruction of water, sanitation and drainage systems (Howard et al, 2016; Hallegatte et al, 2017; Gannon et al, 2018). And we know that land and housing markets often leave new migrants with little choice but to settle in riskier places (Hallegatte, 2017). Those include low-lying areas of the rapidly growing coastal cities of Madagascar and Mozambique, threated by a combination of rising sea levels, coastal erosion/retreat, more frequent and intense storms, and floods. In Mozambique, for example, the fast-growing city of Beira is only 4.9m above sea level and is located in a cyclone-prone area.

Key risk factors in the report

Climate and socio-economic risk analysis is conducted at the regional scale in this report. Geographical regions which share similar climate, such as rainy season characteristics and seasonal temperature ranges, are identified and used as a basis to bring together the climate and socio-economic information, providing context to the climate projections. The climate analysis conducted includes a combination of bespoke climate data analysis in the zones and review of relevant scientific literature, including the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) and the IPCC Interactive Atlas (2021). The interpretation of climate projections and risk analysis is informed by the following six key issues[7]:

- Economic growth and infrastructure, including disparities in income/wealth distribution.
- Capacity and human capital, including ways in which climate risks are shaped by gender and differences in power, rights and opportunities.
- Population and demography, including rapid urbanisation and the growth of informal settlements where climate risks are amplified.
- Livelihood systems and key crops, with a focus on more exposed (rainfed) agricultural and pastoral systems.
- Disaster risks, given projected increases in the frequency and magnitude of extreme events such as floods and droughts.
- Conflict and migration in a region where political instability and violence undermines efforts to build resilience.

[7] This list is not exhaustive or definitive. Other (similar) framings can be used, including the ‘risk informed development’ approach outlined in Appendix B.

Focus box 2: Risk-informed development

There is increasing recognition that development is exposed to multiple, intersecting threats. This, the full implications for development programming will not be captured by traditional single threat analysis, meaning that it fails to be risk-informed. In order to be risk-informed, programme decision making must undertake multi-threat analysis that considers how different threats merge with existing and changing socioeconomic contexts to create complex risk. In practice, this means that climate-resilient development must not only consider threats to programme outcomes from climate and environmental degradation, but also political, economic and financial instability, cyber and technology, transboundary crime and terrorism, geopolitical volatility, conflict and global health pandemics.

This study also notes risk-informed development requires us not only to think about risks to development but also risks from development. Development outcomes are uneven, creating opportunities for some and risks for others. Risk-informed development must account for trade-offs inherent in development choices, including climate adaptation and mitigation. Such decisions are inherently political, involving the redistribution of resources and navigating unequal power structures.

Source: Opitz-Stapleton et al., (2019); Eriksen et al., (2015).

Climate risk rankings and comparisons

Figure B1 presents a snapshot of climate risk across the region using widely used ND-GAIN8 country rankings for 2019 – the most recent year for which data are available. The ND-GAIN country index uses a range of metrics to assess both a country's vulnerability to climate change and other global challenges and its readiness to build resilience. Vulnerability is measured by assessing a country's exposure, sensitivity, and capacity to adapt to the negative effects of climate change, looking at six sectors: food, water, health, ecosystem services, human habitat, and infrastructure. Readiness is measured by assessing a country's ability to leverage investments and convert them into adaptation actions, looking at three components: economic readiness, governance readiness, and social readiness.

Seven of the 13 Southern African countries considered in this report occupy the top left quadrant of the ND-GAIN matrix (red dots). Countries in this quadrant combine high vulnerability with low levels of readiness, indicating an urgent need for adaptation action. All are classified as low income in the latest World Bank ranking with the exception of lower-middle income Zimbabwe (formerly middle income) and Comoros. Collectively, these 'high risk' countries account for 63% of the region's population (roughly 114 million people).

[8]Notre Dame Global Adaptation Initiative: https://gain.nd.edu/ ND-GAIN country scores and rankings are used by, amongst others, the World Bank in their climate risk country profiles – see https://climateknowledgeportal.worldbank.org/. Scores are available for a total of 182 countries based on data for 2019.

South Africa, an upper-middle income country and the solitary yellow dot, just falls into the bottom-left box (low vulnerability, low readiness). This is mainly because it has the capacity and resources to adapt. Upper-middle income Namibia and Botswana, in blue, occupy the high vulnerability and high readiness quadrant as does Seychelles – the region's only high-income country. These are countries with exposed populations and assets, but demonstrable capacity to act and adapt. The only green country, i.e., in the low vulnerability and high readiness quadrant, is Mauritius. However, the latest 2020 estimate indicates its economy has shrunk by more than any other (almost 15%) since the Covid-19 pandemic hit tourism.

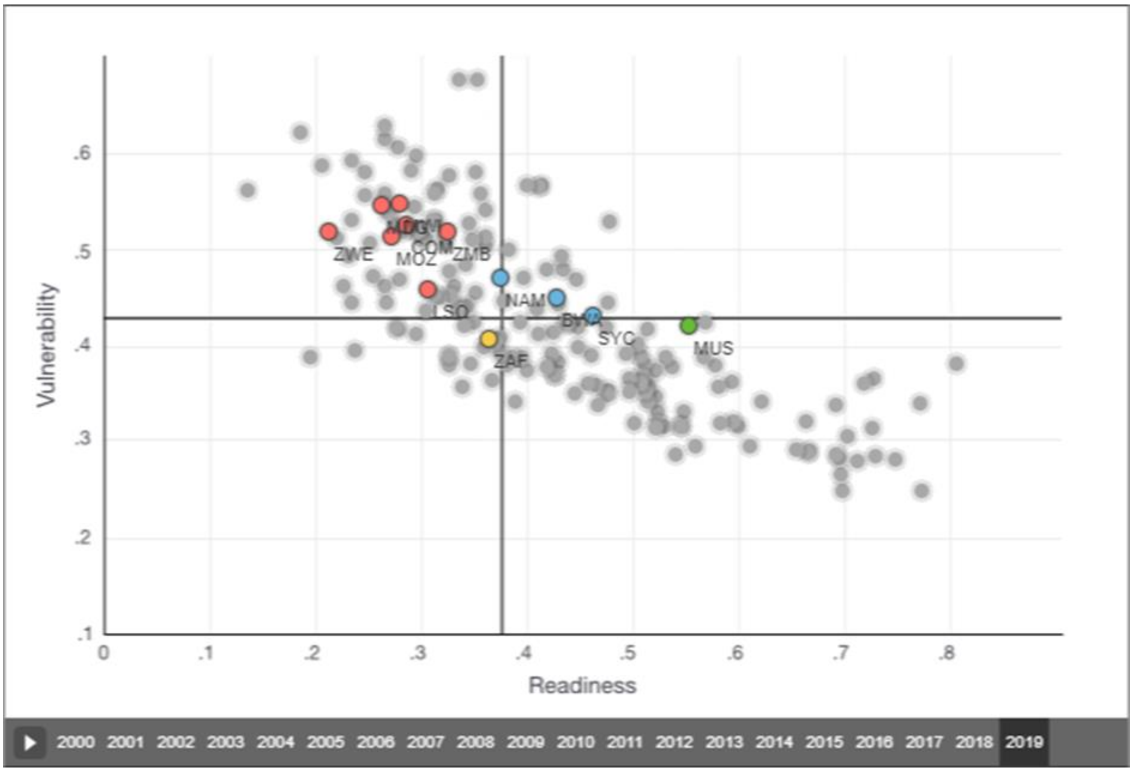

Figure B1: ND-GAIN country scores for the Southern Africa region. Red denotes high vulnerability & low readiness (Zambia ZMB, Malawi MW, Mozambique MOZ, Zimbabwe ZWE, Madagascar MDG, Comoros COM, Lesotho LSO). Yellow denotes low vulnerability & low readiness (South Africa ZAF). Blue denotes high vulnerability & high readiness (Namibia NAM, Botswana BWA, Seychelles SYC). Green denotes low vulnerability & high readiness (Mauritius MUS). Score not available for Eswatini. Source: https://gain.nd.edu/.

C: Drivers of variability

What is weather? The weather varies from day to day and season to season, with the statistics of these variations constituting the climate. These statistics are typically defined over a 30-year period. Climate change can then be characterised as the difference in these statistics between two 30-year climate periods. This will include the annual climate range through the year, from one period to another, as well as changes in the frequency, intensity and duration of extreme events, such as heavy rainfall and high temperatures.

Climate varies naturally over shorter periods of several years, and this natural variability can accentuate or dampen longer-term climate change signals. Both average conditions and the variability around that average can change and can result in increase in events that in the past were rare or extreme. It can also lead to situations where climate change increases the frequency of both heavy rainfall events and the occurrence of very dry conditions (IPCC, 2021).

The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, drier, cooler and wetter periods in relation to the climatological mean. This happens because the local weather is influenced by larger scale processes in the climate, known as climate drivers, which influence regional and local climate over different timescales.

The El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are two main drivers of climate variability in Southern Africa. These refer to oscillations of sea surface temperatures and leads to variations in associated atmosphere and ocean circulations. In Southern Africa, El Niño (the cold phase of ENSO) is linked with an increase in temperatures and below-average rainfall leading to a tendency towards an increase in the number of dry spells and severe seasonal drought (Meque & Abiodun, 2015). La Niña is linked with above-average rainfall in Southern Africa (Nicholson, 2017). The warm phase of the IOD leads to increases in temperature on inter-annual timescales in Southern Africa and wetter conditions in Madagascar (IPCC, 2021).

In addition to the mean trends, year-to-year variability in precipitation amounts and timings will continue in the future as the larger-scale influences on climate continue to remain active. In climate model projections, extreme ENSO events become more frequent and ENSO rainfall variability also increases (Cai et al., 2014). This could result in an increase in wetter and drier years relative to the mean despite a lack of clear signal in average precipitation. However, observed trends over the past 50-100 years do not necessarily support these climate model projections of ENSO changes so future changes in tropical rainfall variability remain uncertain.

Table C1: Summary of the drivers of rainfall and temperature variability in Southern Africa and the influence they have on seasonal climate. Definitions of the drivers of variability are provided in the glossary in the Appendix.

Drivers of variability	Influence on seasonal climate	Regional relevance
El Niño Southern Oscillation (ENSO)	An El Niño event is linked with an increase in temperatures and below-average rainfall, leading to a tendency towards increased frequency of dry spells and severe seasonal droughts (Meque & Abiodun, 2015). A La Niña event is linked with above-average rainfall. (Nicholson, 2017). ENSO events are also the most important global drivers of marine heatwave variability (IPCC, 2019).	Across region
Indian Ocean Dipole (IOD)	The positive phase of the IOD, which is closely related to and often coincides with ENSO phases (Stueker et al. 2017) leads to increases in temperature on inter-annual timescales. In Madagascar a positive phase is linked to wetter conditions (IPCC, 2021).	West Southern Africa, Madagascar
Subtropical Indian Ocean Dipole (SIOD)	The positive phase of the SIOD is closely related to and often coincides with ENSO phases (Stueker et al. 2017), leading to increases in temperature on inter-annual timescales. The SIOD also affects the likelihood of heavy rainfall events in eastern parts of southern Africa during summer months (Reason, 2001). When the SIOD and ENSO are in opposite phases, rainfall reductions are less than those driven by ENSO alone. In contrast, when the SIOD is positive alongside an El Niño phase, the overall impact on rainfall reduction is minimised (Hoell et al. 2017).	Across region for temperature, and impacts heavy rainfall in East Southern Africa
Indian Ocean Basin Mode (IOB)	The positive phase of the IOB leads to increased temperatures and drier conditions on inter-annual timescales (IPCC, 2021).	Across region
Pacific Decadal Variability (PDV) and the Atlantic Multidecadal Variability (AMV)	The positive phases of the PDV and AMV result in increased temperatures and drier conditions on annual timescales (IPCC, 2021).	Across region
Southern Annular Mode (SAM)	The SAM is linked to variability in winter rainfall over interannual and interdecadal scales over the Western Cape of South Africa due to its influence on the subtropical jet and extra tropical cyclones that pass through the region (Reason & Rouault, 2005).	Western Cape, South Africa
Agulhas and Benguela ocean currents	The currents influence local climate and exert a greater control on southern African rainfall during summer when ENSO is not in a strong positive (EL Nino) or negative (La Niña) phase, as well as at times when the SIOD and ENSO phases are aligned (Hoell et al. 2017).	Across region
South-West Indian Ocean tropical cyclone season	The south-eastern coast, in particular Mozambique, and Madagascar are exposed to tropical cyclones during the South-West Indian Ocean tropical cyclone season, which brings heavy winds and strong rains (IPCC, 2021).	Mozambique, Madagascar, Comoros, Mauritius Seychelles

D: Climate analysis in the zones

Selection of spatial analysis zones

To assess the magnitude and direction of projected climate trends at a sub-regional scale it is useful to spatially aggregate gridded climate data over climatologically similar regions. As the Southern Africa region represents a large, climatologically diverse area, it is also important to reflect this. Averaging the climate data by country borders is often not useful, as these do not reflect the climate and some countries may experience a range of climate types. Therefore, the region is divided into nine spatial analysis zones that reflect the different climate types.

The zones were selected using the Köppen-Geiger climate classifications (Figure D1), the baseline climatology (Figures 4-6), projected trends (IPCC, 2021), and also information about elevation, population density and livelihoods (Figure 2), and the Natural Earth[9] country borders (v4.1.0). The nine zones used for the spatial analysis are shown in Figure D2. The zones are specifically aligned to the IPCC AR6 WG I sub-continental analysis boxes (Figure A4): Zones 1-3 relate to the Western Southern Africa (WSAF) box, Zones 4-7 relate to the Eastern Southern Africa (ESAF) box and Zone 8 related to the Madagascar (MDG) box, as shown in Figure D4 (Iturbide et al. 2021). Table D1 relates the countries to the spatial analysis zones for reference.

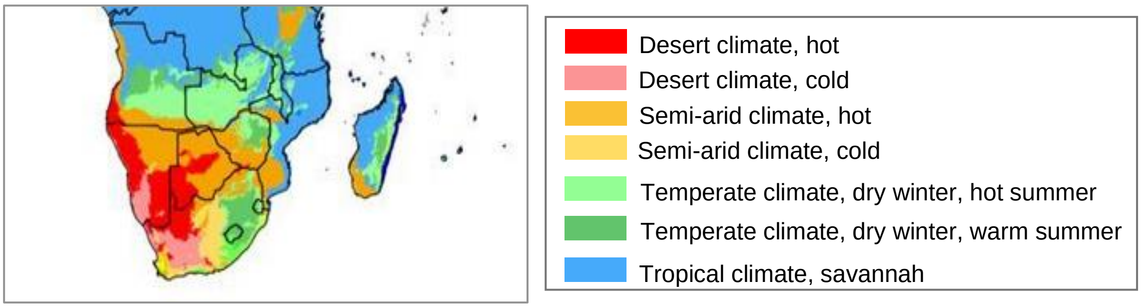

Figure D1: Köppen-Geiger climate classification map for the Southern Africa region, adapted from Beck et al. (2018).

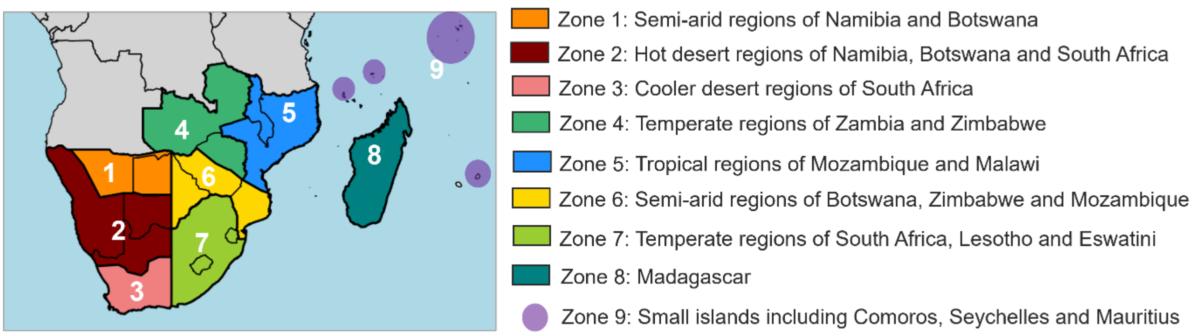

Figure D2: The nine spatial analysis zones across the Southern Africa region.

[9] https://www.naturalearthdata.com/

Figure D3: IPCC AR6 reference regions, as defined by WGI. Source: IPCC AR6 Regional factsheet – Africa[10].

Table D1: Countries in the Southern Africa region and the relevant spatial analysis zones.

Country	Climate analysis zones that cover the country
Botswana	Zones 1, 2 and 6
Comoros	Zone 9
Eswatini	Zone 7
Lesotho	Zone 7
Madagascar	Zone 8
Malawi	Zone 5
Mauritius	Zone 9
Mozambique	Zones 5 and 6
Namibia	Zones 1 and 2
Seychelles	Zone 9
South Africa	Zones 3 and 7
Zambia	Zone 4
Zimbabwe	Zones 4 and 6

The bespoke climate data analysis conducted in the spatial analysis zones (Figure A3) focuses only on characterising the baseline climate of each zone and assessing the projected trends in annual and seasonal mean temperature and precipitation for the 2050s relative to the baseline period (1981-2010; see Appendix A for detail on the data and methods).

10 https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf

Results from the zonal analysis

Maps of the baseline climatology with the zones overlaid are shown in Figure D4. Other outputs from the bespoke zonal data analysis are presented in the following zone-specific sections. This includes time series plots for the baseline climate and scatter plots of the future climate model projections for the 2050s under RCP8.5 (see Appendix A for detail on the data and methods).

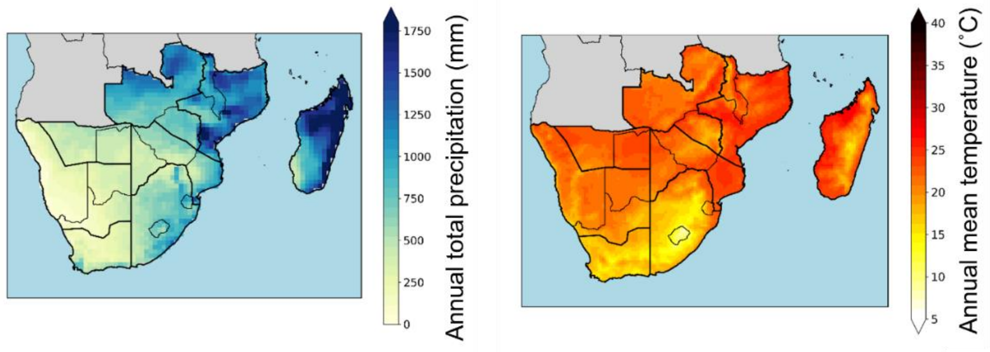

Figure D4: Baseline climate for the Southern Africa region for the period 1981-2010 with the spatial analysis zones overlaid. Maps show climatological average values of annual mean total precipitation (mm/year; left panel) and annual mean temperature (°C; right panel). Temperature and precipitation data come from the ERA5 and WFDE5 reanalysis datasets respectively.

The climate in context assessment at the zone scale includes this bespoke zonal data analysis, supplemented by regional findings from IPCC (2021) and the IPCC Interactive Atlas (as presented in the main report), and the socio-economic and geographic context to identify relevant impacts in each of the zones. Summaries of this assessment are provided in Tables D1-D9 in the following sections. Note that Zone 9 only draws on relevant literature as the islands are too small to be resolved by global and most regional climate models.

Zone 1: Semi-arid regions of Namibia and Botswana

Zone 1 includes north-eastern Namibia and north-western Botswana (Figure D5) which experience a semi-arid climate.

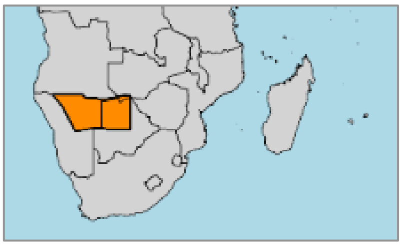

Figure D5: Zone 1.

Plots of the baseline climate are shown in Figures D4 and D6. Scatter plots of the future projections are shown in Figure D7. The climate in context assessment for Zone 1 is summarised in Table D2.

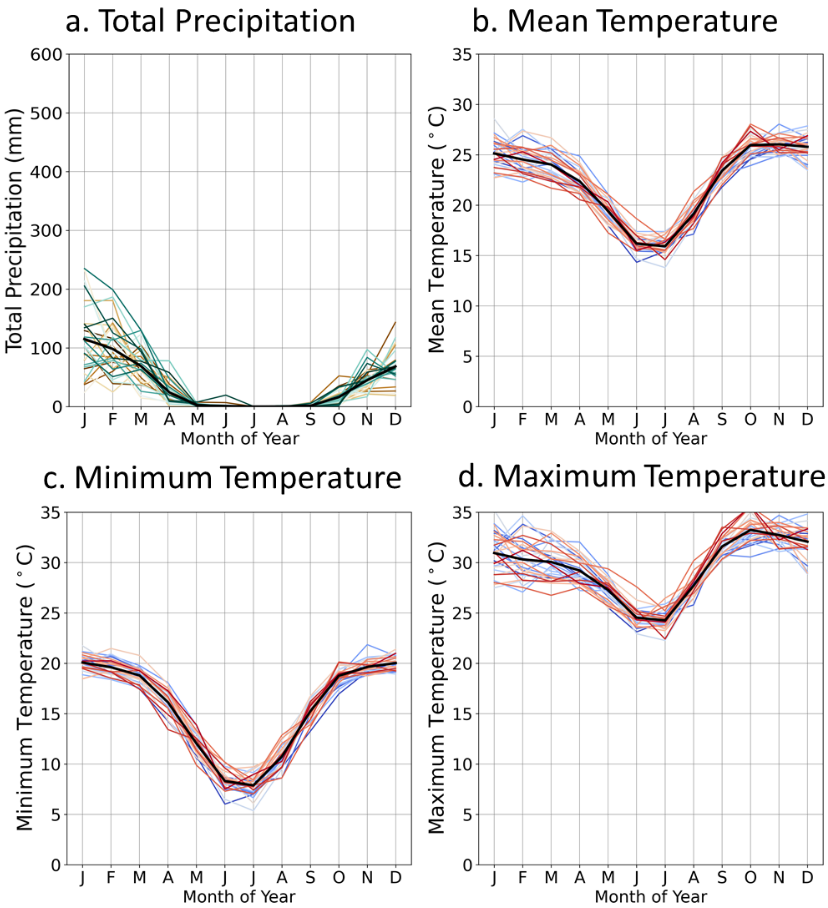

Figure D6: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 1. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

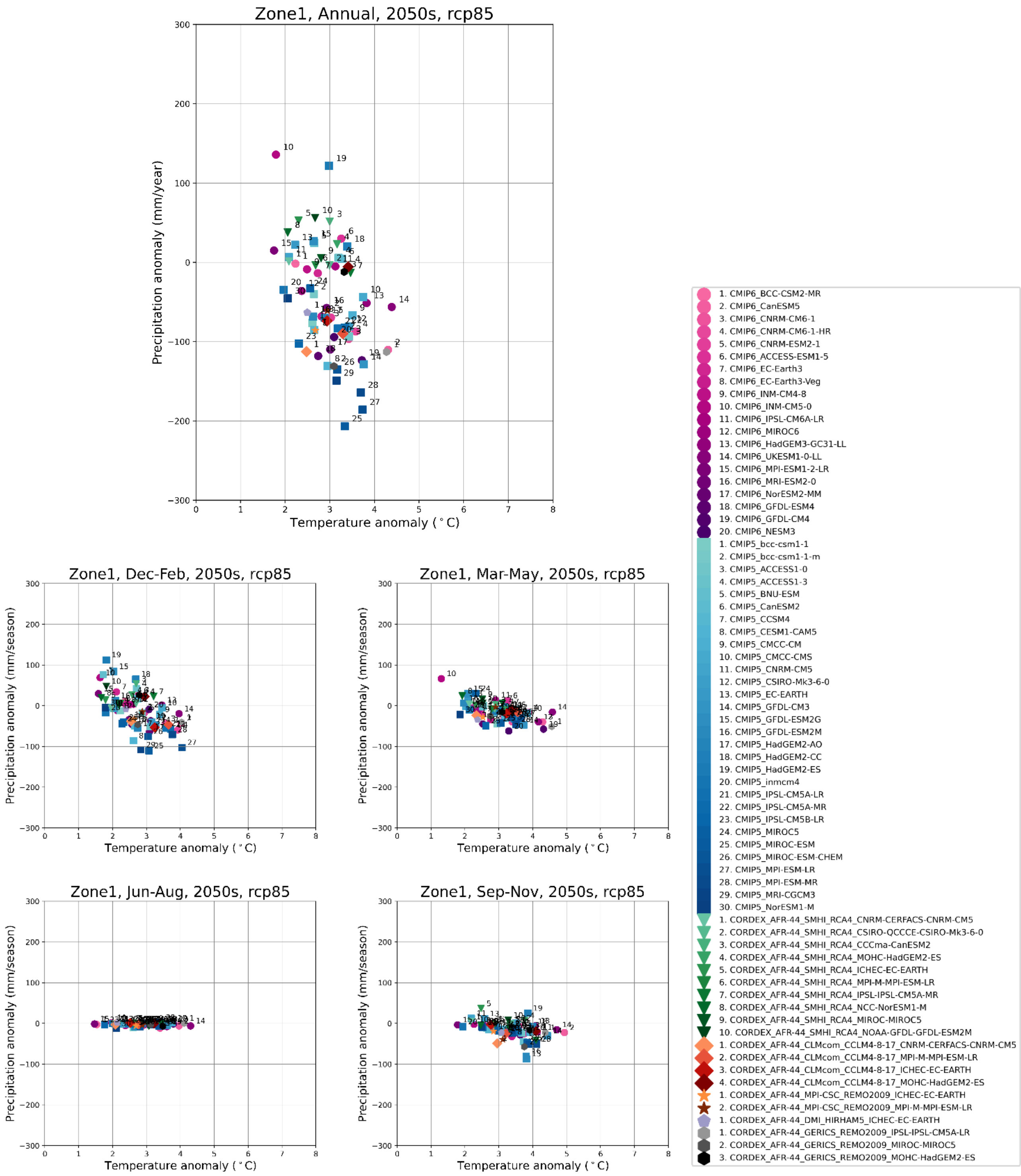

Figure D7: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 1. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D2: Climate in context analysis for Zone 1		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 15˚C (during June – July) - 25˚C (during October – January). Daily maximums exceed 35˚C (40˚C) for 5-45 (0-1) days per year across the zone. • Zone 1 receives ~500mm of precipitation between October and April with a dry season from May - September. • Zone 1 has experienced a warming trend and there is some evidence of a wetting trend in recent decades.
	Context	• Zone 1 includes the Etosha Pan salt flats in Etosha National Park, and the Okavango River and Wetlands. • Agropastoral livelihoods dominate in the north and pastoral livelihoods dominate in the south. • Key climate sensitivities include the impact of heat stress, water availability and the increased risk of wildfires for livestock rearing, crop production and human health.
Future projections (2050s)	**In the 2050s Zone 1 is projected to be hotter and drier on average**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 2˚C and up to 4˚C under a very high emissions scenario (1.1-3.1˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-40 (0-10) days per year across the zone under high emissions. • Medium confidence for Zone 1 to become drier on average which, combined with increasing temperatures and increasing year-to-year rainfall variability, increases the likelihood of longer and more frequent droughts. • Heavy rainfall events are projected to become more intense.
	Relevant impacts	• Increases in heat stress adversely affect crop and livestock production and human health due to higher temperatures and reduced rainfall. • Increases in water stress in the Okavango basin due to the drying trend and increased rainfall variability. • Increased flood risk in wetlands, river basins and urban environments due to increases in rainfall intensity. In Namibia, more frequent floods could increase the risk of water borne diseases such as cholera, typhoid and leptospirosis. • Increases in the period during which diarrhoea bacterial pathogens can survive due to increases in temperature. • Impacts on water quality and availability, including chemical and physical properties of wetland ecosystems, such as in northern Namibia and the Okavango delta, due to increases in temperature and changing rainfall patterns, in turn impacting the productivity of fish, invertebrates and algae. • Increased health impacts associated with poor air quality following forest and savanna fire and biodiversity impacts due to increases in fire weather and risk of dust storms. • Changes in the species mix in grassland and savanna woodlands which will impact the organisms which rely on these habitats. • Increases in heat stress and extreme hot days will threaten the ecotourism industry at National Parks.

Zone 2: Hot desert regions of Namibia, Botswana and South Africa

Zone 2 includes north-western and southern Namibia, south-western Botswana and northern South Africa (Figure D8) which experiences a hot desert climate.

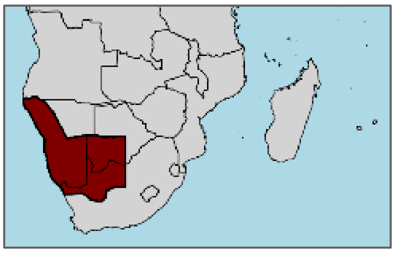

Figure D8: Zone 2.

Plots of the baseline climate are shown in Figures D4 and D9. Scatter plots of the future projections are shown in Figure D10. The climate in context assessment for Zone 2 is summarised in Table D3.

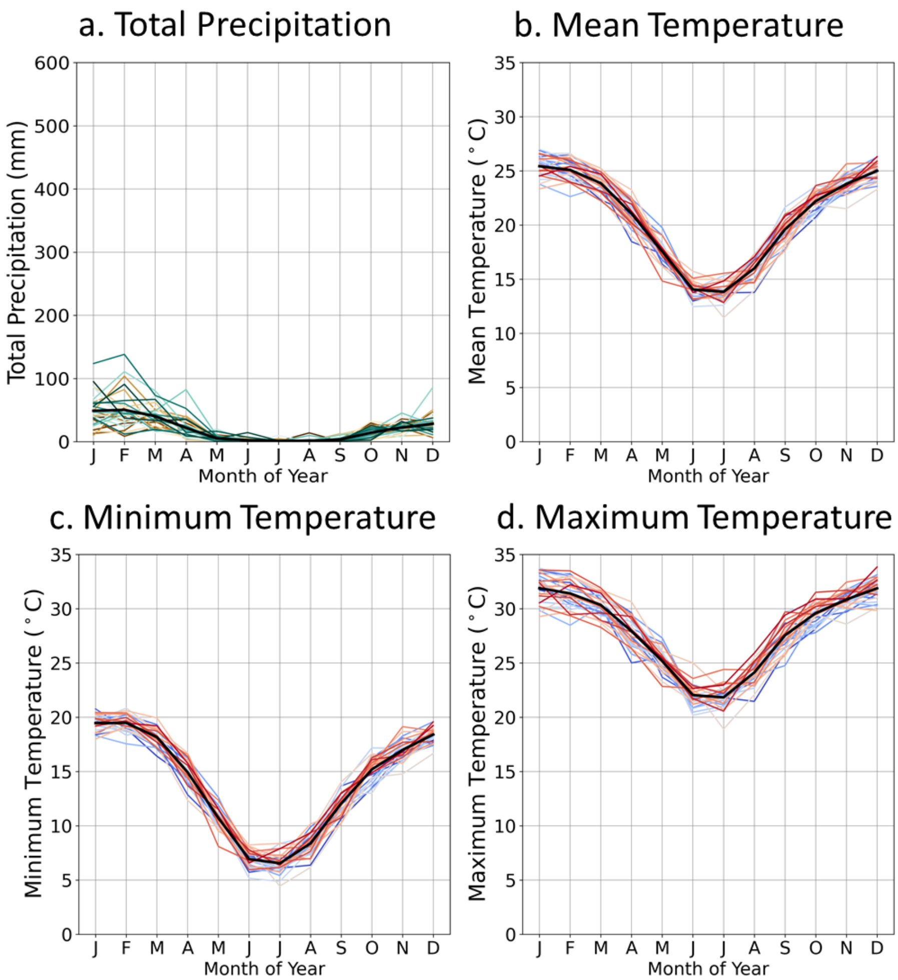

Figure D9: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 2. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

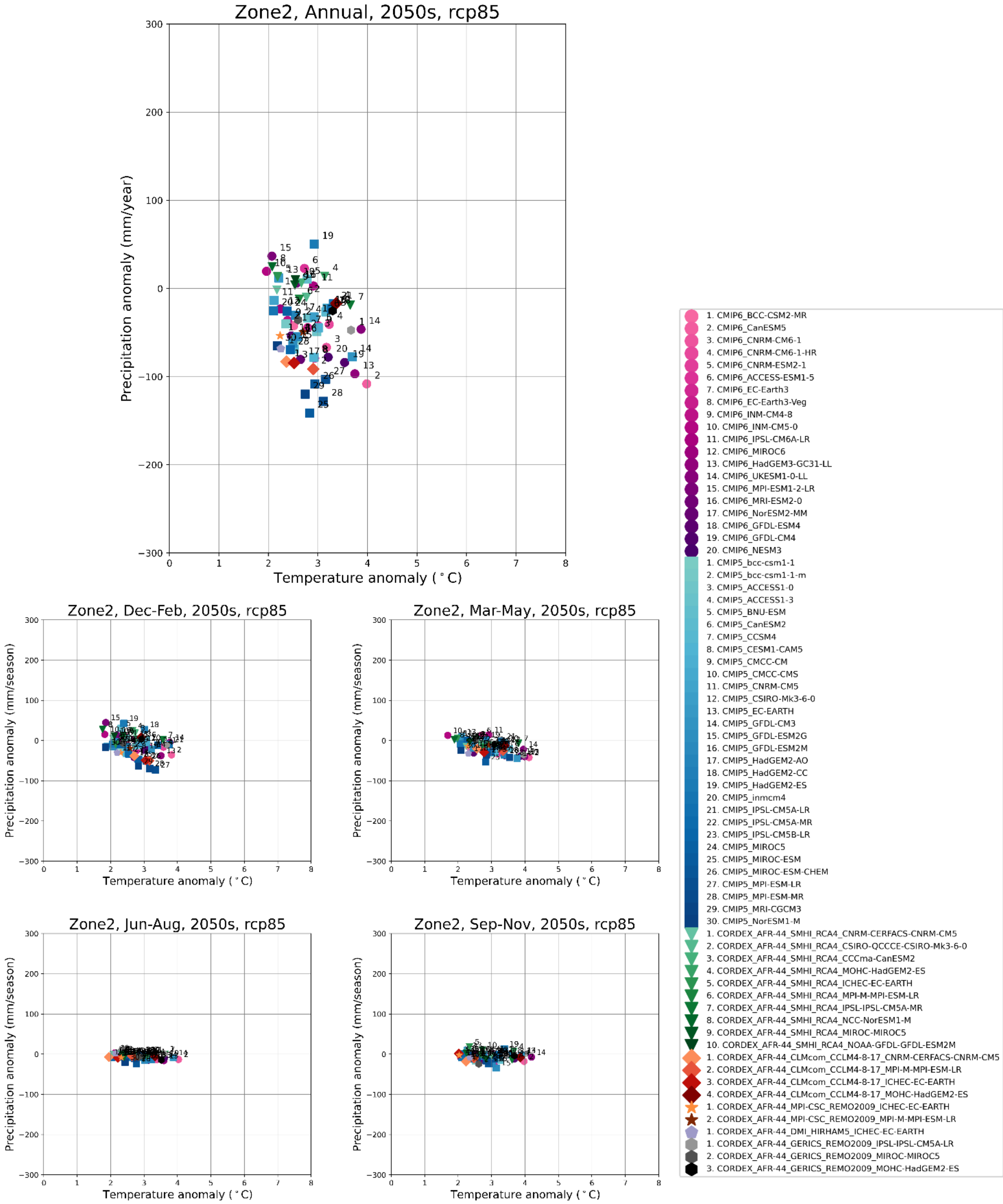

Figure D10: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 2. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D3: Climate in context analysis for Zone 2		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 15˚C (during June - July) - 25˚C (during December – February). Daily maximums exceed 35˚C (40°C) for 0-95 (0-3) days per year across the zone. • Zone 2 is the driest zone across the Southern Africa region. It receives very little precipitation throughout the year with the highest amounts of ~50mm per month during January and February. • Zone 2 has experienced a warming trend and some evidence of a wetting trend.
Baseline (1981-2010)	Context	• Zone 2 includes the western coastline with the South Atlantic Ocean, the Namib Desert, and the Orange and Okavango River basins. The upwelling Benguela System makes waters off Namibia among the most productive fisheries in the world. • Pastoral livelihoods dominate with some regions of arid pastoral and oasis livelihoods in the Namib Desert in the west of the zone. Fishing livelihoods dominate along the western coast. • Key climate sensitivities in include the impact of heat stress and water availability for livestock rearing and human health, and coastal impacts affecting marine fisheries and coastal infrastructure.
Future projections (2050s)	**In the 2050s Zone 2 is projected to be hotter and drier on average**	
Future projections (2050s)	Climate trends	• High confidence for an increase in annual mean temperature of at least 2 ˚C up to 4˚C under a very high emissions scenario (1.1-3.1˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-40 (0-10) days per year across the zone under high emissions. • High confidence for Zone 2 to become drier on average which, combined with increasing temperatures, increases the likelihood of longer and more frequent droughts. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more frequent and intense. • Sea levels are projected to rise, and sea surface temperatures are projected to increase.
Future projections (2050s)	Relevant impacts	• Increases in heat stress will adversely affect livestock production and human health due to higher temperatures and reduced rainfall • Increases in water stress in the Okavango and Orange River basins due to the drying trend and increased rainfall variability. • Flood risk in river basins and urban environments may increase due to increases in the intensity of heavy rainfall events • Increased risk of water and vector borne diseases, particularly within densely populated areas due to increases in temperature and intensity of heavy rainfall events. • Increased risk of dust storms and related health impacts due to increases in temperature that leads to greater drying and evaporation. • Adverse effects on marine ecosystems and fish stocks, particularly hake and monkfish, due to increases in marine heatwaves and ocean acidification

Zone 3: Cooler desert/semi-arid regions of South Africa

Zone 3 includes the south-western part of South Africa (Figure D11) that experiences a combination of cold desert and semi-arid climate types.

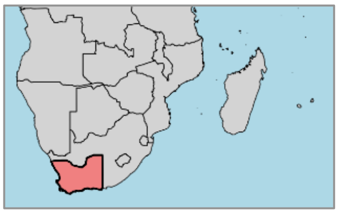

Figure D11: Zone 3.

Plots of the baseline climate are shown in Figures D4 and D12. Scatter plots of the future projections are shown in Figure D13. The climate in context assessment for Zone 3 is summarised in Table D4.

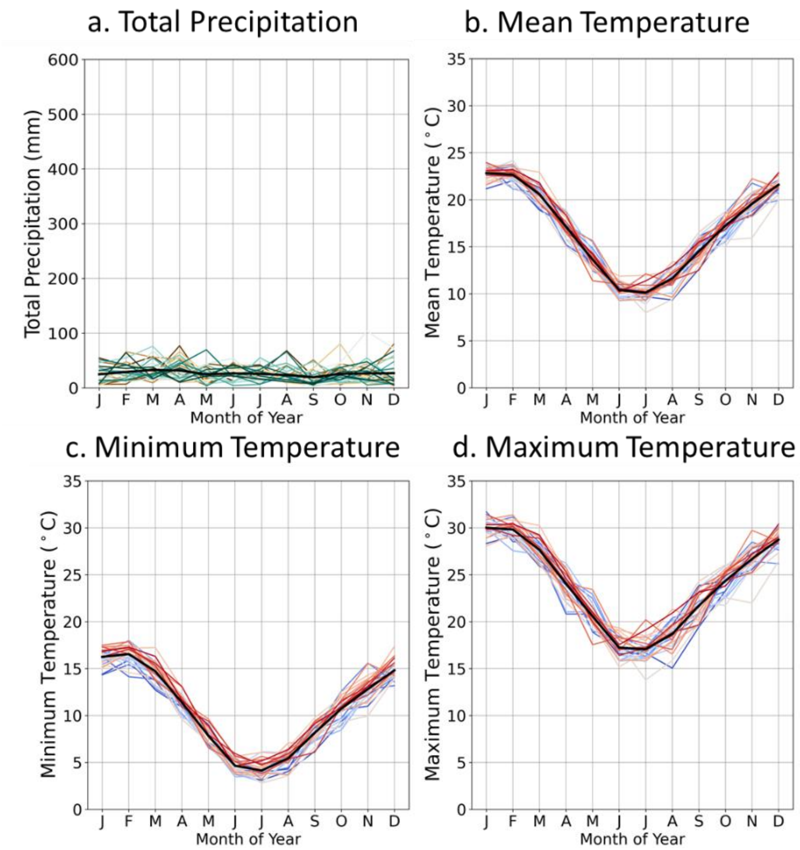

Figure D12: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 3. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

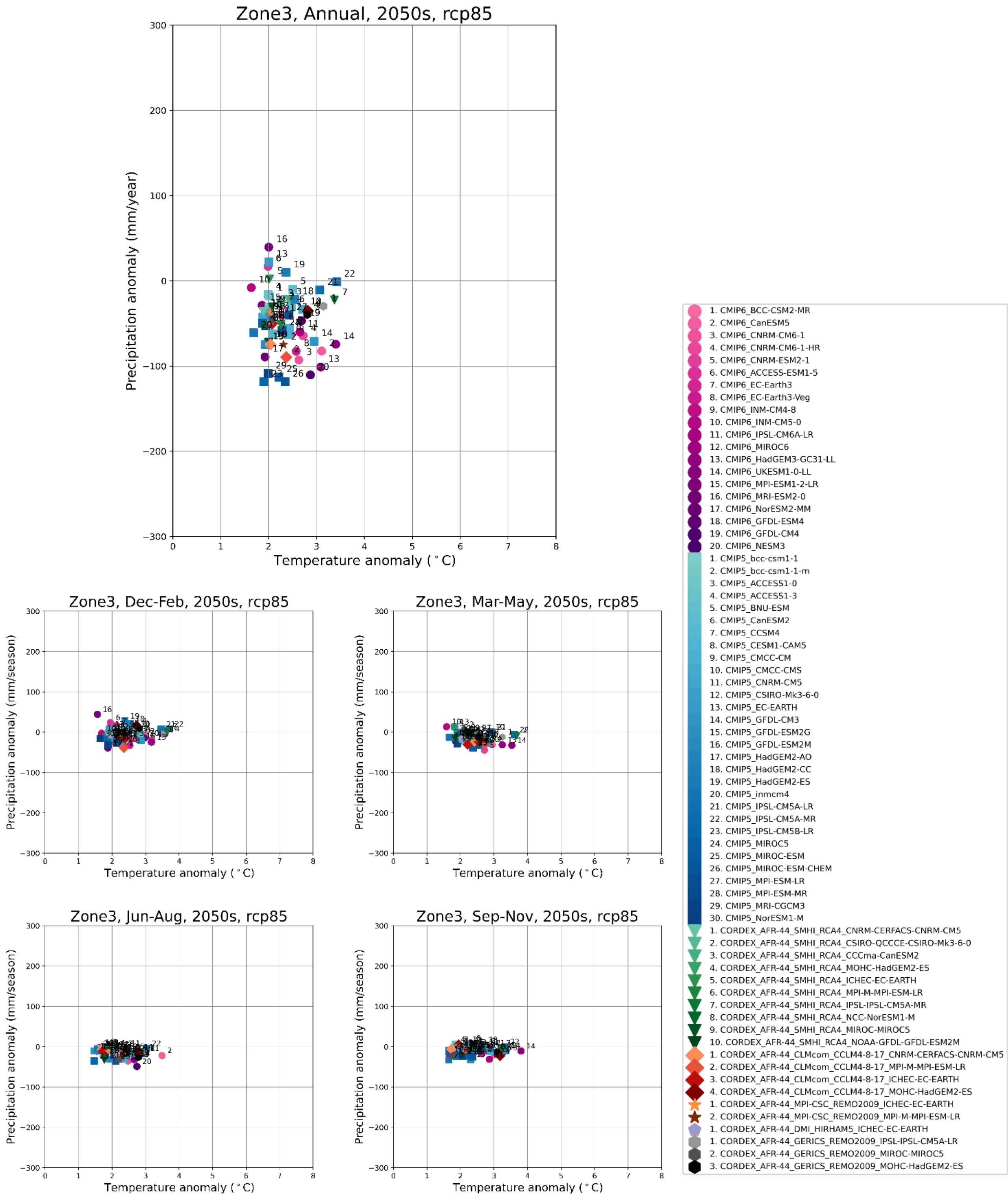

Figure D13: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 3. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D4: Climate in context analysis for Zone 3		
Baseline (1981-2010)	Current climate	• Zone 3 includes the south-western part of South Africa that experiences a combination of cold desert and semi-arid climate types. • Daily mean temperatures typically range from 10˚C (during June – July) - 23˚C (during January – February). Daily maximums exceed 35˚C (40°C) for 0-60 (0-3) days per year across the zone. • Zone 3 is wetter than other zones in Western Southern Africa, receiving ~500mm of precipitation between October and April. • Zone 3 has experienced a warming trend, with no clear evidence of a wetting or drying trend.
	Context	• Zone 3 includes the coastline to the south and west with the South Atlantic Ocean including the Agulhas Bank, the Cederberg mountains and the Orange River. • Pastoral livelihoods dominate in the north and perennial mixed livelihoods dominate in the south. Fishing livelihoods dominate along the western coast. • Key climate sensitivities include the impact of increasing heat and water stress on crop and livestock production and increasing ocean temperatures and acidity on the health and observed migration of fish stocks. South Africa is already under 'medium' water stress, withdrawing nearly 2/3 of its renewable water supplies annually.
Future projections (2050s)	**In the 2050s Zone 3 is projected to be hotter and drier on average**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 1.5 up to 3.5˚C under a very high emissions scenario (0.6-2.6˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 0-40 (0-5) days per year across the zone. • High confidence for Zone 3 to become drier on average which, combined with increasing temperatures, increases the likelihood of longer and more frequent droughts. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more intense but may reduce in frequency. • Sea levels are projected to rise, and sea surface temperatures are projected to increase.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop and livestock production and human health. • Increases in water stress in the Orange River basin due to the drying trend, increased rainfall variability and reduced groundwater recharge, will affect rural and urban water supplies, sanitation and irrigation. Large urban cities (e.g. Cape Town) will be impacted by reduced water availability. • Decreasing freshwater quality due to increasing temperatures and variable stream flows. • Impacts on water availability and the properties of wetland ecosystems, impacting productivity of fish, invertebrates and algae due to increases in temperature and changing rainfall patterns. • Increased risk of the water and vector borne diseases, particularly within densely populated areas due to increases in temperature and intensity of heavy rainfall events. • Threats to heat and drought intolerant vegetation within the Afro Temperate forests due to higher temperatures and drier conditions. • Port facilities and offshore oil and gas extraction sites are threatened by sea level rise and storms. • Adverse impacts on mangroves, seagrasses and saltmarshes along South Africa's coast due to rising sea levels, marine heatwaves and ocean acidification. • Coastal and marine tourism may be impacted by coastal erosion and changes affecting charismatic species such as marine turtles and sharks.

Zone 4: Temperate regions of Zambia and Zimbabwe

Zone 4 includes Zambia and the higher elevation parts of Zimbabwe (Figure D14) that experience a temperate climate.

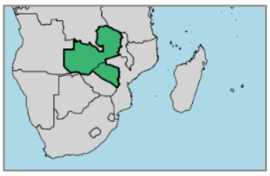

Figure D14: Zone 4.

Plots of the baseline climate are shown in Figures D4 and D15. Scatter plots of the future projections are shown in Figure D16. The climate in context assessment for Zone 4 is summarised in Table D5.

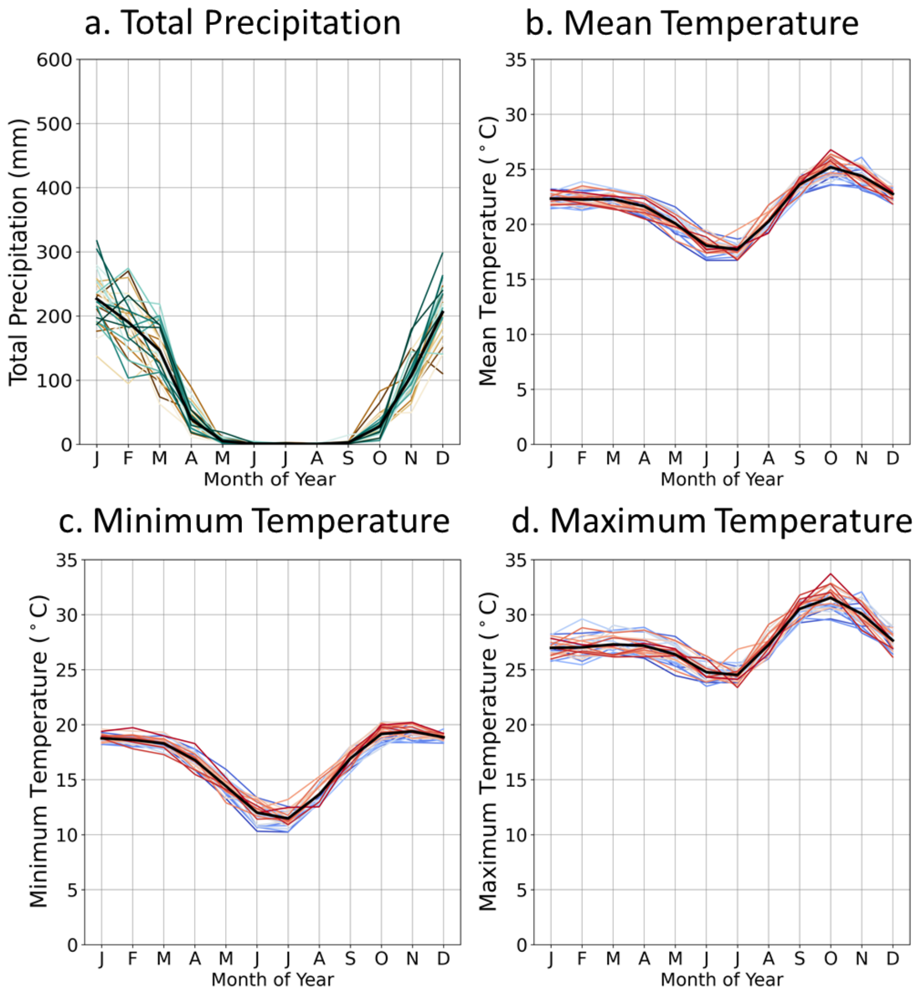

Figure D15: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 4. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

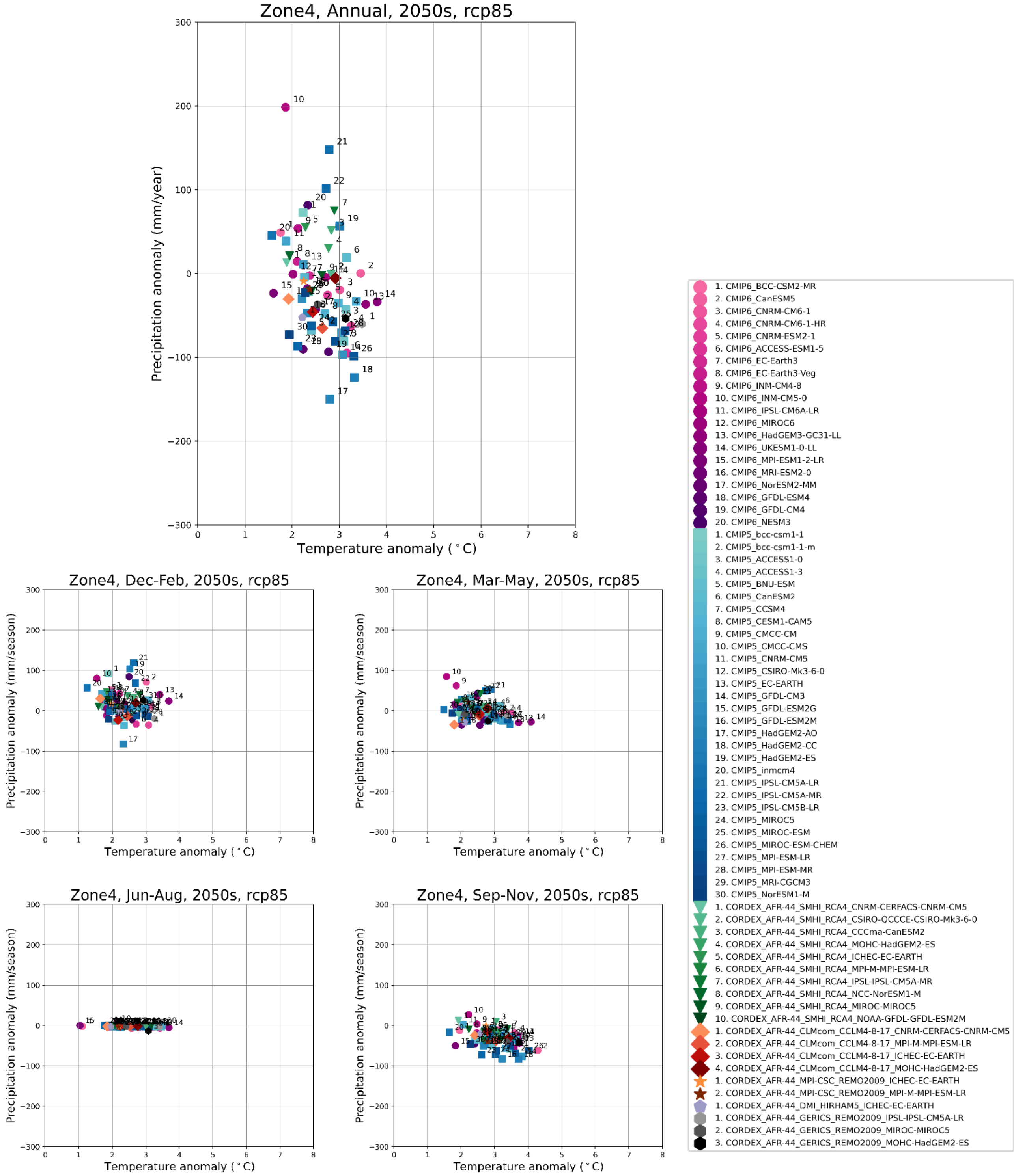

Figure D16: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 4. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D5: Climate in context analysis for Zone 4		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 17˚C (during June – July) - 25˚C (during October). Daily maximums exceed 35˚C (40°C) for 0-40 (0) days per year across the zone. • Zone 4 is one of the wettest across the Southern Africa region and experiences one rainy season (October – April) with 200-300mm per month during the peak months (December – February). The northern part of the zone experiences higher rainfall amounts than the south. • Zone 4 has experienced a warming trend and there is some evidence of a wetting trend in some parts of the zone in recent decades.
	Context	• Zone 4 includes the Zambezi and Congo River basins (zones 4 and 5), which include several hydropower generation sites and are central to Southern Africa's hydropower generation. Rainfall variability and droughts can cause widespread power outages across the region. • The dominant livelihoods are maize mixed with some agropastoral livelihoods in southern Zambia and some highland mixed livelihoods in eastern Zimbabwe. • Key climate sensitivities include the impact of increasing heat and water stress on crop and livestock production, exposure to Malaria, and rainfall variability affecting hydropower generation.
Future projections (2050s)	**In the 2050s Zone 4 is projected to be hotter with a drier start to the rainy season**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 1.5 ˚C up to 4˚C under a very high emissions scenario (0.7-3.2˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-35 (0-5) days per year across the zone. • There is no decisive trend for whether Zone 4 will become wetter or drier, although there is evidence for a small delay to the start of the rainy season. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more frequent and intense.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop production (particularly maize), livestock and human health. • Increases in water stress may occur due to increasing temperatures and rainfall variability affecting groundwater recharge, rural and urban water supplies and sanitation and agriculture. • Increasing risk of drought-related hydropower outages in the Zambezi basin. • A decline in the Kafue flats wetland system due to higher temperatures and greater rainfall variability. • Flood risk in urban environments may increases due to increases in rainfall intensity posing a risk to transport networks and access to essential services. Flood risk will also impact the availability of clean drinking water, particularly in informal settlements, such as those in Lusaka. • Forest environments, biodiversity and air quality will be affected by increases in fire weather conditions due to projected increases in mean windspeeds and higher temperatures. • Increased health impacts associated with poor air quality due to increases in fire weather. • A shift in the current boundaries of Malaria with a risk of expansion to new areas may occur due to changes in rainfall patterns and temperature.

Zone 5: Tropical regions of Malawi and Mozambique

Zone 5 includes Malawi and northern Mozambique (Figure D17) which experience a tropical climate and represents one of the hottest, wettest zones in the Southern Africa region.

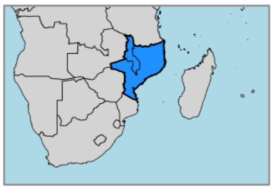

Figure D17: Zone 5.

Plots of the baseline climate are shown in Figures D4 and D18. Scatter plots of the future projections are shown in Figure D19. The climate in context assessment for Zone 5 is summarised in Table D6.

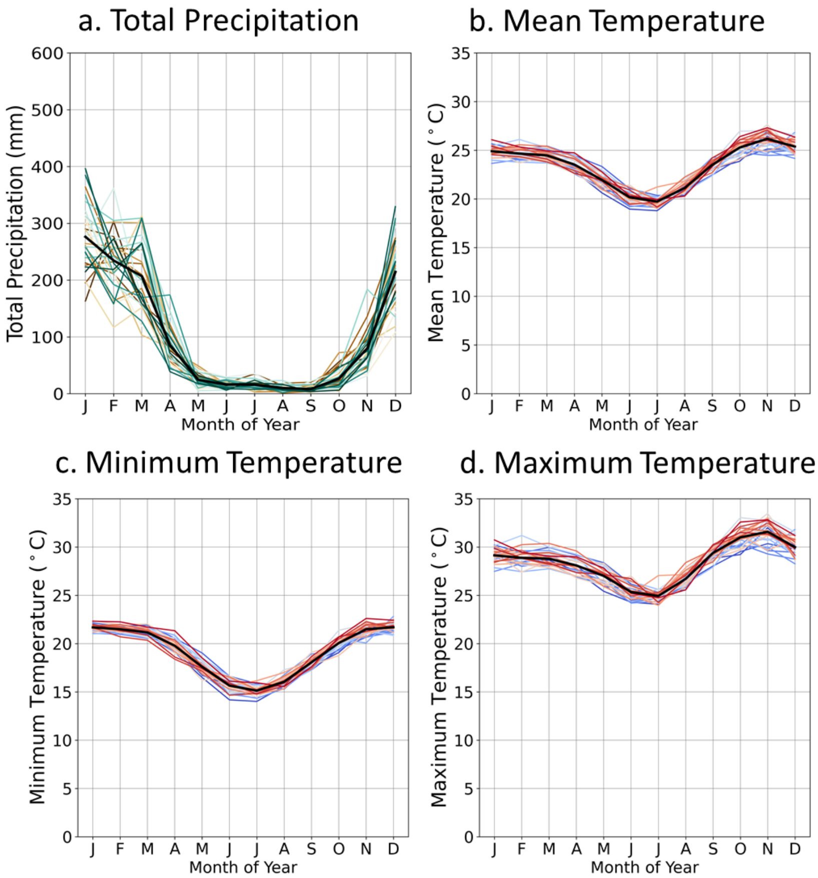

Figure D18: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 5. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

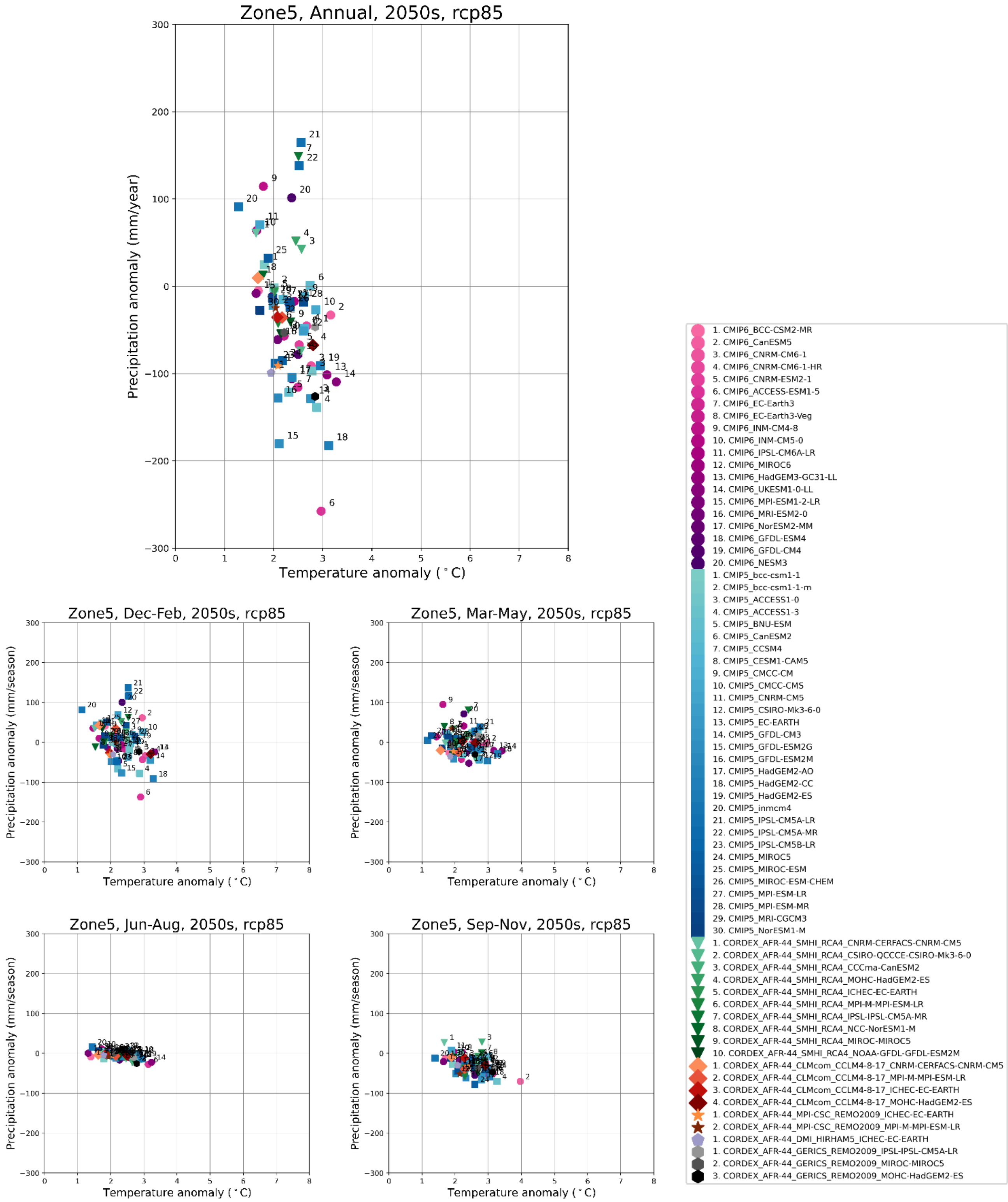

Figure D19: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 5. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D6: Climate in context analysis for Zone 5

Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 20˚C (during June – July) - 27˚C (during November). Daily maximums exceed 35˚C (40°C) for 5-40 (0-5) days per year across the zone. • Zone 5 experiences one rainy season (October – April) with 200-400mm per month during the peak months (December – March). • Zone 5 has experienced a warming trend and shows no clear evidence of a wetting or drying trend in recent decades.
	Context	• Zone 5 includes the eastern coastline on the Indian Ocean, the Zambezi River which is central to Southern Africa's hydropower generation, and several lakes. • The dominant livelihoods in Zone 5 are maize mixed with some agropastoral livelihoods in western Mozambique. Highly vulnerable fishing livelihoods dominate along the eastern coast. • Key climate sensitivities include maize production, rainfall variability impacting hydropower generation, marine biodiversity and already vulnerable coral reefs, exposure to Malaria, and offshore mining.
Future projections (2050s)	**In the 2050s Zone 5 is projected to be hotter with a drier start to the rainy season**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 1.5 ˚C up to 3.5˚C under a very high emissions scenario (0.7-2.7˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-35 (0-5) days per year across the zone. • There is no decisive trend for whether Zone 5 will become wetter or drier, although there is evidence for a small delay to the start of the rainy season. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more frequent and intense. • Sea levels are projected to rise, sea surface temperatures are projected to increase, and tropical cyclone wind speeds are projected to increase.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop production (particularly maize), livestock and human health. • Increases in water stress may occur due to changes in temperature, rainfall and groundwater recharge, affecting rural and urban water supplies, sanitation and agriculture. • Increasing risk of drought-related hydropower outages. • Flood risk in urban environments may increase due to increases in rainfall intensity, posing a risk to transport networks and access to essential services (particularly in Mozambique) and also impacting availability of clean drinking water and spread of disease in cities and in informal settlements. • A shift in the current boundaries of Malaria, risk of expansion to new areas and a change from seasonal to endemic presence in some locations may occur due to changes in rainfall patterns and temperature. • Increases in fire weather conditions due to projected increases in mean windspeeds and higher temperatures, will/may affect forest environments, biodiversity and air quality. • Adverse effects on freshwater fisheries due to increases in lake and river temperatures. • Adverse impacts on marine ecosystems, such as marine turtles, coral reefs, mangroves, and seagrasses due increases in marine heatwaves and ocean acidification. • Exposure of coastal populations and infrastructure to increased flood risk due to rising sea levels. • Mozambique's fishing sector and coastal infrastructure, including offshore oil and gas extraction may be adversely impacted by increases in tropical cyclone intensity.

Zone 6: Semi-arid regions of Botswana, Zimbabwe, Mozambique and South Africa

Zone 6 includes southern Zimbabwe, western Botswana and southern Mozambique (Figure D20) which experience a semi-arid climate.

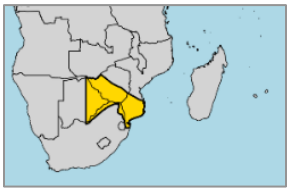

Figure D20: Zone 6.

Plots of the baseline climate are shown in Figures D4 and D21. Scatter plots of the future projections are shown in Figure D22. The climate in context assessment for Zone 6 is summarised in Table D7.

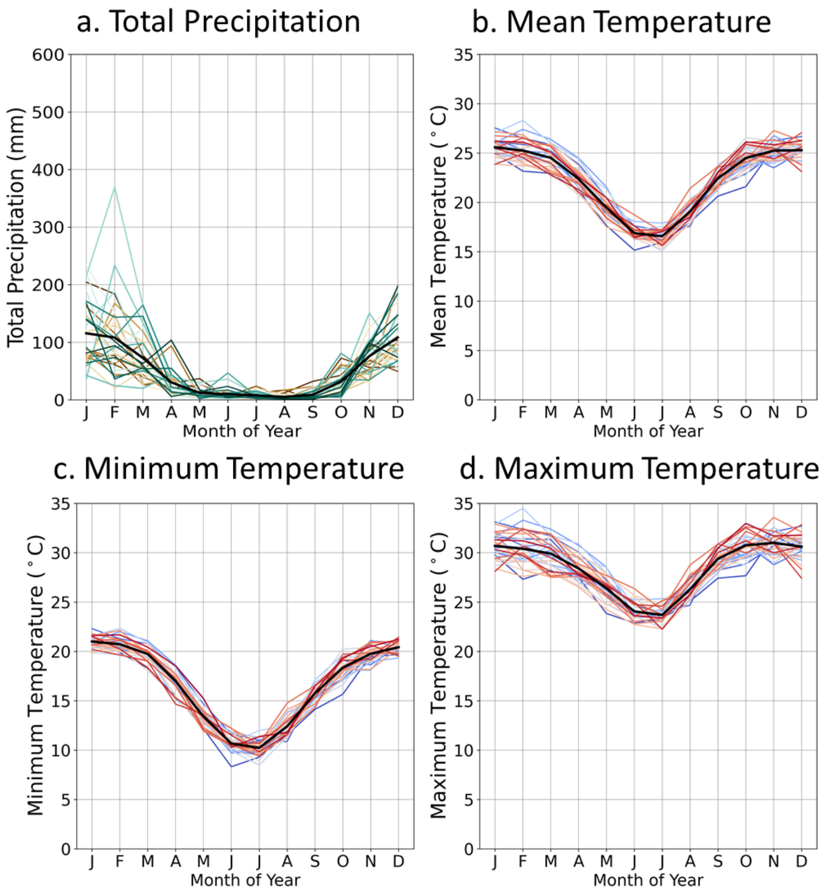

Figure D21: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 6. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

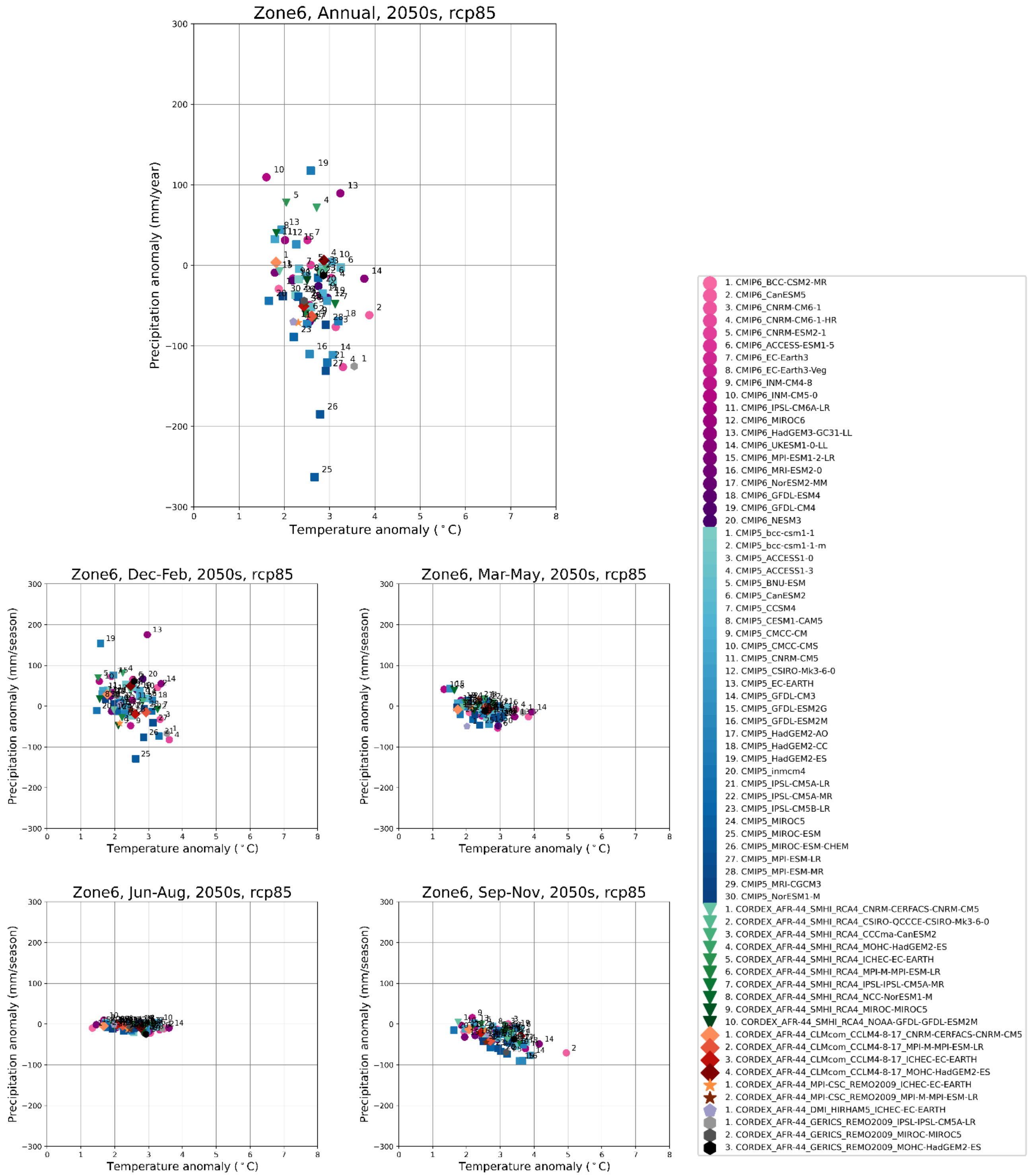

Figure D22: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 6. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

<table>
<tr><th colspan="3">Table D7: Climate in context analysis for Zone 6</th></tr>
<tr><td rowspan="2">Baseline (1981-2010)</td><td>Current</td><td>• Daily mean temperatures typically range from 17˚C (during June – July) - 26˚C (during December – February). Daily maximums exceed 35˚C (40°C) for 10-60 (0-8) days per year across the zone.
• Zone 6 experiences one rainy season (October – April) with around 100mm per month during the peak months (December – February).
• Zone 6 has experienced a warming trend, with no clear evidence of a wetting or drying trend.</td></tr>
<tr><td>Context</td><td>• Zone 6 includes the eastern coastline with the Indian Ocean and the Limpopo River.
• Pastoral livelihoods dominate in the north and perennial mixed livelihoods dominate in the south. Fishing livelihoods dominate along the eastern coast.
• Key climate sensitivities include poor access to clean water, exposure to Malaria, vulnerable coral reefs, eco-tourism, and the impact of drought on hydropower.</td></tr>
<tr><td rowspan="3">Future projections (2050s)</td><td colspan="2">In the 2050s Zone 6 is projected to be hotter with a drier start to the rainy season</td></tr>
<tr><td>Climate trends</td><td>• High confidence for an increase in annual mean temperature of at least 1.5˚C up to 4˚C under a very high emissions scenario (0.7-3.2˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-35 (0-5) days per year across the zone.
• There is no decisive trend for whether Zone 6 will become wetter or drier, although there is evidence for a small delay to the start of the rainy season. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more frequent and intense.
• Sea levels are projected to rise, sea surface temperatures are projected to increase, and tropical cyclone wind speeds are projected to increase.</td></tr>
<tr><td>Relevant impacts</td><td>• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop and livestock production and human health.
• Impacts on freshwater quality and availability due to increases in water stress in the Limpopo River Basin, associated with increasing temperatures and variable streamflows.
• Flood risk in urban environments and the incidence of communicable water-borne diseases may increase with increases in intensity of heavy rainfall events, particularly in informal settlements.
• A shift in the current boundaries of Malaria and risk of expansion to new areas may occur due to changes in rainfall patterns and temperature.
• Increased risk of dust storms and related health impacts due to increases in temperature leading to greater drying and evaporation.
• Forest environments, biodiversity and air quality may be affected by increases in fire weather conditions due to projected increases in mean windspeeds and higher temperatures.
• Threats to the ecotourism industry at National Parks due to increases in heat stress.
• Adverse impacts on marine ecosystems and fish stocks due to increases in marine heatwaves and ocean acidification.
• Mozambique’s fishing sector and coastal infrastructure, including offshore oil and gas extraction may be adversely impacted by increases in tropical cyclone intensity.</td></tr>
</table>

Zone 7: Temperate regions of South Africa, including Lesotho and Eswatini

Zone 7 includes eastern South Africa and the landlocked nations of Lesotho and Eswatini (Figure D23) which experience a temperate climate.

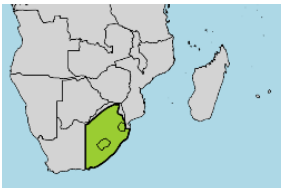

Figure D23: Zone 7.

Plots of the baseline climate are shown in Figures D4 and D24. Scatter plots of the future projections are shown in Figure D25. The climate in context assessment for Zone 7 is summarised in Table D8.

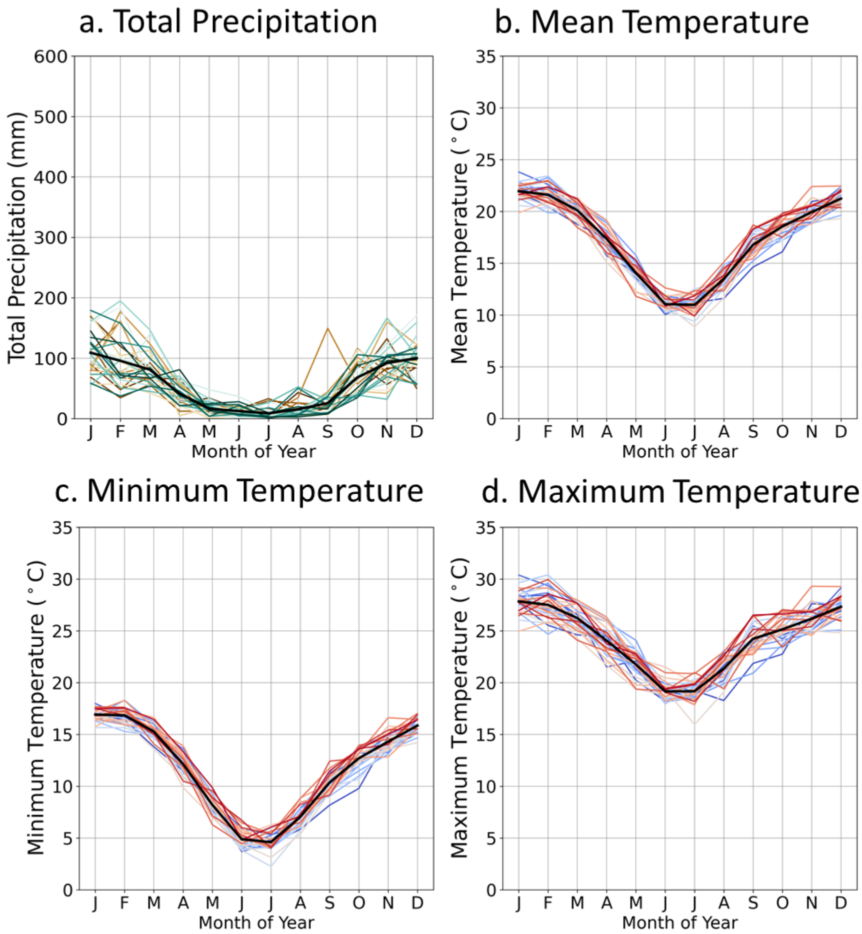

Figure D24: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 7. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

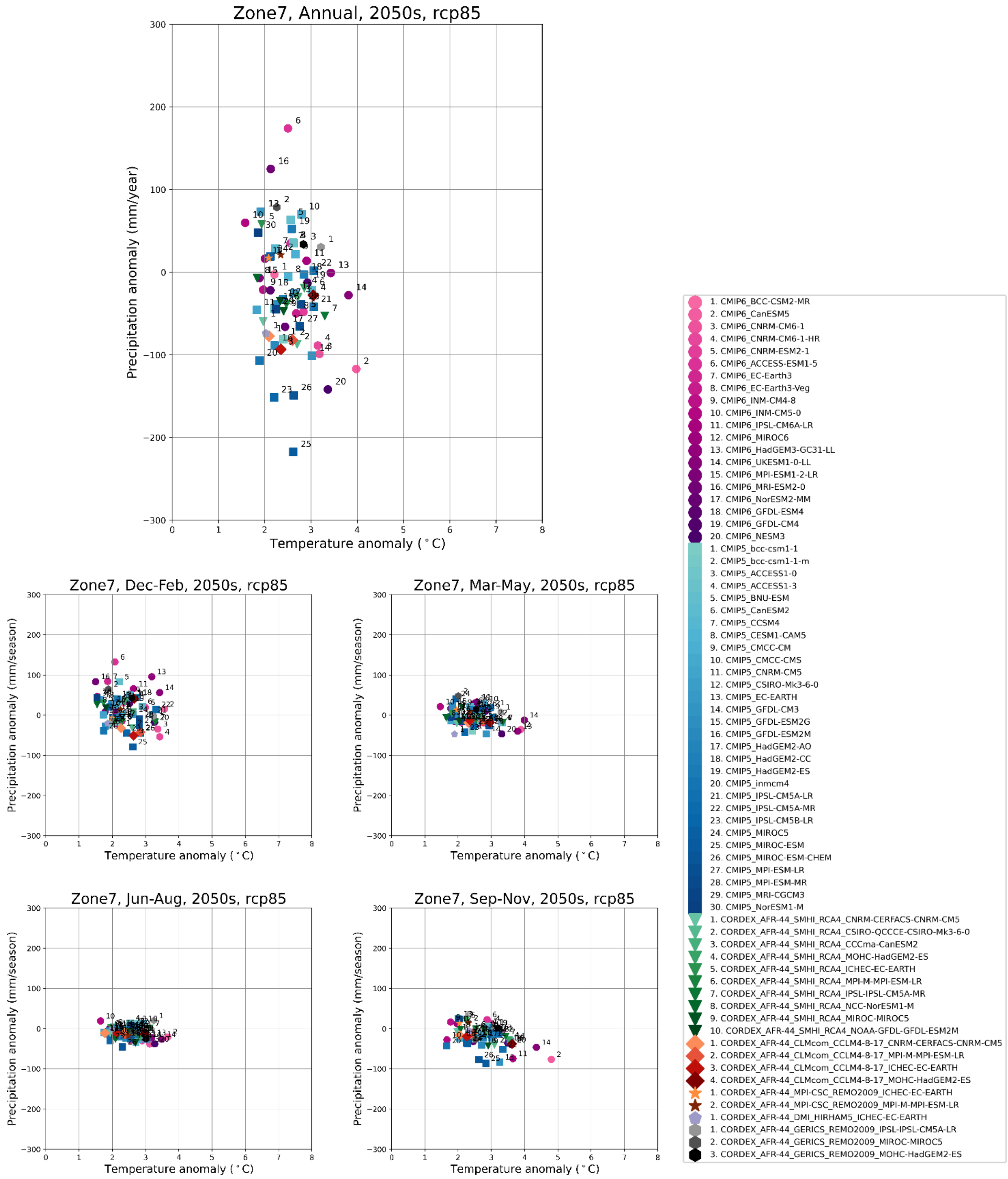

Figure D25: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 7. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D8: Climate in context analysis for Zone 7		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 10˚C (during June – July) - 22˚C (during January - February). Daily maximums exceed 35˚C (40°C) for 0-20 (0-4) days per year across the zone. • Zone 7 experiences one rainy season (October – April) with around 100mm per month during the peak months (December – February). • Zone 7 has experienced a warming trend and East Southern Africa has not had a significant trend in precipitation in recent decades on average.
	Context	• Zone 7 includes the south-eastern coastline with the Indian Ocean, Drakensberg and Magaliesberg mountains, the Orange and Limpopo river basins, several lakes and hydropower sites. • Pastoral livelihoods dominate in the north and perennial mixed livelihoods dominate in the south. Fishing livelihoods dominate along the eastern coast • Key climate sensitivities include vulnerability to changes in temperature and drought frequency, affecting drought- and heat-intolerant vegetation and hydropower. South Africa is already under 'medium' water stress, withdrawing nearly 2/3 of its renewable water supplies annually.
Future projections (2050s)	**In the 2050s Zone 7 is projected to be hotter with uncertain changes in rainfall**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 1.5˚C up to 4˚C under a very high emissions scenario (0.7-3.2˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C (40°C) is projected to increase by 15-35 (0-5) days per year across the zone. • There is no decisive trend for whether Zone 7 will become wetter or drier. Year-to-year variability in rainfall amounts is expected to increase and heavy rainfall events are projected to become more frequent and intense. • Sea levels are projected to rise, and sea surface temperatures are projected to increase.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop and livestock production and human health. • Increases in water stress and may occur due to changes in temperature, rainfall and groundwater recharge, affecting rural and urban water supplies, water quality, sanitation and agriculture. • Increasing risk of drought-related hydropower outages. • Flood risk in urban environments and the incidence of communicable water-borne diseases may increase with increases in intensity of heavy rainfall events, particularly in informal settlements. • Forest environments, biodiversity and air quality may be affected by increases in fire weather conditions due to projected increases in mean windspeeds and higher temperatures. • Heat and drought intolerant vegetation within the Afro Temperate forests will be threatened by higher temperatures and greater rainfall variability. • Port facilities and offshore oil and gas extraction sites threatened by sea level rise and cyclones. • Adverse impacts on mangroves, seagrasses and saltmarshes along South Africa's coast due to rising sea levels, marine heatwaves and ocean acidification. • Coastal and marine tourism may be impacted by coastal erosion and changes affecting charismatic species such as marine turtles and sharks. • Adverse effects on freshwater fisheries due to increases in lake and river temperatures.

Zone 8: Madagascar

Zone 8 includes the island of Madagascar (Figure D26), the majority of which experiences a tropical climate type, with some temperate climate on the east side of the island where there is higher elevation, and some semi-arid climate in the south.

Figure D26: Zone 8.

Plots of the baseline climate are shown in Figures D4 and D26. Scatter plots of the future projections are shown in Figure D27. The climate in context assessment for Zone 8 is summarised in Table D9.

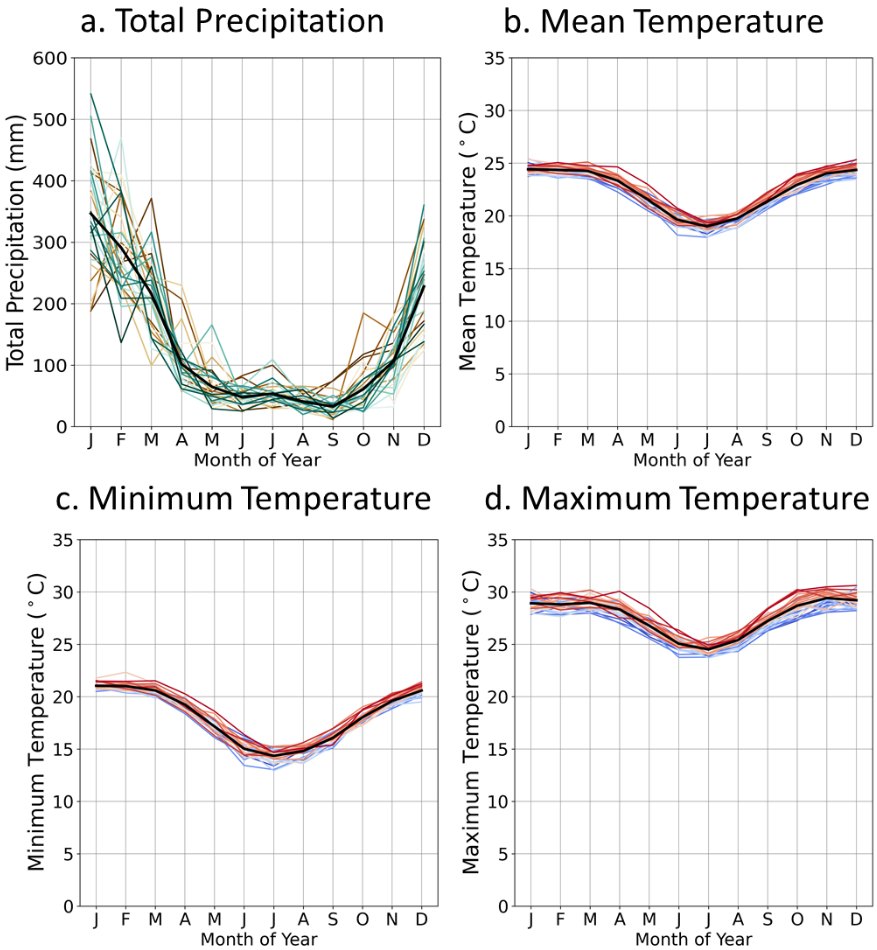

Figure D26: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 8. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

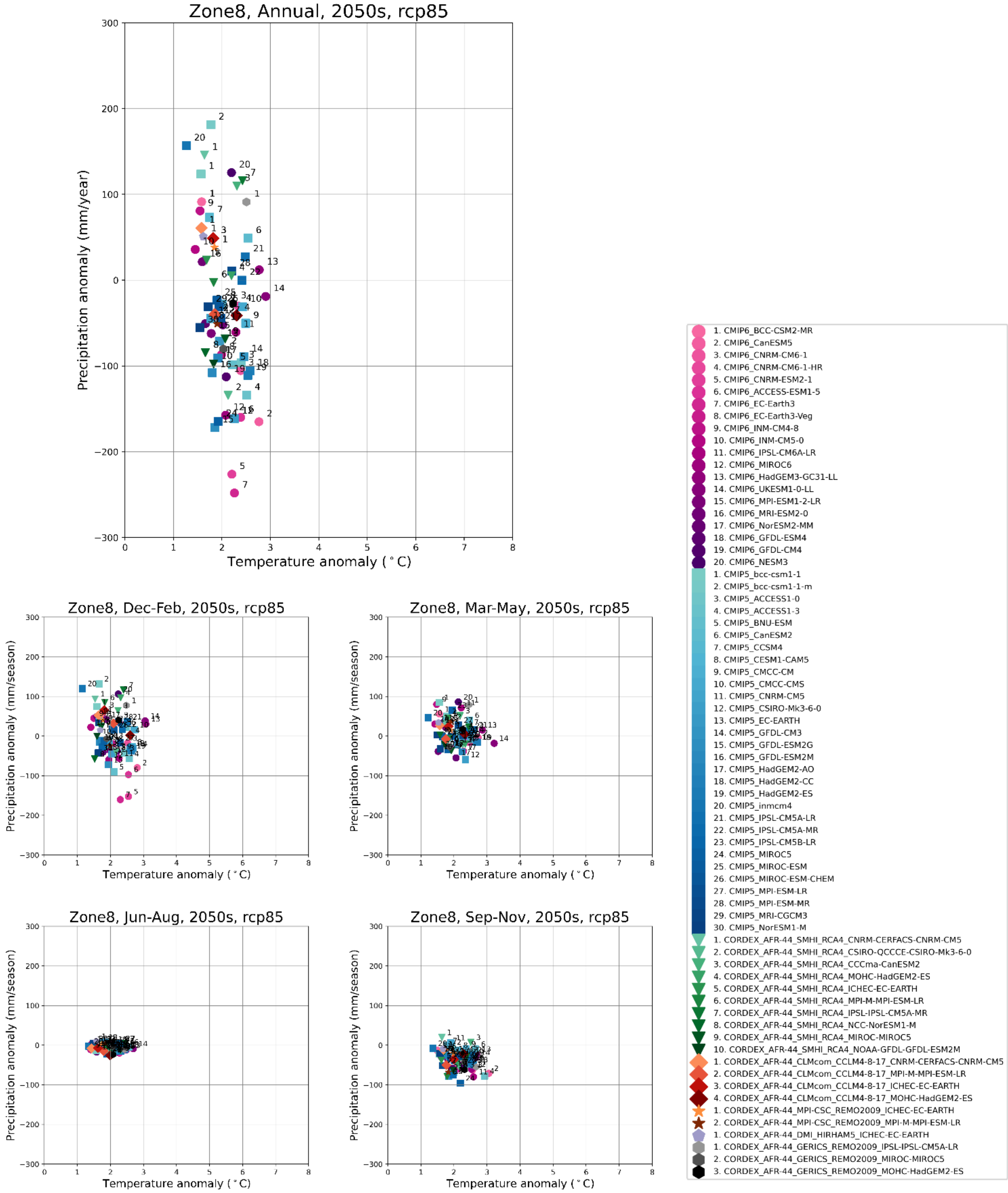

Figure D27: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 8. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table D9: Climate in context analysis for Zone 8		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 20˚C (during June – August) - 25˚C (December - March). Daily maximums exceed 35˚C for 0-10 days per year across the zone. • Zone 8 has the highest rainfall across the Southern Africa zones, receiving rainfall throughout the year with the larger amounts October – March and around 400mm per month during the peak (January). • Zone 8 has experienced a warming trend, drying in the east and wetting in the west.
	Context	• Zone 8 includes various plateaus, lakes and rivers and the Indian Ocean coastline. • Agropastoral livelihoods dominate in the west and there are some areas in the east where maize mixed, and tree crop livelihoods dominate. Fishing livelihoods dominate along the western coast. • Key climate sensitivities include the flooding of coastal cities, poor access to clean water, exposure to Malaria and decline of already critically endangered coral reefs.
Future projections (2050s	**In the 2050s Zone 8 is projected to be hotter with uncertain changes in rainfall**	
	Climate trends	• High confidence for an increase in annual mean temperature of at least 1.5˚C up to 3˚C under a very high emissions scenario (0.8-2.3˚C under a low emissions scenario) and associated increases in evaporation. Daily minimum and maximum temperatures will also increase and the number of days exceeding 35°C is projected to increase by 3-6 days per year across the zone. • There is no decisive trend for whether Zone 8 will become wetter or drier, although there is evidence for a decrease in seasonal rainfall at the start of the rainy season. Year-to-year variability in rainfall amounts is also expected to increase and heavy rainfall events are projected to become more frequent and intense. • Sea levels are projected to rise, sea surface temperatures are projected to increase and tropical cyclone wind speeds and associated heavy rainfall are projected to increase.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop and livestock production and human health. • Increases in water stress due to changes in rainfall and ground water recharge, affecting irrigation, rural water supplies, sanitation and agriculture. • Forest environments, biodiversity and air quality may be affected by increases in fire weather conditions due to projected increases in mean windspeeds and higher temperatures. • Adverse impacts on marine ecosystems and fish stocks, particularly marine turtles, coral reefs, mangroves and seagrasses due to increases in marine heatwaves and ocean acidification. • Adverse impacts on Madagascar's fishing sector and coastal infrastructure due to increases in tropical cyclone intensity. • Exposure of the coastal population and infrastructure to increased flood risk due to rising sea levels.

Zone 9: Small islands

The climate in context assessment for Zone 9 is summarised in Table D10. Note that current and future climate information for the small islands comes from the World Bank Climate Change Knowledge Portal and the IPCC (2021).

Table D10: Climate in context analysis for Zone 9

Baseline (1981-2010)	**Current climate**	• The small islands of Comoros, Seychelles, and Mauritius lie to the east of the main continent of Africa and have a tropical maritime climate, strongly influenced by the Indian Ocean. • There is a low seasonal variation in temperature, with less than 5°C difference on average between the hottest and coolest months. Between November and May, the islands are affected by tropical cyclones and associated hazards of high winds, storm surges and extreme rainfall. Many islands are low-lying and are exposed to regular flooding from natural high-tide and wave activity. • ***Comoros***: Daily mean temperatures are around 27°C with little variation throughout the year. The rainy season is between November-April, with more rainfall in western regions. • ***Seychelles***: Daily mean temperatures vary between 25°C in July, and 28°C in April. Rainfall is strongly influenced by local topography, with more rain falling over higher ground. The wettest month is January, and the driest month is July. • ***Mauritius***: Daily mean temperatures are on average 25°C during summer and 21°C during winter, with local variations between the coastal areas and the higher central plateau. The rainy season is from December - April. • The small islands in Zone 9 have experienced a warming trend.
	Context	• The islands are generally low elevation, with the exception of Mauritius consisting of a coastal plain rising to a higher plateau with some mountain peaks up to 1000m. • Key climate sensitivities include the vulnerable coral reefs (many reefs in zone 9 are rated as Critically Endangered) and other marine ecosystems which are nationally important sources of food security, employment and revenue via tourism and exports.
Future projections (2050s)	**In the 2050s Zone 9 is projected to be hotter and drier on average**	
	Climate trends	• High confidence for an increase in annual mean temperature of 1°C–2°C under a very high emissions scenario and associated increases in evaporation. Daily minimum and maximum temperatures will also increase. • Although the annual trend varies by location, most islands in the Western Indian Ocean will become drier, with less rainfall over parts of the Indian Ocean, particularly from June to August. • Sea levels are projected to rise, sea surface temperatures are projected to increase and tropical cyclone wind speeds and associated heavy rainfall are projected to increase, although there is uncertainty about future storm track and landfall locations.
	Relevant impacts	• Increases in heat stress resulting from higher temperatures and reduced rainfall will adversely affect crop and livestock production and human health. • Adverse impacts on coastal infrastructure and tourism due to rising sea levels and intensity of tropical cyclones, causing increases in coastal flooding, storm surges and coastal erosion. • Adverse impacts on marine ecosystems and fish stocks, particularly marine turtles, coral reefs, mangroves and seagrasses due to increases in marine heatwaves and ocean acidification. • Amplification of other existing human pressures on marine ecosystems such as overfishing, pollution, and habitat destruction.

E: Socio-economic Data

Table E1: Demographic, economic, climate readiness and poverty data

	Demographics						Economics				Climate Readiness, Poverty			
Country	**Total pop (M)**	**Pop growth/year (%)**	**Pop project 2050**	**Rural pop (%)**	**Urban slum (%)**	**Largest city (%)**	**GDP cap (US$)**	**GDP growth (%)**	**Agric (%)**	**Cereal import ratio (%)**	**NDGAIN and (rank)**	**NDGAIN vuln**	**Below US$1.90/day (%)**	**Food insec (%)**
Zambia	18.4	2.9	43.9	55	55	34	985	-2.8	3	-10	40.5 (137)	142	59	51
Malawi	19.1	2.7	42.9	83	65	34	637	0.8	23	10	36.7 (162)	160	74	82
Mozambique	31.2	2.9	74.4	63	77	14	449	-1.2	26	54	38.1 (154)	139	64	71
Zimbabwe	14.8	1.5	23.2	68	34	32	1215	-6.2	8	38	34.9 (171)	143	40	70
Botswana	2.4	2.1	4.5	29	ND	ND	6405	-8.5	2	84	49 (87)	112	14.5	51
Namibia	2.5	1.8	4.3	48	42	33	4180	-8.5	9	69	45.4 (107)	122	14	58
Eswatini	1.2	1.0	1.6	76	32	ND	3424	-1.9	8	67	ND	ND	29	64
Lesotho	2.1	0.8	2.7	71	54	ND	875	-9.6	6	75	42.5 (124)	116	27	50
South Africa	59.3	1.3	87.6	33	26	15	5656	-6.4	2.5	15	48 (95)	83	19	45

Madagascar	27.7	2.6	60.4	61	61	32	472	-7.1	25	20	36 (165)	159	81	ND
Seychelles	0.098	0.9	0.1	43	ND	ND	10,800	-10.8	2	100	51.7 (71)	93	0.5	15
Mauritius	1.3	0	1.3	59	ND	ND	8628	-14.9	3	95	56.7 (50)	93	0.2	24
Comoros	0.8	2.2	1.6	71	68	ND	1421	-0.1	37	81	38.1 (153)	149	19	ND
Reg %	_	*1.7*	_	*54*	_	_	_	*-6*	_	_	_	_	*48*	_
Reg % excl UMI	_	*2.1*	_	*66*	*61*	_	_	*-4*	_	_	_	_	*65*	_
Total number	*181*	_	*349*	_	_	_	_	_	_	_	_	_	_	_

Data sources and notes:

<u>Demographics</u>
Total population, rural population, population growth rate, largest city: World Development Indicators, 2020 data (accessed May 2022).
Slum population: World Development Indicators, 2018 data (accessed May 2022). Note: represents proportion of urban pop living in slum households, defined as households lacking >1 basic conditions (improved water & sanitation, sufficient living area, housing durability, secure tenure). Original data from UN-HABITAT.
Pop projection to 2050: authors' own calculation applying growth rate to initial 2020 population and compounding to 2050.
<u>Economics</u>
GDP/capita, growth and agric as a % GDP: World Development Indicators, 2020 data (accessed May 2022). Note: countries shaded red defined as low income (<USD1045), orange lower-middle income (USD1046 – USD 4095) and yellow upper-middle income (USD 4096 – USD 12,695 by World Bank, 2023 fiscal year update.
Cereal import dependency ratio %: FAO/WFP estimate 2017-21 five-year average (FAOSTAT accessed May 2022). Note: provides a measure of dependence on cereal imports; the bigger the number, the higher the dependence (cereals include wheat, rice, and coarse grains - maize, barley, sorghum, millet, rye and oats).
<u>Climate readiness, poverty</u>
ND GAIN score & rank: Notre Dame Global Adaptation Initiative, Index of 182 countries using a score indicating a country's vulnerability to climate change and other env pressures plus readiness to improve resilience. Data from July 2021 update accessed May 2022. See https://gain.nd.edu/
Food insecure % population: Prevalence of moderate or severe food insecurity in the population, FAO estimates 2018-20 (3 yr average). FAOSTAT accessed May 2022. Note: Indicator 2.1.2 in SDG framework to monitor target 2.1: 'By 2030 end hunger and ensure access by all people…to safe, nutritious and sufficient food year-round'

% living below USD1.90/day poverty line (2011 PPP): World Development Indicators citing most recent World Bank survey data various years (accessed May 2020) or World Bank country data sheets. Data for Zambia (2015); Malawi (2019); Mozambique (2014); Zimbabwe (2019); Botswana (2015); Namibia (2015); Eswatini (2016); Lesotho (2017); South Africa (2014); Madagascar (2020); Seychelles (2017); Mauritius (2017); Comoros (2014). Note: poverty headcount ratio at current <USD1.90 threshold of extreme poverty defined by World Bank.

Regional (Reg) total and %

Excl UMI: excluding upper-middle income countries, i.e. low and lower-middle income countries only (see Economics above for definitions). Note: % calculations account for different country populations.

Table E2: Water resources, water withdrawals, access to basic services and hydropower data

	Water resources, withdrawals									Access to basic services: water, sanitation, electricity						Hydro
Country	**Water/cap (m^3)**	**Int water/ cap (m^3)**	**Dep ratio (%)**	**Water stress (%)**	**Water wit/cap (m^3)**	**Irrig area (%)**	**Agric with (%)**	**Indust with (%)**	**Munic with (%)**	**Basic water all (%)**	**Basic water rural (%)**	**Basic san all (%)**	**Basic san rural (%)**	**Elec all (%)**	**Elec rural (%)**	**Hydro (%)**
Zambia	6040	4622	23.5	2.8	91	4	73	8	18	65	48	32	25	45	14	85
Malawi	952	890	6.5	17.5	75	2.4	86	4	11	70	67	27	25	15	7	70
Mozambique	7360	3400	53.8	0.9	50	2	73	2	25	63	49	37	23	31	5	80
Zimbabwe	1385	849	38.7	35.4	261	4	81	2	17	63	48	35	32	53	37	65
Botswana	5430	1065	80.4	2.0	86	0.6	36	12	52	92	79	80	52	72	26	0
Namibia	16,301	2516	84.6	0.9	117	0.9	70	5	25	84	71	35	20	56	36	51
Eswatini	3969	2323	41.5	0.5	940	26	94	2	4	71	63	64	68	80	76	60
Lesotho	1433	2,481	0.0	2.6	516	0.6	9	46	46	72	64	50	52	47	35	95
S Africa	889	775	12.8	63.6	344	13	58	21	21	94	83	78	81	85	75	6
Madagascar	12,832	12,832	0.0	11.3	516	23	96	1	3	53	36	12	8	34	11	18
Seychelles	ND	ND	0.0	ND	141	17	7	28	66	97	97	100	100	100	100	0
Mauritius	2171	2171	0.0	21.5	470	20	51	2	47	99	99	96	95	100	100	4
Comoros	1442	1442	0.0	0.03	17	0.1	4	26	69	80	77	36	32	87	81	4
Reg %	_	_	_	_	_	_	_	_	_	*74*	*58*	*46*	*35*	*53*	*27*	_
Reg % excl UMI	_	_	_	_	_	_	_	_	_	*62*	*50*	*29*	*23*	*35*	*14*	_

Data sources and notes:

Water resources, withdrawals

Water avail/capita: total renewable water resources (internal & external sources) per capita, 2018 estimates (m^3/person/year) (FAO-AQUASTAT, accessed May 2022).

Int water/cap: total internal renewable water resources (excluding inflows from neighbouring countries) per capita, 2018 estimates (m^3/person/year) (FAO-AQUASTAT, accessed May 2022).

Dep ratio %: percentage of renewable water originating outside country, 2018 estimates (FAO-AQUASTAT, accessed May 2022.

Water stress %: SDG 6.4.2 water withdrawals as a percentage of renewable freshwater, 2018 estimates (FAO-AQUASTAT, accessed May 2022). Note: countries where this % falls in the 0-25% bracket classified as 'no stress' (blue); >25-50% 'low stress' (yellow), >50-75% 'medium stress' (orange) in the SDG 6.4.2 monitoring framework.

Water with/cap: total water withdrawals per capita, 2018 estimates (m^3/year/person) (FAO AQUASTAT, accessed May 2022).

Irrigated area %: percentage of arable land equipped for irrigation, 2016-18 average except for Mauritius (2018 only) (FAOSTAT, accessed May 2022). Note: includes full and partial control irrigation, including pastures and spate irrigation.

Agric, Indus and Munic with %: water withdrawals by sector as a % of total withdrawals (agriculture, industrial, municipal), 2018 estimates (FAO-AQUASTAT, accessed May 2022).

Access to basic services: water, sanitation, electricity

Basic water all: % of total population with access to at least basic water services, 2020 data except for Seychelles and Comoros (2019) (WHO/UNICEF 2021). Note: basic means from an improved source, collection time <30 mins.

Basic water rural: as above, rural only.

Basic san all: % of population with access to at least basic sanitation, 2020 data except Mauritius (2015) and Comoros (2019) (WHO/UNICEF 2021). Note: improved facilities i.e. not shared with other households.

Basic san rural: as above, rural only.

Elec all: % of total population with access to electricity, 2020 data (World Development Indicators, accessed May 2022).

Elec rural: as above, rural only

Hydropower

Hydro %: contribution of hydropower to total installed capacity. Various sources for period 2015-20, including International Hydropower Association (IHA) annual reports, World Bank Country Profiles, USAID-Power Africa fact sheets, Our World in Data country profiles. Note: a measure of hydro % of total installed (in-country) generating capacity, i.e. the max design output of a project/scheme (on grid). Does not include electricity imports which in this region can be significant – bilateral agreements or brokered via the Southern Africa Power Pool.

Regional (Reg) %

Excl UMI: excluding upper-middle income countries, i.e. low and lower-middle income countries only (see Economics above for definitions). Note: % calculations account for different country populations.

F: Glossary

Acronyms

Table F1: A table of acronyms used in this report is provided below.

AR5	IPCC 5th Assessment Report
AR6	IPCC 6th Assessment Report
CMIP5	Coupled Model Intercomparison Project Phase 5
CMIP6	Coupled Model Intercomparison Project Phase 6
CORDEX	CoOrdinated Regional climate modelling Downscaling EXperiment
ENSO	El Niño Southern Oscillation
FCDO	Foreign, Commonwealth & Development Office (UK Government)
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMST	Global Mean Surface Temperature
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
MHW	Marine Heat Waves
MJO	Madden-Julian Oscillation
NAO	North Atlantic Oscillation
NBS	Nature-Based Solutions
NCD	Non-Communicable Diseases
ODI	Overseas Development Institute
QBO	Quasi-Biennial Oscillation
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RVF	Rift Valley Fever
SDG	Sustainable Development Goal
SES	Semi-Enclosed Seas
SLR	Sea Level Rise
SSP	Shared Socio-economic Pathway
SST	Sea Surface Temperature
SSA	sub-Saharan Africa
SWI	Saltwater Intrusion
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
WASH	Water, Sanitation and Hygiene
WCRP	World Climate Research Project
WHO	World Health Organisation

Technical terms

Term	Definition
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Aerosols	A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: through both interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback.
Agropastoral [livelihood]	Mixed crop-livestock farming found in semi-arid (medium rainfall) areas of Africa, typically with low access to services. It includes the dryland mixed farming system of North Africa, often depending on wheat, barley and sheep. In SSA the main food crops are sorghum and millet, and livestock are cattle, sheep and goats. In both cases, livelihoods include pulses, sesame, poultry and off-farm work.
Anomaly	The deviation of a variable from its value averaged over a reference period.
Anthropogenic	Resulting from or produced by human activities.
Atlantic Multi-decadal Variability (AMV)	Large-scale fluctuations observed from one decade to the next in a variety of instrumental records and proxy reconstructions over the entire North Atlantic Ocean and surrounding continents. Fingerprints of AMV can be found at the surface ocean, which is characterized by swings in basin-scale sea surface temperature anomalies reflecting the interaction with the atmosphere. The positive phase of the AMV is characterized by anomalous warming over the entire North Atlantic, with the strongest amplitude in the subpolar gyre and along sea ice margin zones in the Labrador Sea and Greenland/Barents Sea and in the subtropical North Atlantic basin to a lower extent.
Atmosphere	The gaseous envelope surrounding the earth, divided into five layers – the *troposphere* which contains half of the Earth's atmosphere, the *stratosphere*, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere.
Arid pastoral and oasis [livelihood]	Extensive pastoralism and scattered oasis farming associated with sparsely settled arid zones across Africa, generally with very poor access to

	services. Livelihoods include date palms, cattle, small ruminants and off-farm work, irrigated crops and vegetables.
Baseline	The state against which change is measured. It might be a ‘current baseline,’ in which case it represents observable, present-day conditions. It might also be a ‘future baseline,’ which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Biodiversity	The variability among living organisms from terrestrial, marine, and other ecosystems. Biodiversity includes variability at the genetic, species, and ecosystem levels.
Carbon Dioxide (CO2)	A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes (LUC) and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth’s radiative balance.
Catchment	An area that collects and drains precipitation.
Cereal-root crop mixed [livelihood]	Mixed farming with medium-high access to services dominated by at least two starchy staples (typically maize and sorghum) alongside roots and tubers (typically cassava) found in the subhumid savannah zone in West and Central Africa. Other livelihood sources include legumes, cattle and off-farm work.
Climate	In a narrow sense, climate is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization.
Climate Change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
Climate Feedback	An interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced.
Climate Information	Information about the past, current state, or future of the climate system that is relevant for mitigation, adaptation and risk management. It may be tailored or “co-produced” for specific contexts, taking into account users' needs and values.

Climate Impacts	Impacts describe the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability.
Climate Indicator	Measures of the climate system including large-scale variables and climate proxies.
Climate Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Climate Model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties.
Climate Projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHG) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.
Climate Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Climate System	The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them.
Climate Variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events.
Communicable Disease	Refers to an illness caused by an infectious agent or its toxins that occurs through the direct or indirect transmission of the infectious agent or its products from an infected individual or via an animal, vector or the inanimate environment to a susceptible animal or human host (CDC, 2012).
Confidence	The robustness of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data,

models, expert judgment) and on the degree of agreement across multiple lines of evidence.

Crop Water Deficit	A water deficit occurs whenever water loss exceeds absorption. The use of total water potential as the best single indicator of plant water status has its limitations while attempting to understand the effect of water deficits on the various physiological processes involved in plant growth. Water deficits reduce photosynthesis by closing stomata, decreasing the efficiency of the carbon fixation process, suppressing leaf formation and expansion, and inducing shedding of leaves.
Disaster	A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNGA, 2016).
Deltaic	Of or pertaining to a river delta.
Downscaling	A method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.
El Niño Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called La Niña.
Emissions Scenario	A plausible representation of the future development of emissions of substances that are radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and land use) and their key relationships.
Enhanced Greenhouse Effect	The process in which human activities have added additional greenhouse gases into the atmosphere, this has resulted in a 'stronger' greenhouse gas effect as there are more gases available to trap outgoing radiation.
Evaporation	The physical process by which a liquid (e.g., water) becomes a gas (e.g., water vapour).
Evapotranspiration	The process in which water moves from the earth to the air from evaporation (= water changing to a gas) and from transpiration (= water lost from plants).

Exposure	Exposure describes the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Extreme/heavy precipitation event	An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.
Fifth Assessment Report (AR5)	A series of IPCC reports published in 2013-2014, reports are divided into publications by three working groups.
Fish-based [livelihood]	Found along coasts, lakes and rivers across Africa with medium-high access to services, with fish a major livelihood. Other livelihood sources include coconuts, cashew, banana, yams, fruit, goats, poultry and off-farm work.
Fossil Fuels	Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and natural gas.
Global Breadbasket	The term "breadbasket" is used to refer to an area with highly arable land. The breadbaskets of the world are the regions in the world that produce food, particularly grains to feed their people as well as for export to other places.
Global Warming	The estimated increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.
Greenhouse Effect	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth’s surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.
Greenhouse Gas (GHG) Concentrations	Lead to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.

Greenhouse Gases (GHGs)	The gaseous constituents of the atmosphere. both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). [IPCC, 2018].
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
Heat Stress	A range of conditions in, e.g., terrestrial or aquatic organisms when the body absorbs heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water breathing animals, hypoxia and acidification can exacerbate vulnerability to heat. Heat stress in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity and low wind-speeds, causing regulation of body temperature to fail.
Heatwave	A period of abnormally hot weather often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions.
Highland mixed [livelihood]	Highland mixed farming above 1700 m dominated by wheat and barley, found predominantly in subhumid north-east Africa with pockets in Southern, West and North Africa. Other livelihood sources include teff, peas, lentils, broad beans, rape, potatoes, sheep, goats, cattle, poultry and off-farm work.
Highland perenniall [livelihood]	Highland perennial farming is characterized by a dominant perennial crop (banana, plantains, enset or coffee) and good market access, and is found in humid East African highlands. Other livelihoods derive from diversified cropping including maize, cassava, sweet potato, beans, cereals, livestock and poultry augmented by off-farm work.
Ice sheet	An ice body originating on land that covers an area of continental size, generally defined as covering >50,000km^2, and that has formed over thousands of years through accumulation and compaction of snow. [IPCC, 2019].
Impacts	

	Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.
Indian Ocean Basin Mode (IOB)	The Indian Ocean basin (IOB) mode is a mode of interannual variability characterized by a temporal alternation of basin-wide warming and cooling of the Indian Ocean sea surface. It mostly develops in response to El Niño–Southern Oscillation (ENSO), but often persists after ENSO's equatorial eastern Pacific signal has dissipated. The IOB affects atmospheric circulation, temperature, and precipitation in South, South East, and East Asia as well as Africa, and modulates tropical cyclone activity in the north-western Pacific.
Indian Ocean Dipole (IOD and SIOD)	The Indian Ocean Dipole (IOD) is an irregular oscillation of sea surface temperatures in which the western Indian Ocean becomes alternately warmer (positive phase) and then colder (negative phase) than the eastern part of the ocean. The Subtropical Indian Ocean Dipole (SIOD) is featured by the oscillation of sea surface temperatures (SST) in which the southwest Indian Ocean (i.e. south of Madagascar is warmer) and then colder than the eastern part i.e. off Australia.
Intergovernmental Panel on Climate Change (IPCC)	The leading international body for the assessment of climate change. Scientists come together approximately every six years, to assess peer-reviewed research in working groups to generate three reports including the Physical Science Basis, impact adaptation and vulnerability, and Mitigation of Climate Change.
Intertropical Convergence Zone (ITCZ)	The Intertropical Convergence Zone (ITCZ) is a band of low pressure around the Earth which generally lies near to the equator. The trade winds of the northern and southern hemispheres come together here, which leads to the development of frequent thunderstorms and heavy rain.
Irrigated [livelihood]	Large-scale irrigation schemes associated with large rivers across Africa, e.g. Nile. Often located in semi-arid and arid areas but with medium-high access to services. Includes the associated surrounding rainfed lands. Diversified cropping includes irrigated rice, cotton, wheat, faba, vegetables and berseem augmented by cattle, fish and poultry.
Maize mixed [livelihood]	Mixed farming dominated by maize with medium access to services in subhumid areas of East, Central and Southern Africa. Other livelihood sources include legumes, cassava, tobacco, cotton, cattle, goats, poultry and off-farm work.
Marine heatwave	A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the ocean and at scales of up to thousands of kilometres.
Mitigation	

	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Nature-Based Solutions (NBS)	Nature-based solutions (NBS) refers to the sustainable management and use of nature for tackling socio-environmental challenges. The challenges include issues such as climate change, water security, water pollution, food security, human health, biodiversity loss and disaster risk management.
Ocean acidification	A reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.
Overharvested	Refers to harvesting a renewable resource to the point of diminishing returns.
Pacific Decadal Variability (PDV)	The PDV is the coupled decadal-to-interdecadal variability of the atmospheric circulation and underlying ocean that is typically observed over the entire Pacific Basin beyond the El Niño–Southern Oscillation (ENSO) time scale. Typically, the positive phase of the PDV is characterized by anomalously high sea surface temperatures in the central-eastern tropical Pacific that extend to the extratropical North and South Pacific along the American coasts, encircled to the west by cold sea surface anomalies in the mid-latitude North and South Pacific. The negative phase is accompanied by sea surface temperature anomalies of the opposite sign. Those sea surface temperature anomalies are linked to anomalies in atmospheric and oceanic circulation throughout the whole Pacific Basin. The PDV is associated with decadal modulations in the relative occurrence of El Niño and La Niña.
Paris Agreement	The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change.

Pastoral [livelihood]	Extensive pastoralism (dominated by cattle), found in dry semiarid (low rainfall) areas with poor access to services. Other livestock include camels, sheep and goats alongside limited cereal cropping, augmented by off-farm work.
Pelagic Fish	Pelagic fish live in the pelagic zone of ocean or lake waters – being neither close to the bottom nor near the shore.
Projection/projected	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.
Radiative Forcing	The change in the net, downward minus upward, radiative flux (expressed in W m-2) at the tropopause or top of atmosphere due to a change in a driver of climate change, such as a change in the concentration of carbon dioxide (CO2) or the output of the sun.
Reanalysis	Atmospheric and oceanic analyses of temperature, wind, current and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques.
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Resolution	In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard.
Root and tuber crop [livelihood]	Lowland farming dominated by roots and tubers (yams, cassava) found in humid areas of West and Central Africa. Other livelihood sources include legumes, cereals and off-farm work.
Runoff	

	The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate or refreeze and is not transpired.
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.
Signal	Climate signals are long-term trends and projections that carry the fingerprint of climate change.
Sixth Assessment Report (AR6)	The latest series of IPCC reports published in 2021-2022, reports are divided into publications by three working groups. At the time of writing this report only the Working Group I contribution to the Sixth Assessment Report published in 2021 was available to use.
Soil moisture	Water stored in the soil in liquid or frozen form. Root-zone soil moisture is of most relevance for plant activity.
Southern Annular Mode	Annular modes are hemispheric scale patterns of atmospheric variability characterized by opposing and synchronous fluctuations in sea level pressure between the polar caps and mid-latitudes, with a structure exhibiting a high degree of zonal symmetry, and with no real preferred time scales ranging from days to decades. In each hemisphere, these fluctuations reflect changes in the latitudinal position and strength of the mid-latitude jets and associated storm tracks. Annular modes are defined as the leading mode of variability of extratropical sea level pressure or geopotential heights and are known as the Northern Annular Mode (NAM) and Southern Annular Mode (SAM) in the two hemispheres, respectively.
Special Report on Emissions Scenarios (SRES)	A report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007.
Storm surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. [IPCC, 2019].
Stream Flow	Water flow within a river channel, for example, expressed in m^3s^{-1}. A synonym for river discharge.
Teleconnection	Association between climate variables at widely separated, geographically fixed locations related to each other through physical processes and oceanic and/or atmospheric dynamical pathways. Teleconnections can be

	caused by several climate phenomena, such as Rossby wave-trains, mid-latitude jet and storm track displacements, fluctuations of the Atlantic Meridional Overturning Circulation, fluctuations of the Walker circulation, etc. They can be initiated by modes of climate variability thus providing the development of remote climate anomalies at various temporal lags.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In climate change analysis, it may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour.
United Nations Framework Convention on Climate Change (UNFCCC)	The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the *Kyoto Protocol* and the *Paris Agreement*. [IPCC, 2018].
Urban Heat Island	The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface albedo.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt.
Weather	The conditions in the air above the earth such as wind, rain, or temperature, especially at a particular time over a particular area.

Met Office Hadley Centre ODI UKaid

G: References

Beck et al. (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data*. Aug 17;7(1):274. doi: 10.1038/s41597-020-00616-w.

Cai, W., Borlace, S., Lengaigne, M. *et al.* (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change* **4**, 111–116 https://doi.org/10.1038/nclimate2100

Conway, D., Dalin, C., Landman, W.A. and Osborn, T.J. (2017). Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy*, Vol. 2, December 2017, 946-953.

Cucchi, M. et al., 2020: WFDE5: bias-adjusted ERA5 reanalysis data for impact studies. *Earth System Science Data*, 27 **12(3)**, 2097–2120, doi:10.5194/essd-12-2097-2020

Devereux, S. (2009). *Seasonality and Social Protection in Africa*. Growth and Social Protection Working Paper 07, Future Agricultures Programme, IDS. January 2009.

Ellis, F. (2013). *Topic Guide: Agriculture and Growth*. Evidence on Demand, DFID. https://www.gov.uk/research-for-development-outputs/topic-guide-agriculture-and-growth

Eriksen et al. (2015) Reframing adaptation: The political nature of climate change adaptation *Global Environmental Change*, **35**, 523-533, 10.1016/j.gloenvcha.2015.09.014

Eyring et al., (2016) Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization *Geosci. Model Dev*., 9, 1937–1958

FAOSTAT (2022) Food and agriculture data. https://www.fao.org/faostat/en/#home

Gannon, K.E., Conway, D., Pardoe, J., Ndiyoi, M., Batisani, N., Odada, E., Olago, D., Opere, A., Kgosietsile, S., Nyambe, M., Omukuti, J. and Siderius, C. (2018). Business experience of floods and drought-related water and electricity supply disruption in three cities in sub-Saharan Africa during the 2015/2016 El Niño. *Global Sustainability* 1, e14, 1-15. https://doi.org/10.1017/sus.2018.14

Giorgi, F., Jones, C., et al. (2009) Addressing Climate Information Needs at the Regional Level: The CORDEX Framework. *WMO Bulletin*, **58**, 175-183.

Hallegatte, S. et al. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: World Bank.

Hallegatte, S. et al. (2017). *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. Climate Change and Development. Washington, DC: World Bank.

Hallegatte, S., Rentschler, J. and Rozenberg, J. (2019). *Lifelines: The Resilient Infrastructure Opportunity*. Sustainable Infrastructure Series. Washington DC: World Bank. Doi: 10.1596/978-1430-3

Herschbach, H. et al (2020) The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society. 146(730), 1999-2049

Hoell, A., et al. (2017) Modulation of the Southern Africa precipitation response to the El Niño Southern oscillation by the subtropical Indian Ocean Dipole**.** *Climate Dynamics*. **48** (7), 2529-2540, 10.1007/s00382-016-3220-6

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, (2021) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

IPCC Interactive Atlas (2021). Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/

Meque, A., & Abiodum, B. (2015) Simulating the link between ENSO and summer drought in Southern Africa using regional climate models. *Climate Dynamics*. **44,** 1881-1900

Nicholson, S. (2017) Rainfall over the African continent from the 19th through the 21st century. *Global and Planetary Change*. **165**, 114-127

Opitz-Stapleton et al., (2019) Risk informed development : from crisis to resilience. *Economics.*

Prevention Web (2022). *Climate Change – Exacerbated Rainfall Causing Devastating Flooding in Eastern South Africa*. Research Brief, 13 May 2022. https://www.preventionweb.net/news/climate-change-exacerbated-rainfall-causing-devastating-flooding-eastern-south-africa

Raga, S. and Pettinotti, L. (2022). *Economic vulnerability to the Russia–Ukraine war Which low- and middle-income countries are most vulnerable?* ODI Emerging Analysis, April 2022. ODI: London.

Reason, C. (2001) Subtropical Indian Ocean SST dipole events and Southern Africa rainfall. *Geophysical Research Letters. 28(11), 2225-2228*

Reason, C & Rouault (2005) Links between the Antarctic Oscillation and winter rainfall over western South Africa. *Geophysical Research Letters.* 32, L07705

Richardson, K. et al (2022) Climate in context: An interdisciplinary approach for climate risk analysis and communication. Met Office. Exeter, UK

Siderius, C., Kolusu, S.R., Todd, M.C., Washington, R.T., Bhave, A., Dougill, A.J., Reason, C.J.C, Mkwambisi, D.D., Kashaigili, J.J., Pardoe, J. Harou, J.J., Vincent, K., Hart, N.C.G, James, R., Washington,R., Geressu, R.T. and Conway, D. (2021). Climate variability affects water-energy-food infrastructure performance in East Africa, *One Earth*, Volume 4, Issue 3, 2021, Pages 397-410, ISSN 2590-3322, https://doi.org/10.1016/j.oneear.2021.02.009.

Stueker et al. (2017) Revisiting ENSO/Indian Ocean Dipole phase relationships. *Geophysical Research Letters*. 44, 2481-2492

Taylor et al. (2012) An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society*. 93, 485–498

USAID (2016a). *Climate change risk profile: Madagascar*. United States Agency for International Development.

USAID. (2016b). *Climate change risk profile: Mozambique*. United States Agency for International Development.

USAID. (2016c). *Climate change risk profile: Southern Africa*. United States Agency for International Development.

USAID. (2016d). *Climate change risk profile: Zambia*. United States Agency for International Development.

USAID. (2017). *Climate change risk profile: Malawi*. United States Agency for International Development.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., et al. (2011) The Representative Concentration Pathways: An Overview. *Climatic Change*, **109**, 5-31. https://doi.org/10.1007/s10584-011-0148-z

Wiggins, S. and Lankford, B. (2019) *Farmer-led irrigation in sub-Saharan Africa: synthesis of current understandings*: DEGRP Synthesis Report. https://www.gov.uk/research-for-development-outputs/farmer-led-irrigation-in-sub-saharan-africa-synthesis-of-current-understandings

World Bank (2022). 'World Development Indicators DataBank', https://databank.worldbank.org/source/world-development-indicators. Accessed May 2022.

World Bank (2022) Madagascar Economic UpdateWorld Bank (2022) Mozambique Country Overview

Image location: South Luangwa National Park, Zambia

www.metoffice.gov.uk