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Southern Africa Projections and Impacts Guidance Paper

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List of Acronyms

Acronym	Long-Form
CRIDF	Climate Resilient Infrastructure Development Facility
AR	Assessment Report
CCRA	Climate Change Risk Assessment
CCRM	Climate Change Risk Management ltd.
DFID	Department for International Development
ENSO	El Nino Southern Oscillation
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
MAAT	Mean Annual Air Temperature
PMU	Project Management Unit
RCP	Representative Concentration Pathway
SADC	Southern African Development Community
SOM	Self-Organising Map
SST	Sea Surface Temperature

Introduction

The Climate Resilient Infrastructure Development Facility (CRIDF) is DFID's innovative water infrastructure programme for southern Africa. CRIDF prepares small-scale water infrastructure projects and facilitates access to finance for the implementation of these projects. Activities are selected according to a set of CRIDF principles to ensure that investments align with strategic objectives that have been developed specifically for each SADC river basin.

According to the CRIDF Climate Resilience Strategy, climate resilience should be practically integrated into all CRIDF Projects, at Programme, Project and Activity levels, and in order to do so there is a need to develop a systematic assessment of the vulnerability and risks associated with CRIDF's portfolio of infrastructure Projects.

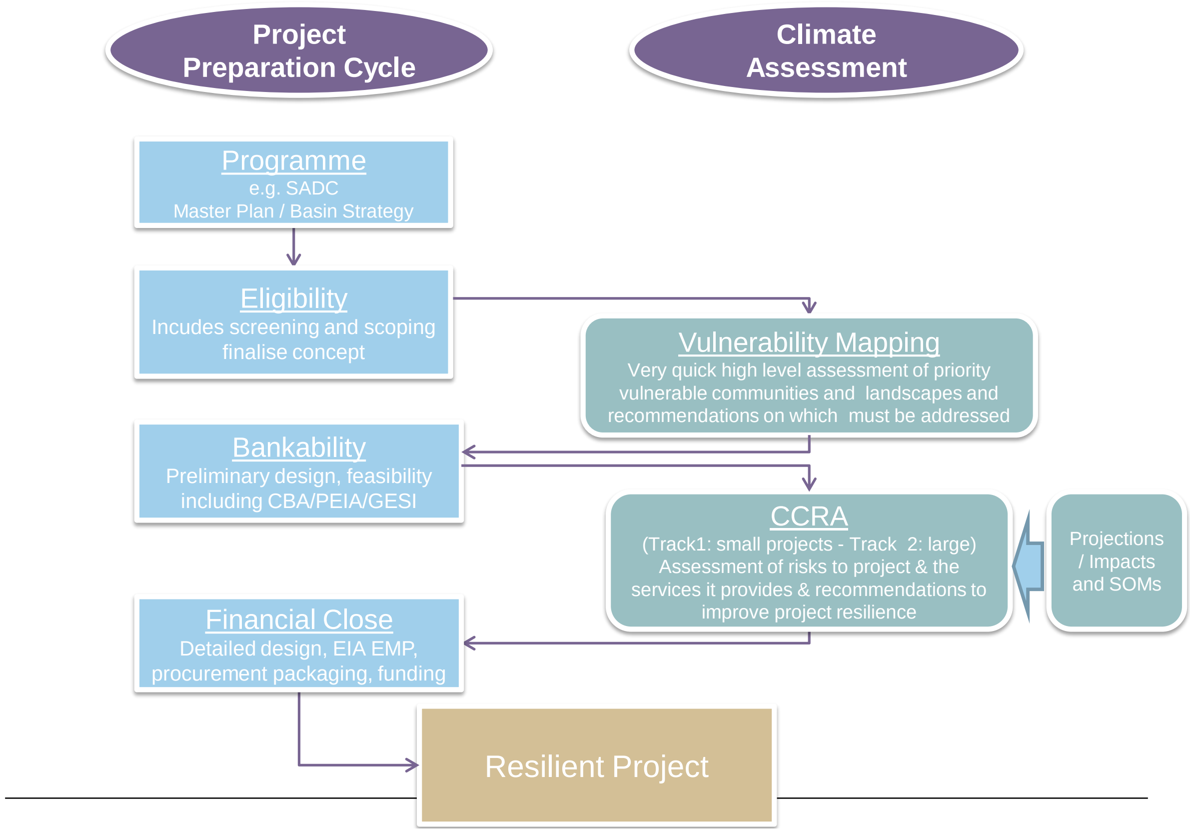
To date, the development and roll-out of the Climate Resilience Strategy has been an iterative process, with the aim of developing a series of tools that are fit-for-purpose and appropriate for the stage and scale of CRIDF's infrastructure Projects. Climate Change Specialists, CRIDF PMU members, external technical Project consultants, and DFID, have all been extensively engaged since the inception of this Strategy in 2013 – which comprises a three step process to mainstreaming resilience throughout CRIDF; namely:

1. **Step 1: Vulnerability Mapping Tool:** The development of a high level, CRIDF-tailored geographical information system based upon existing information from secondary sources, which could be used to efficiently assess the climate vulnerability of CRIDF's Projects during the initial scoping and screening process.
2. **Step 2: Risk Assessment**: The development of a more detailed project level climate change risk assessment tool, comprising two tracks (to applied as appropriate to the scale and complexity of each Project):

    A **track 1** CCRA is used to mainstream resilience thinking more systematically into the design process. This requires input primarily from the Project Directors and Project Managers, who will lead the assessment. It is based on a set of *projections and impacts* that are pre-prepared at the regional level.

    A **track 2** CCRA is used if the Project CapEx budget exceeds £5m and the design is deemed complex enough to require more resources (i.e. specialist skills and extensive onsite evaluations).
3. **Step 3: Lessons Learned Information Transfer**: The identification and documentation of lessons learned from the process of undertaking a series of pilot track 1 CCRAs in line with the Protocol, with ultimate aim of transferring the skills, knowledge and findings generated from this process to both CRIDF and other actors more widely in the region.

Figure 1 **Mainstreaming Climate resilience into small scale water infrastructure preparation**



Progress to date

After successfully developing and rolling out a Vulnerability Mapping Tool for application during the Scoping/Pre-Feasibility Stages of all Projects, CRIDF then proceeded with designing a systematic protocol[1] for assessing the climate risks associated with each infrastructure Project as it reaches detailed design. It was envisaged that the Climate Change Risk Assessment (CCRA) protocol would consider the following aspects:

- Past climate risks and capacity to adapt
- Current vulnerability (using the CRIDF Vulnerability Mapping Tool[2])
- An analysis of future climate variables (including *projections, impacts* and *uncertainty*)
- Details of the Project's technical components, as well as topography, environment, demographics, institutions and socio economic considerations

[1] See '*Resiliency Screening and Climate Change Risk Assessment Guidelines (Protocol)*', www.cridf.com
[2] http://geoservergisweb2.hrwallingford.co.uk/CRIDF/CCVmap.htm

Purpose of the Paper

Most immediately, the purpose of this paper is to complement the CCRA track 1 Protocol developed for smaller[3] projects, by providing a consistent set of Southern Africa climate projections in the most cost appropriate and effective manner. These are accompanied with the identification of the most likely on-the-ground impacts associated with these projections, which have been derived from a literature review conducted by climate scientists (based in South Africa and the United Kingdom). For the purposes of reporting theses impacts in as meaningful way as possible, at such a large scale, Southern Africa has been divided into 5 agri-climatic zones where particular projections and impacts are approximately correlated (see Figure 2).

Moreover, these projections and impacts are accompanied by a discussion on the risks and uncertainty associated with these information sets, using evidence from a statistical technique called Self Organising Maps which help to provide some basis for managing the uncertainly inherently associated with using a suite of climate models.

It has always been envisaged that the projections, impacts table, tools and CCRA methodology developed by CRIDF should ultimately be disseminated to a broad range of players, for wider application across the region. This paper therefore also serves as a summary document for external audiences, and references more detailed literature, CORDEX mapping outputs and SOMs produced by CRIDF Experts that support the information and findings contained in this document. These documents, along with the Protocol, can be found at www.cridf.com.

[3] See track 1 description and limitations on page 7

Methodological approach to developing SADC projections and impacts tables

In recent years, over 40 global atmospheric and oceanic climate models have been developed, summarised and reported against in the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR). The IPCC's AR5 states that future climate changes will have a wide range of impacts across Southern Africa – including changes in ecosystems, water stresses and agricultural systems. In addition, there is a high confidence that managing risk and developing adaptive capacities for ensuring food security, managing health vulnerabilities and governance systems will be insufficient to deal with the predicted impacts of climate change in the short (2025) and medium (2055) term.

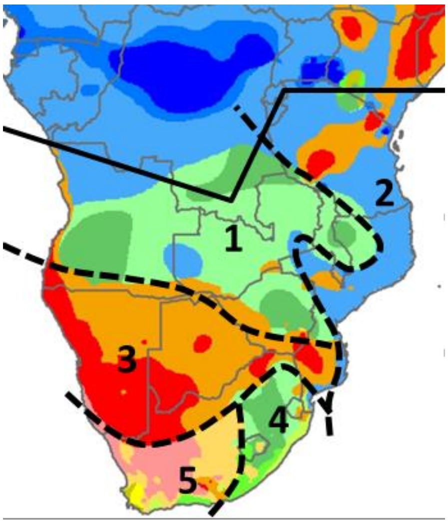
Predicted future patterns of atmospheric circulcation in Southern African are not well known, but it is widely recognised and accepted that the: zonal circulation within the Hadley cell[4], the Inter Tropical Convergence Zone (ITCZ) location and dynamics, the passage of cyclones from the Atlantic and Indian oceans, and the impacts of changing El Nino strength, are important as climate drivers in Southern Africa. This has been examined in numerous studies, where the climate impacts on key aspects of sustainability in Southern Africa (primarily food and water security) have been examined. However, what is still missing is an integrated approach to consider feedbacks and interconnections between physical and human environmental systems, and the ways in which they converge on aspects of sustainability of the human environments, health and wellbeing.

The following sub-sections outline key elements of the methodological approach that have shaped the development of the sets of projections and corresponding impacts for Southern Africa, in a form that is consistent with available science.

Sub-Regional Climatic Zones

IPCC findings indicate that the extent, type and intensity of hydroclimatological hazards will differ significantly across the region; the region should therefore not be viewed as a single climatic zone, but rather as 5 sub-regional zones (see Figure 2 below). The boundaries between adjacent zones are particularly sensitive to change; there is thus highest climate variability and predictive uncertainty in these areas. However, more information is still needed on the rate of environmental change as a result of climate change at these boundary areas between climatic zones, and any analyses of the projections and impacts of climate change at project sites located near these boundaries needs to acknowledge these uncertainties.

[4] The Hadley Cell is a tropical atmospheric circulation: air rises up at or near the equator, flows toward the poles above the surface of the Earth, returns to the Earth's surface in the subtropics, and flows back towards the equator.



Climatic Zones in SADC

- **Region 1, Summer ITCZ (Intertropical Convergence Zone) region**. Angola, Zambia, and Malawi, central and NE Zimbabwe - This is a temperate/tropical region with dry winters (subtropical high pressure cells) and rainy summers (tropical lows driven by seasonal migration of the ITCZ).
- **Region 2, Summer Indian Ocean cyclone/monsoon zone.** Mozambique, Tanzania - Tropical/seasonal monsoon climate characterized by incoming cyclones from the Indian Ocean.
- **Region 3, Arid descending arm of Hadley cell.** Namibia, Botswana, SW Zimbabwe, S Mozambique - This region has a negative hydrological balance, low and variable precipitation and seasonally high temperatures.
- **Region 4, Temperate cyclonic zone**. E South Africa, Swaziland, and Lesotho - This region has a wet summer regime with thunderstorms and subtropical cyclones.
- **Region 5, Semi arid/winter rainfall zone.** W South Africa - This region is characterized by a steppe climate inland with winter rainfall and fog at the coast.

Figure 2 **Climatic Zones in SADC**

Representative Concentration Pathways (RCPs)

RCPs are greenhouse gas concentration trajectories that describe varying climate future scenarios, where the higher the number at the end of each 'RCP', the higher the emissions and atmospheric GHG concentrations. The work undertaken by CRIDF towards developing the projections and impacts data for the 5 SADC Climate Zones focussed on two of the four RCP scenarios considered by the IPCC AR5 – that is, RCP4.5[5] and RCP8.5[6]. Climate Scientists currently expect that the most likely scenario will fall somewhere between these two RCPs.

It should be noted that while temperature changes increase progressively across higher RCPs, the same cannot be said for rainfall. Models indicate that rainfall does not consistently intensify in the same direction as the

[5] RCP4.5 is a stabilisation scenario that assumes climate policies on GHG emission prices will be invoked in time for emissions to peak around 2040, and then begin to decline

[6] RCP8.5 is characterised by increasing GHG emissions throughout the 21st Century. It assumes anthropogenic GHG emissions continue beyond 2100 and is the most extreme trajectory currently considered by climate scientists

concentration of GHGs due to the extensive number of variables affecting precipitation, and the complex relationships between annual totals and seasonality of precipitation and evaporation. A more valuable measurement would likely be the 'change in precipitation less evaporation'; however, sufficient data on this has not yet been published by the IPCC. The impacts table therefore presents median estimates of change in precipitation with corresponding guidance in the text on appropriate values to be used for infrastructure planning purposes.

Timescales

The climate change projections and impacts have been considered under two time scales; i) short term (2025 – representative of the period 2016 – 2035) and ii) medium term (2055 – representative of the period 2046-2065)[7]. High-level predictions at these time scales include:

- **Short time scale**: Over the next 10 years, climate variability is expected to increase across the region, consistent with present day climate patterns and synoptic circulation. Over this is superimposed short time scale variations imposed by strong ENSO (El Nino Southern Oscillation) events, although the effects on the strength of the Indian Ocean dipole are uncertain. It is more likely that strong cyclone events from high SST (sea surface temperature) in the Indian Ocean will continue at this time, brining flooding to eastern coasts of southern Africa.
- **Medium time scale**: Changes in temperature and precipitation patterns will show higher variability across the region, with feedbacks associated with decreased humidity and land surface aridification under hotter climates as a result of decreased rainfall, especially seasonally. Land surface feedbacks become more significant controls on hazard responses and climate impacts[8]. Continentality effects become more pronounced as inland areas become dryer, with smaller changes observed along the coast.

[7] These are considered sufficient for smaller scale infrastructure planning (below £5,000,000). Larger scale projects should also use the third IPCC time scale of 2080.

[8] In other words geomorphology (land surface processes) and land use play an increasingly important role in driving hazards and in understanding the impacts of climate change.

CORDEX Projection Mapping

CORDEX is a set of projections from Regional Climate Models (RCMs). RCMs work over a limited domain on higher resolutions than the global models, both spatially and temporally.

CRIDF's climate modellers undertook to look at the range of IPCC CMIP3 (Coupled Model Intercomparison Project Phase 3) (AR4), CMIP5 (Coupled Model Intercomparison Project Phase 5) (AR5) models and CORDEX downscaled outputs, to understand the variability in projections for temperature, rainfall and seasonality for the southern African region of interest.

These sets of projections provide one with an ensemble of what probable future temperatures and annual rainfall totals may be at a given timescale and at a specific geographic location in southern Africa (see Figures 2 and 3 below).

It should be noted that CORDEX projections do not provide one with information on variability and timing/duration of rainfall, heatwaves, frosts etc. It is therefore recommended that the information drawn from the CORDEX maps be coupled with discussions and interviews[9] with the Project Team and Key Stakeholders to ascertain whether/what noticeable changes in the variability and intensity of rainfall may have occurred in recent years. This will allow one to develop a more useful interpretation of the information contained in the CORDEX maps. An example of this is that the maps may suggest a high increase in annual rainfall at a certain location, which would support the notion of rain fed agriculture. However, local stakeholders may inform the Project Team that they receive majority of this rain over a very short space of time and do not have the infrastructure in place to collect and store the water – rendering it useless for sustained agricultural practises year-round.

[9] Detailed guidance on conducting these interviews provided in '*Resiliency Screening and Climate Change Risk Assessment Guidelines (Protocol)*', www.cridf.com

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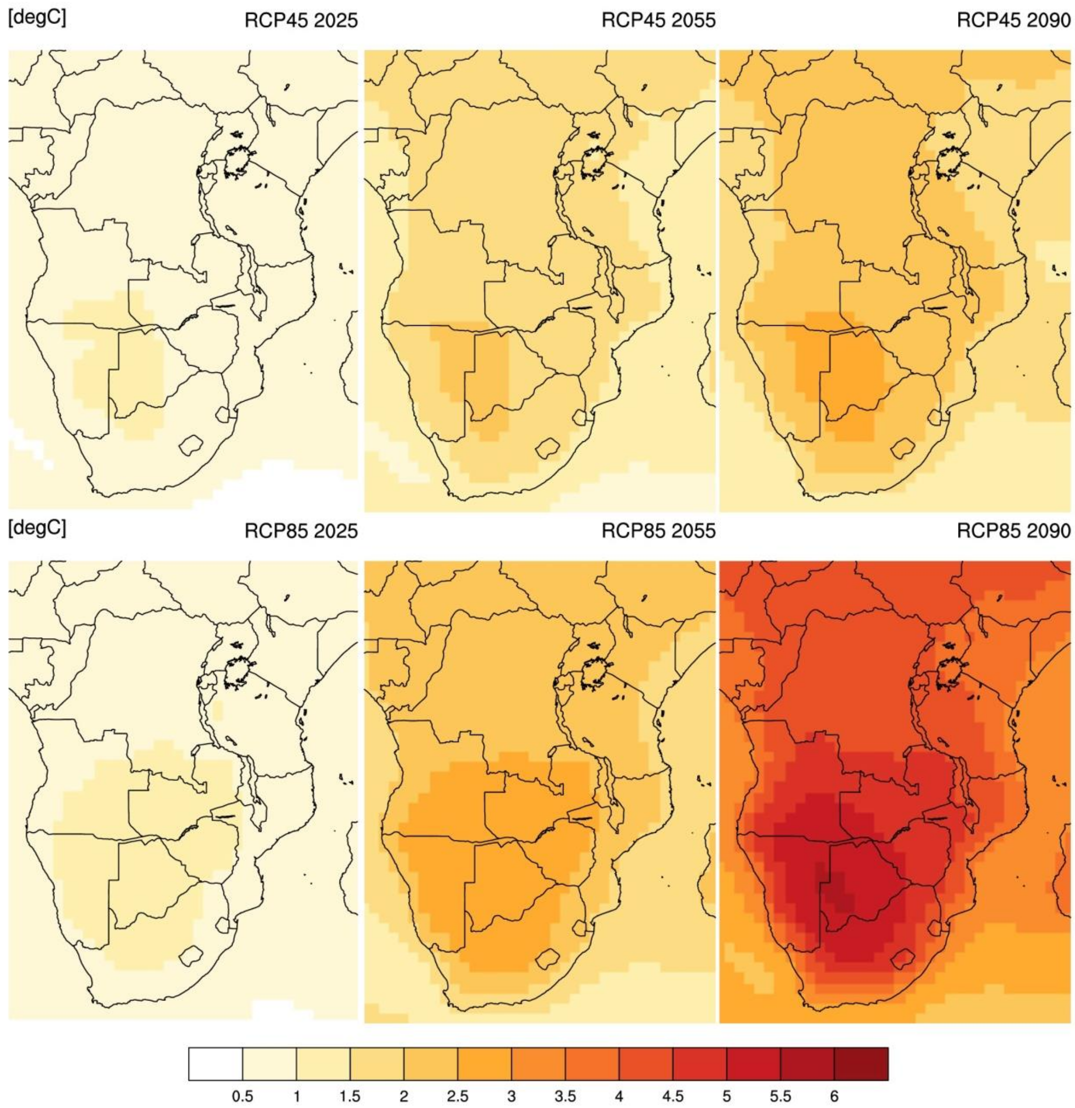

Figure 3 **Ensemble mean average annual temperature rises from the AR5 ensemble; the scale is the change in °C for timescales 2020, 2055 & 2090**

In general the greatest rises are in central parts of the SADC region, in particular over western Zimbabwe and eastern Namibia, with predicted annual average temperature rises approaching an unprecedented 6°C by the end of the 21st Century under RCP8.5. Increases for the coastal areas are a little lower than this, although in the upper basin they still exceed 5°C by the end of the Century under RCP8.5.

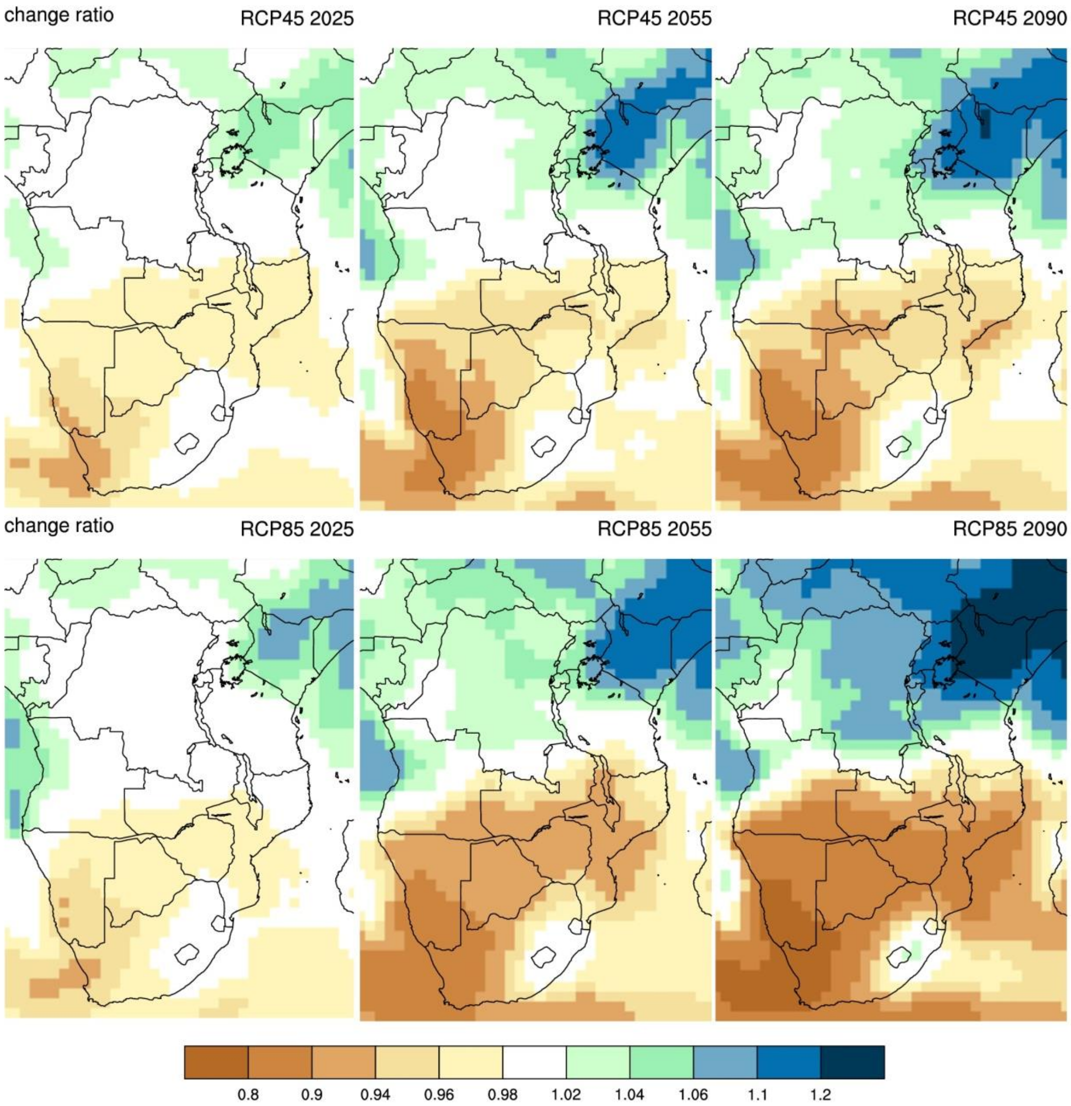

Figure 4 **Changes in annual rainfall totals according to the ensemble means for RCPs 4.5 and 8.5 calculated as ratios (on scale) for timescales 2020, 2055 & 2090**

According to these ensembles, mean average annual rainfall totals will decline into the future, to below 70% of current values by the end of the Century in an area to the north of Cape Town, South Africa, under RCP8.5. Almost the only parts of the SADC region in which future increases will occur according to these results are north-western Angola, Northern Tanzania, small areas of South Africa around Kwazulu-Natal, and Lesotho.

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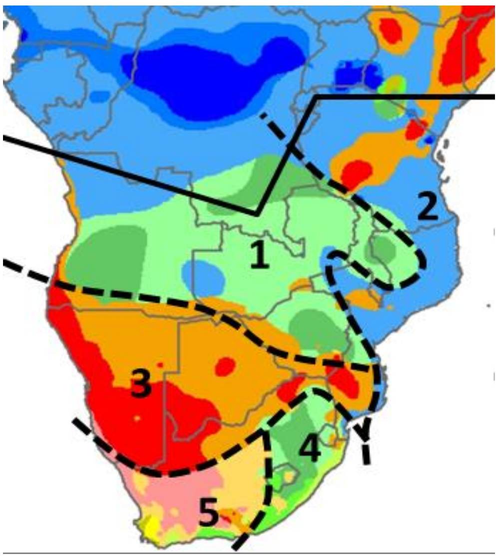
Climate Impacts

Climate Change Themes

Using the aforementioned RCPs, time scales and CORDEX projections, climate impacts have been identified under the following themes **Error! Reference source not found.**:

- **Precipitation variability**, including rainfall events (annual total, seasonality, intensity, precipitation source), humidity/cloudiness, river systems, aquatic ecosystems/aquaculture, groundwater, water security, water supply and variability;
- **Temperature variability**, including heatwaves, seasonal temperature ranges, frost, wildfires, aridity;
- **Extreme events**, including floods/droughts;
- **Agriculture**, including food production, food security, land degradation/soil erosion, ecosystems/biodiversity;
- **Health**, including disease epidemiology, air/water pollution, biohazards, nutrition, sanitation



The Impacts Table provides an up-to-date and consistent approach to interpreting the climate change projections in the five southern Africa sub-regions based on current scientific literature (largely from IPCC AR5), as well as additional interpretation from leading climate scientists. The purpose of the table is to help the Project Team interpret the likely impacts that each of the themes may have on the project site at future time scales. The information contained in the below table should be coupled with information gathered from site missions reports and interviews with the Project Team and Key Stakeholders, to ascertain whether i) any of these impacts have started occurring already, and the effect this is having on the local population; and ii) an impact/occurrence is noted by a Stakeholder or Team Member, but does not fit within the Impacts table template, in which instance further internet/desktop research should be conducted.

This process should allow the Project Team to both identify risks and justify a risk score in the CCRA track 1 Risk Matrix (see

), with the aim of highlighting which key risks need to be carefully considered prior to finalising the project designs and thereafter providing recommendations as to how these risks can be managed and/or mitigated through design choices.

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Table 1 **Climate Impacts Table**

Region	Climate change trend	Impacts	
		By 2025	**By 2055**
1	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation. A transition zone between areas where the annual rainfall is more likely to increase (to the north) and more likely to decrease (to the south). Any changes are most likely (but not definitively) in the range −10% to +10%. The possibility of increased rainfall rises with higher emissions.	Continuing trend of seasonal and interannual variability in precipitation, decreased winter rainfall and increased aridity, in combination with wind gustiness, drying out of seasonal wetlands/pans and ephemeral rivers. Variability in particular at boundary with southernmost extent of intertropical convergence zone (ITCZ). A transition zone between areas where the annual rainfall is more likely to increase (to the north) and more likely to decrease (to the south). Any changes are most likely (but not definitively) in the range −10% to +10%. The possibility of decreased rainfall is higher than around 2025. Water supply is challenged by increased temperatures (and associated evaporation), and more erratic rainfall patterns, leading to vulnerability of perennial river systems and decreased level of the groundwater table.
	Temperature variability	Continuing trend of increased mean annual air temperature (MAAT). Likely increase of MAAT by 0.5°C to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, aridity trend will reinforce decreased humidity especially under more erratic seasonal precipitation regimes; increased heatwaves; increased thunderstorm activity, heatwaves. Likely increase of MAAT by 0.5°C to 3.0°C, but lower/higher values not excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	More erratic precipitation and temperature regimes, resulting in some likely increase in extreme flood/drought	More erratic precipitation and temperature regimes, resulting in an increased likelihood of extreme flood/drought events, both in severity and

Region	Climate change trend	Impacts	
		By 2025	**By 2055**
		events.	duration. This will have a multiplier effect in increasing vulnerabilities to other risk events and thus result in wider likely impacts.
	Agriculture	Food insecurity arising from political instability across the region and challenges to both food production and supply, climatic instability.	Increased overall drying trend and decreased winter rains result in decreased food production in total and land surface degradation and soil erosion due to increased aridity and soil moisture loss. Deforestation and loss of biodiversity an increasing issue. Aridification and spread of sand dunes in Sahelian areas. Rain-fed agriculture will be likely less reliable in many areas and irrigated agriculture will become more significant, but this poses problems for famers' access to technology, investment and training (including provision of GM seeds).
	Health	Pockets of different disease types as a result of site-specific water/air/pollution, amplified by incorrect water, agricultural and land management practices, and mining wastes. Low nutrition/health in some areas due to food insecurity.	Widespread health effects due to food/water insecurity, availability of potable water, water contamination by runoff, and low water quality due to biological diseases, pollution/sewage runoff into rivers, wastewater and groundwater contamination due to poor sanitation in informal settlements and due to industries such as mining.
2	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation related to strength of ITCZ and frequency/magnitude of incoming cyclones from Indian Ocean. For planning purposes it might be best to work on decreased annual rainfall, with any decrease most likely	Continuing trend of seasonal summer and interannual variability in precipitation. Variability in particular at boundary with southernmost extent of ITCZ. Variations in strength of cyclones also associated with storm surges, coastal flooding, and wind damage. For planning purposes it might be best to work on decreased annual rainfall, with any decrease most

Region	Climate change trend	Impacts	
		By 2025	By 2055
		not exceeding 10%; however increases of up to, perhaps, 10% are possible. Limited dependency on emissions.	likely not exceeding 10%, although decreases of perhaps 20% are possible in parts; however increases of up to, perhaps, 10% are also possible. The likelihood of decreased rainfall rises with greater emissions. Possibility of higher rainfall, and stronger winds and storm surges with Indian Ocean tropical cyclones. Likely greater seasonal water availability but issues of water quality.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5^{o}C to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, increased thunderstorm activity, higher sea surface temperatures (SST) driving strong cyclone events, drying out of coastal wetlands. Likely increase of MAAT by 0.5^{o}C to 3.0°C, but lower/higher values cannot be excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	More erratic precipitation regimes and increased subtropical cyclones, resulting in some likely increase in extreme flood events.	More erratic precipitation regimes, resulting in an increased likelihood of extreme flood events, both in severity and duration. This will have a multiplier effect in increasing vulnerabilities to other risk events and thus result in wider likely impacts, in particular in agriculture and health.
	Agriculture	Food insecurity arising from climatic instability with soil erosion.	Food insecurity arising from climatic instability, deforestation, increased intensity rain events driving higher soil erosion and soil fertility loss, higher sediment and nutrient runoff posing problems for eutrophication, water quality, precipitation hazards impacting on food production especially in rainfed agricultural areas.

Region	Climate change trend	Impacts	
		By 2025	By 2055
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to land surface erosion, effects on water quality due to soil erosion and floodwater contamination by sediments and organics; waterborne and biological diseases, including pests and diseases on agricultural crops. Flood events result in low water quality with implications for sanitation and water-borne diseases.
3	Precipitation variability	Continuing aridity of desert and semiarid environments. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 20% in parts; increases are unlikely in the west but may reach 10% in the east.	Continuing aridity of desert and semiarid environments; increased wind erosion, migration of sand dunes, decreased air quality and pollution, health effects, due to land surface aridity; episodic thunderstorms may result in soil erosion, flooding, especially in coastal areas; increased borehole extraction will result in decreased groundwater table, some ephemeral rivers will become permanently dry, perennial rivers may become ephemeral. Groundwater recharge will be reduced under all scenarios. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 20%, or even 30%, in parts; increases are unlikely in the west but may reach 10% in the east. Water supply will decrease under all future scenarios.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5°C to 2.0°C, but lower/higher values cannot be excluded; some increase in length of warm/drought spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, heatwaves inland, increased thunderstorm activity. Likely increase of MAAT by 0.5°C to 4.0°C, but lower/higher values cannot be excluded; almost certain increase in length and severity of warm/drought spells and reduced frequency of cold

Region	Climate change trend	Impacts	
		By 2025	**By 2055**
			periods.
	Extreme events	Increased frequency of drought and heatwave events.	Increased frequency and magnitude of drought events and soil moisture anomalies, which will have significant impacts on agricultural systems and sustainability.
	Agriculture	Food insecurity arising from climatic instability	Increased aridity may result in increased food insecurity, spread of invasive plant and insect species, locusts?, loss of rainfed agriculture and subsistence agricultural systems become less viable, decreased food production in some areas
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability	Health and nutrition effects, mainly as a result of longer term decreases in food production due to increased aridity, deflation of dry soils from the land surface, episodic soil erosion; food and water insecurity will increase, may be health impacts of increased pests and diseases; health impacts due to decreased water and air quality. Decreased surface water availability results in increased health and sanitation risk.
4	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation related to frequency/magnitude of incoming cyclones from Indian Ocean. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 10%, any increases are more likely east of the Escarpment.	Continuing trend of seasonal summer and interannual variability in precipitation, variations in strength of cyclones also associated with storm surges, coastal flooding, wind damage, heavy rainfall inland resulting in river flood events. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 10%; any increases are more likely east of the Escarpment. Possibility of higher rainfall, and stronger winds and storm surges with Indian Ocean

Region	Climate change trend	Impacts	
		By 2025	By 2055
			tropical cyclones. Water supply is maintained despite increased variability, but issues of decreased water quality during flood events.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5°C to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, increased thunderstorm activity, higher SST driving strong cyclone events, drying out of coastal wetlands that are important biodiversity hotspots. Likely increase of MAAT by 0.5°C to 3.0°C, but lower/higher values cannot be excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	Increased frequency of flood/wind events as a result of likely increased frequency of subtropical cyclones.	Increased frequency and/or magnitude of flood and wind events from the Indian Ocean.
	Agriculture	Food insecurity arising from climatic instability, deforestation and land degradation.	Food insecurity arising from climatic instability, increased intensity rain events driving higher soil erosion and soil fertility loss, higher sediment and nutrient runoff posing problems for eutrophication, water quality, precipitation hazards impacting on food production especially in rainfed agricultural areas, increased coastal flooding due to sea level rise.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to land surface erosion, effects on water quality due to soil erosion and floodwater contamination by sediments and organics; waterborne and biological diseases, including pests and diseases on agricultural crops, salinization of low lying areas, impacts on sanitation

Region	Climate change trend	Impacts	
		By 2025	By 2055
			through wastewater and sewage contamination of surface water, especially during floods.
5	Precipitation variability	Likely increases in rainfall variability and some evidence for increased annual rainfall totals. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with decreases up to 10% but perhaps reaching 20% in parts; any increases are most likely only in the far east of the region; some evidence for larger decreases with highest emissions.	Increasing variability in rainfall patterns, with variation in strength of winter cyclones from the Atlantic; resulting in coastal flooding and over mountains; aridity in northern and inland locations, decreased groundwater table in areas of increased aridity, variations in river discharge with associated changes in water quality during low flow stages and with increase water temperatures; increased land surface instability, soil erosion and deflation. Water supply and variability is driven by winter cyclone strength. Similar to the situation around 2025 but with greater chances of decreases to 20%, perhaps even towards 30%, along the west coast. There is some possibility that storm tracks affecting the south-west Cape region may move further south, consistent with reduced overall rainfall.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT of 0.5^{o}C to 1.5°C, but lower/higher values cannot be excluded; perhaps 0.5°C less warming over coastal regions; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, heatwaves inland with increased aridity, increased thunderstorm activity. Likely increase of MAAT of 0.5^{o}C to 3.0°C, but lower/higher values cannot be excluded; perhaps 0.5°C less warming over coastal regions; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	Increased variability of winter storm events from the Atlantic.	Increased frequency and/or magnitude of winter storms especially along the coast, flood events and thunderstorms inland especially over the Great

Region	Climate change trend	Impacts	
		By 2025	By 2055
			Escarpment.
	Agriculture	Food insecurity and land surface degradation arising from climatic instability.	Increased aridity may result in increased food insecurity in inland locations, spread of invasive plant and insect species especially affecting the fynbos biome, loss of rainfed agriculture and subsistence agricultural systems become less viable, decreased food production in some areas with less surface water availability and increased cost of extracting water by groundwater pumping.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to increased rainfall variability, deflation of dry soils in northern parts of the area, episodic soil erosion and impacts on water quality; may be health impacts of increased pests and diseases. Implications for sanitation where flood events result in water contamination.

Table 2 **Track 1 Risk Matrix**

	Hazard					
Project component	Flood	Drought	Fire	High Winds / Cyclones	Sea level rise	…
Irrigation pipe work	High	Low	Medium	No risk - N/A	No risk - N/A	Medium
River off-take infrastructure	High	Low	Low	No risk - N/A	No risk - N/A	Low
Boreholes	Medium	Low	Low	No risk - N/A	No risk - N/A	Low
Weir or dam	Medium	Low	Low	No risk - N/A	No risk - N/A	Low
Power generators	High	Low	Medium	No risk - N/A	No risk - N/A	Medium
Roads	High	Low	Low	No risk - N/A	No risk - N/A	Low
VIP Latrines	High	Low	Low	No risk - N/A	No risk - N/A	Low
Training & capacity building	Low	Low	Low	No risk - N/A	No risk - N/A	Low
…	Low	Low	Low	No risk - N/A	No risk - N/A	Low

Self-Organising Maps: Trying to Manage Uncertainty

The impacts interpretations given in **Error! Reference source not found.** are based on published IPCC information (2013). An improved interpretation would be offered by the use of Self-Organising Maps (SOMs) and downscaled climate model outputs. SOMs break down a series of data sets into groups or clusters of models with a statistical relationship to their projections, doing so without any assumptions of background distributions. SOMs are a statistical technique that collates similar values within the full set of possibility at as laid out in a data set.

SOM analyses can provide more detail than straightforward statistics (calculating the simple mean temperature and precipitation from the 40 GCMs discussed above – which are not normally distributed), and allow for planning/designs to be influenced by at least two differing scenarios. For maximum benefit, SOMs need to be calculated across relatively small areas (i.e. basin level) over which the climatology rainfall regimes are relatively consistent. However, part of the analysis carried out by CRIDF's climate change experts tested whether SOMs might be used (and indeed useful) over an area the size of southern Africa; the results of which indicated that the domain's climatology varied too significantly for the values presented in the SOMs to be treated as *absolute (*particularly for a project in a specific location). They should instead be used as indications of the *relative* ranges of predicted temperature and rainfall changes that may occur at given timescales and RCPs[10].

While it is not recommended that the southern Africa SOMs be used as an integral part of the Track 1 CCRA in terms of ascertaining absolute values of temperature and rainfall changes – they should still be consulted by the Project Team in an effort towards acknowledging and appreciating the potential range of uncertainty associated with this climate science, where both extreme and conservative scenario ranges are expressed in a visual manner.

The southern Africa SOMs for temperature and rainfall are illustrated and elaborated on below (see **Error! Reference source not found.** and Figure 6 with corresponding explanations).

It should be noted that temperature changes are along the x-axis and rainfall changes along the y axis. Colour codes are used for different periods throughout the Century; blue for 2020, black for 2050 and red for 2080.

Four charts have been selected, as climate scientists deem this a reasonable number of data sets/clusters. The following explanation refers to the charts as sequential numbers (1: top left, 2: bottom left, 3: top right, 4: bottom right).The sequence of the charts has no bearing on their importance; however it is assumed that the more likely groupings contain the greater number and more concentrated number of dots, each of which represent the

[10] Part of the SOMs calculations is to produce averages across the domain. Because of that SOMs are best calculated across areas, typically relatively small, over which the rainfall climatology is reasonably consistent. Over SADC a number of different regimes are present, and hence the mean is a mix of all of these. SADC-wide SOMs could be interpreted as the typical across the region. Consequently they should be used as a guide to managing uncertainty rather than a basic planning tool.

combined projections of temperature and rainfall changes for an individual model (colour coded according to time period).

All changes are provided in **relative** terms, an approach that allows for the fact that most models may not provide precise simulations of *local* climates.

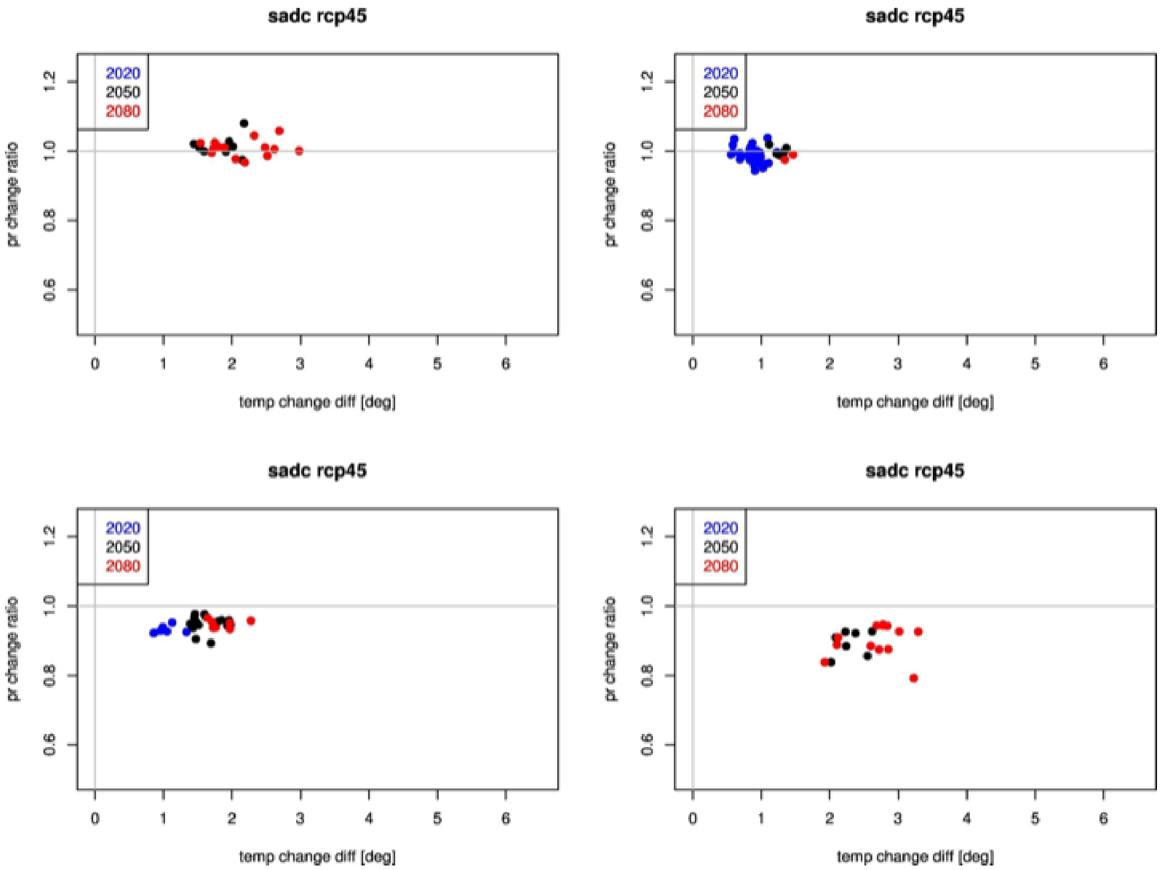

Figure 5 **SOMs analysis allowing 4 maps for the SADC region under RCP4.5.**

Observations from Figure 5:

- The RCP 4.5 is an optimistic scenario which the world is not currently on course to meet (based on the current Intended Nationally Determined Contributions [INDC] submitted by countries to date)[11].
- Models, without exception, project increased temperatures throughout the timescales presented.

[11] Based on the Paris (COP21) outcome it might argued that the best approach is to use RCP6.5, roughly what the world will achieve under the current INDCs submitted by Paris, and RCP2.6 which is the emissions pathway that is required to keep the world below a 2^{0}C rise in temperature (the target all countries agreed to at COP21). However, Cordex (the data base of Regional Climate Models which we have used to obtain our projections) does not include projections from RCP 6.5. Furthermore, given the uncertainty surrounding the sensitivity of the climate system and land system (i.e. it is likely to be non-linear) associated with a given increase in the concentration of Green House Gasses (GHG) the impacts identified with RCP8.5 could well occur under an emissions scenario similar to RCP6.5. The CRIDF approach is risk based and thus it encourages the analysis to explore a reasonable worst case scenario. In this case we have adopted RCP8.5, which is the emissions trajectory the world has been on to date.

- Majority of models project little change or decreasing rainfall in the future, with only a relative few projecting an increase. The predicted decreased average up to 20% across the region.
- There are four basic future climate scenarios arising from this analysis
  - Scenario 1 - Top right shows a tight cluster of 2020 projections (blue colour) where there is a 1^{o}C rise but no change in precipitation. This could then move through to the top left graph where the average temperature rises to about 1.5^{o} C and precipitation is reduced by around 5% by the 2050s (black dots)
  - The second scenario starts again in the top right (1^{o}C rise but no change in precipitation) this then moves to the bottom right chart where temperature rise beyond 2^{o}C and precipitation is reduced by 10% or more by the 2050s
  - The remaining 2 scenarios begin on the bottom left chart where there is a 1^{o}C temperature increase by 2020 and a 5% decrease in precipitation. This then moves into the top left (average temperature rises to about 1.5^{0}C and precipitation is reduced by around 5% by 2050s) or bottom right (temperature rise beyond 2^{o}C and precipitation is reduced by 10% or more by the 2050s.

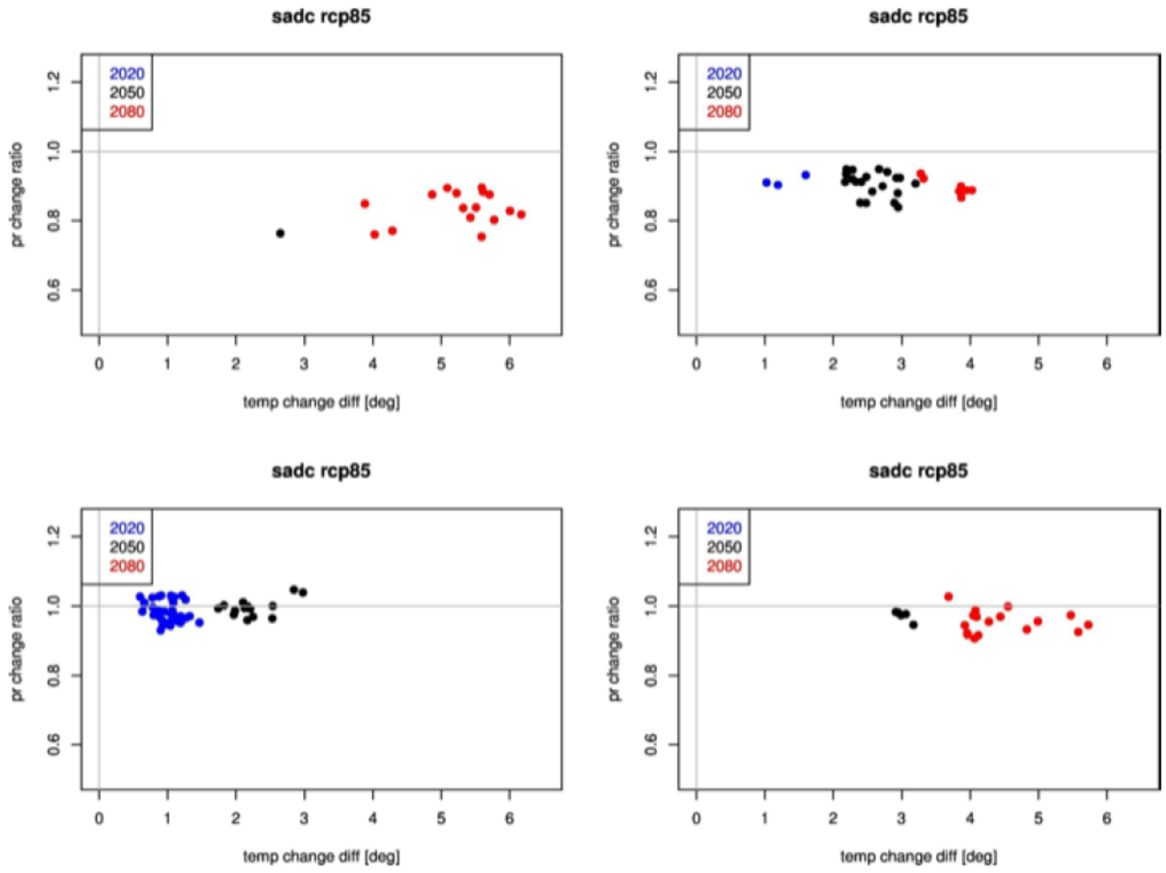

Figure 6 **SOMs analysis allowing 4 maps for the SADC region under RCP8.5.**

Observations from Figure 6:

- Scenario 1: Bottom left chart – the 2020s are characterised by about a 1°C temperature rise and roughly no change in precipitation. It then moves to the top right chart where the temperature rises to 2.5°C by 2050 and precipitation is reduced by over 10%
- Scenario 2: The 2020s start with a roughly similar temperature rise but a reduction in precipitation of about 5%. This then moves to a 3°C temperature rise but little change in precipitation by 2050.
- Scenario 3: Bottom left chart - 2020s are characterised by about a 1°C temperature rise and roughly no change in precipitation this then moves to an increase in temperature (2°C but still no change in precipitation.

- Finally it is worth noting that under RCP8.5 there starts to be **extreme changes** in temperature and precipitation by the 2080s over 5°C increase and over 20% reduction in rainfall (red dots)

These scenarios, in conjunction with those explained above for a RCP4.5, should be interrogated and discussed by the Project Team to determine which scenario(s) most accurately reflect the most likely/expected temperature and rainfall changes at the Project site, across the three time scales. This discussion should feed into the overall risk matrix ratings and recommendations component of the CCRA.

However, one must once again bear in mind that this is a sub optimal use of the SOMS due to the fact they represent an average change in temperature and precipitation across the whole of Southern Africa. Whilst this probably doesn't matter so much for temperature it might do so a little more for precipitation. Therefore outside Tanzania (the north of the region) the reduction in precipitation is likely to be less than might be identified by a basin level SOM from the southern part of the region. Whilst in the north of the area the increase in precipitation may be less exaggerated than a basin level SOM of that area might suggest. Consequently, once again this section on uncertainty should only be used as a guide or basis to discuss uncertainty and risk not a basic planning tool.

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