Climate Risk Profile for Southern Africa

Summary

This profile provides an overview of projected climatic changes and related impacts on different sectors in Southern Africa until 2080 **under different climate change scenarios** (called Representative Concentration Pathways, RCPs). RCP2.6 represents the low emissions scenario that aims to keep global warming likely below 2 °C above pre-industrial temperatures. RCP6.0 represents a medium to high emissions scenario that is likely to exceed 2 °C. **Model projections do not account for effects of future socio-economic impacts**, unless indicated otherwise.

Depending on the scenario, the **air temperature** over Southern Africa is projected to rise by 1.9 to 4.1 °C compared to pre-industrial levels, with the **highest temerature increases in Botswana, eastern Namibia and the north of South Africa**. Very hot days will also increase, especially over the Kalahari Desert, which covers parts of Botswana, Namibia and South Africa.

Precipitation trends are uncertain and vary across Southern Africa, indicating different directions of change. For example, under RCP2.6, by 2080, annual mean precipitation will change by between −19 and +1 mm, compared to the year 2000. **The southwest, centre as well as most of Zimbabwe and Mozambique are projected to become drier.** On the other hand, **Lesotho, Eswatini and eastern South Africa are projected to become wetter**. Future dry and wet periods are likely to become more extreme.

Under RCP6.0, **sea levels** are expected to **rise by 43 cm along the coast of Southern Africa until 2080**. This threatens coastal communities and economies and may cause saline intrusion in coastal waterways and groundwater reservoirs.

Water availability is driven by climatic and socio-economic factors. Projections show high uncertainty regarding changes in water availability, with **changes in opposite directions under the two emissions scenarios**. However, per capita water availability will likely decline by 2080, mostly due to population growth.

Due to changing climatic conditions, yields of cassava, groundnuts, maize and rice are projected to benefit from CO_2 fertilisation, while yields of **millet and sorghum are projected to decrease**. Wheat projections are highly uncertain.

Climate change is likely to cause **damage to the infrastructure sector** in Southern Africa including major roads, bridges and urban areas. Roads are the backbone of the region’s transportation network and essential in linking farmers and markets. Investments will need to be made into **building climate-resilient roads** and other infrastructure to maintain agricultural supply chains and foster economic growth.

Agro-ecological zones (AEZs) in Southern Africa might shift, affecting ecosystems, biodiversity and crop production. Models project **decreases in species richness** in most parts of the region under higher emissions and **varying trends for tree cover**, depending on the region and scenario.

The **share of the population affected** by at least one **heatwave** per year in Southern Africa is projected to rise **from 0.6 %** in 2000 **to 7.6 %** under RCP6.0 in 2080. This increase is likely to have adverse effects on human health, particularly that of vulnerable groups like women, children, elderly and chronically ill people. If appropriate measures are not taken, **heat-related mortality** is expected to **nearly triple** by the year 2080.

* This climate risk profile is a collaboration between Weathering Risk and the AGRICA project at PIK. It draws on the methodology developed within the AGRICA project.

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Context

Rising temperatures, changing precipitation patterns and more extreme weather events as a result of climate change pose **existential challenges to Southern Africa.** For millions of people across the region, climate impacts and related losses and damages will be felt in various sectors, including water, agriculture, infrastructure, ecosystems and human health.

Southern Africa is an African sub-region which has access to both the **Atlantic Ocean** and the **Indian Ocean** through more than **8,400 km of coastline**. While there are different definitions of the countries constituting Southern Africa, this climate risk profile follows the definition of the African Union [1], in which the region is defined as the states of **Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia** and **Zimbabwe** (Figure 1). In Southern Africa, the population amounts to **over 190 million people**, with South Africa being the most populous country (59 million) [2]. The region is characterised by varying population growth rates, ranging from 1.0 % in Eswatini and in South Africa to 3.2 % in Angola [2]. Based on these trends, the population of Southern Africa could reach more than 360 million by 2050 [2]. Furthermore, the population in Southern Africa is **one of the youngest in the world**, with more than 39 % aged 14 years and below [2].

Economic growth rates vary widely within the region and GDP per capita rates cover the spectrum from 389 US dollar in Malawi to 6,367 US dollar in Botswana [2]. Although most economies in Southern Africa recovered quickly after the **COVID-19 pandemic**, smallholder farmers were hit hard through sickness and trade restrictions. The **war in Ukraine** has further strained smallholder farmers through **increased prices** for different foods, fuel and fertilisers [3]. Irrespective of these more recent crises, Southern Africa has been long characterised by **high poverty** rates, with **large parts of the population living on less than 2.15 US dollar a day**, which is the World Bank threshold for extreme poverty. Especially Malawi (70 %), Mozambique (65 %) and Zambia (61 %) have high rates of extreme poverty, according to this definition [2]. Consequently, most countries in the region rank **among the lowest on the Human Development Index (HDI)** [4].

Figure 1:
Topographic map of Southern Africa.

Although the services sector contributes the largest share to Southern African economies, **agriculture** continues to be the **most important sector in terms of employment**, providing livelihoods for the majority of the population [2]. In some countries like Malawi, Mozambique or Zimbabwe, the share of employment in agriculture is over 60 % [2]. The majority of agricultural production in Southern Africa is **subsistence-based and rain-fed**. Hence, especially smallholder farmers suffer from climate impacts like rising temperatures, droughts or flooding, all of which can lead to crop failures and reliance on food assistance programs [5]. Especially **women are disproportionately affected** by climate impacts, due to a greater dependence on natural resources and disparities in climate information, mobility and gendered responsibilities for children and other family members. In addition, climate change is impacting the **availability of fertile soils and grasslands**, which are essential resources not only for farmers but also for herders. Particularly in **Botswana and Namibia**, where **pastoral or agropastoral livelihoods** are among the dominant agricultural systems, a reliance on livestock production has been challenged by increasingly unpredictable precipitation patterns and decreasing grassland productivity [6], [7]. In turn, these changes have led to increasing **competition over limited natural resources** among different pastoral communities but also **between livestock and wildlife**, with mounting cases of crop raiding and livestock depredation [8].

Although **many countries on the African continent tend to be characterised by weak governance**, including poor provision of participatory structures, basic services and accountability mechanisms, **Southern Africa scores relatively high** in terms of its overall governance, with Botswana, South Africa and Namibia being among the top 10 countries on the 2022 Ibrahim Index of African Governance [9]. The remaining countries in the region take varying ranks, with **Angola scoring lowest** on place 40 out of 54.

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Topography and environment

Southern Africa's **topography is very diverse**, ranging from **coastal plains** and **plateaus** to **mountainous regions** and **deserts.** Narrow plains line the areas both on the Atlantic and Indian Ocean coasts. A steeply rising inland plateau, the Great Escarpment, extends from Angola to the border of Mozambique and Zimbabwe, separating the coastal areas from the interior highlands. It reaches the region's highest peak at **Thabana Ntlenyana (3,482 m)** in the Drakensberg Mountains in Lesotho. The interior of Southern Africa consists of mainly hilly plateaus. The extremely dry Namib Desert in southwestern Angola and Namibia merges into the Kalahari Desert in Namibia's southwest, which extends through Botswana and South Africa's Northern Cape Province.

The region comprises **different agro-ecological zones (AEZs)** with specific temperature and moisture regimes (Figure 2). A **tropical humid to sub-humid climate** extends over most of Angola, Zambia, Malawi, Zimbabwe, as well as northern Botswana and Namibia. The **arid tropical climate** of the Namib Desert and Kalahari Desert covers large parts of Namibia and Botswana, as well as border regions shared by Zimbabwe, Mozambique and South Africa. The climate shifts to a subtropical arid (in the west) and semi-arid (in the east) zone in large parts of South Africa, southern Namibia and Botswana, with increasing humidity towards the coastal regions, where a sub-humid climate prevails.

Lake Malawi (also known as Lake Nyasa), bordering Malawi to the east, Zimbabwe to the south and Mozambique to the west, is the largest lake of the region and the fifth-largest freshwater lake in the world (in terms of water volumes), presenting an **essential freshwater resource** for the population in the region [10]. Important rivers include the Zambezi, Limpopo, Orange and Okavango Rivers, all of which flow eastward to the Indian Ocean, except the Orange River (Figure 1). The Zambezi is the longest river. It rises in Zambia and empties into the Indian Ocean on the coast of Mozambique. Eight countries (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe) have a share in its catchment area of around 1.4 million m³, making it the fourth-largest African river basin. Similarly, the Limpopo and Orange river basins are shared by four countries each [11], and all countries share at least two river basins with neighbouring states, which complicates **an equal distribution of water resources** in the region. In Botswana, 94 % of total river discharge originates from outside the country [12]. Mozambique, too, is a downstream recipient of water resources from most river basins, making the country highly dependent on inflows from countries further upstream [11].

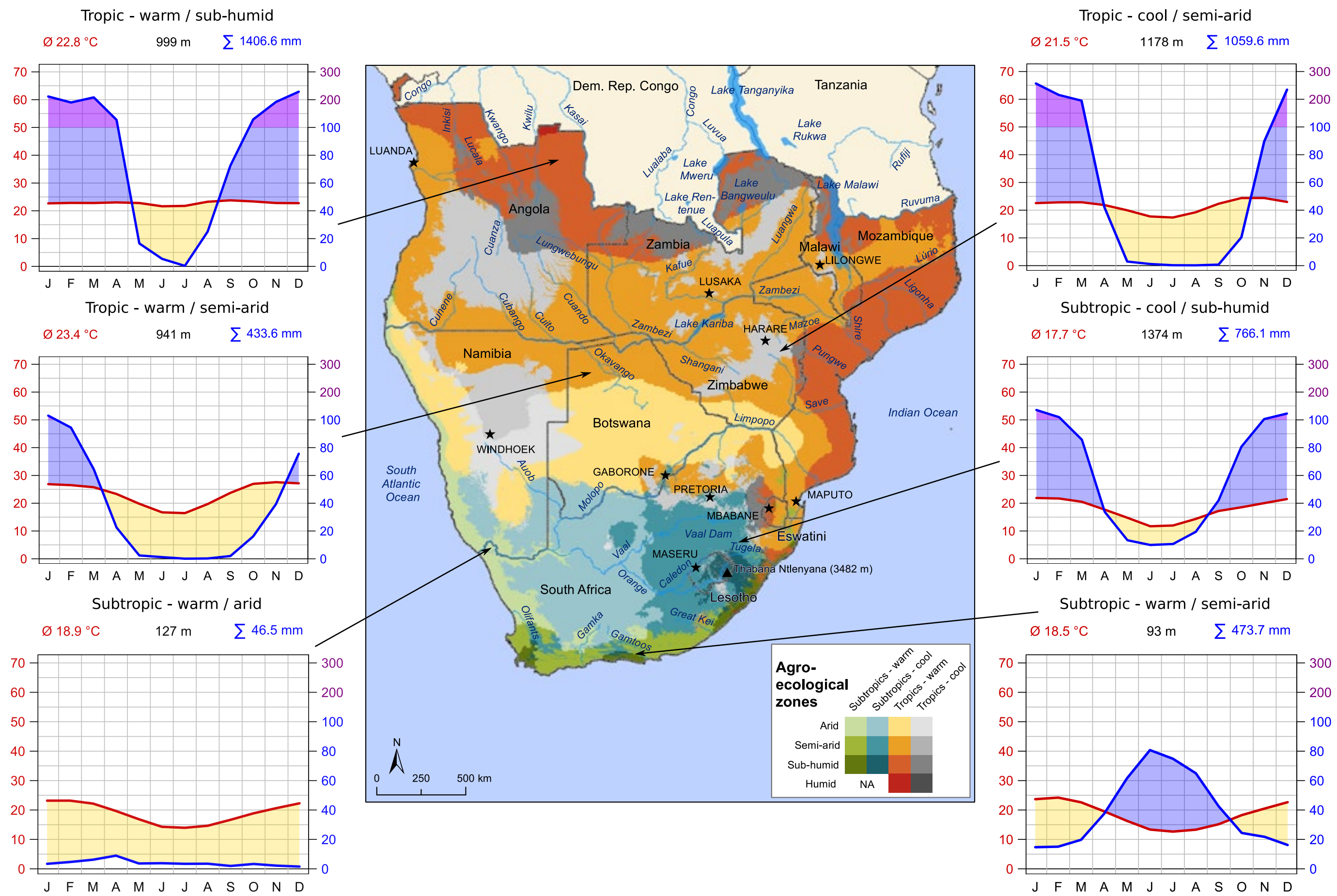

Figure 2: Map of Southern Africa showing agro-ecological zones and location-specific examples of annual temperature and precipitation patterns.

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Present and past climate

Present climate

Southern Africa has a very **diverse climate,** which is largely **influenced by its geographic location and elevation**. Mean annual **temperatures vary significantly**: Over the desert regions of Namibia and Botswana, daytime temperatures exceed 40 °C during the summer months. Temperatures decrease southwards and are lowest in the highlands of Lesotho, South Africa and Zimbabwe [13].

Precipitation in the region depends on the interaction of **multiple drivers**, including global atmospheric patterns, the influences of the warm Indian Ocean and the cold Atlantic Ocean, as well as the seasonal movement of the Intertropical Convergence Zone (ITCZ).[1] Typically, the region experiences **two seasons** (unimodal precipitation regime), with a rainy season occurring from November to March and a dry season from April to October, except for the Western Cape region, which receives most of its precipitation from June to August. There is a **significant variation in precipitation amounts across the region**, which follows an **east-to-west gradient**. The western Namibian coast experiences arid conditions, while the tropical coastal region of Mozambique receives higher levels of precipitation. Consequently, annual precipitation sums range from around 2,000 mm in central Mozambique to less than 20 mm in the Namib Desert [13]. Furthermore, the region experiences **high year-to-year variabilities** which are related to the El Niño-Southern Oscillation (ENSO)[2]. During El Niño events, temperatures increase and precipitation decreases, while during La Niña events, above-average precipitation is typical. The ENSO also influences the occurrence of extreme weather events such as cyclones, droughts and flooding in Southern Africa.

Past climate

Between **1961 and 2015**, mean **annual temperatures** over Southern Africa increased by between **1.04 and 1.44 °C.** This increase was even higher in Botswana and Zimbabwe, with an increase of 1.6 °C to 1.8 °C in the period 1961–2010. Hot days became more frequent, while the frequency of cold extremes decreased [15]. Overall, a **reduction in mean annual precipitation** has been observed over Southern Africa, although parts of Namibia, Botswana and southern Angola experienced increasing precipitation from 1980 to 2015. The frequency of droughts has increased since 1961, while **heavy precipitation events** have become more intense over the last century [15]. Furthermore, a rise in the occurrence of prolonged episodes of heavy precipitation, lasting for more than five consecutive days, has also increased since the 1950s [16].

1) The ITCZ is the global low-pressure zone through which northern and southern trade winds converge [14].

2) The El Niño-Southern Oscillation (ENSO) is an irregular climate phenomenon that causes fluctuations in sea surface temperatures and associated changes in atmospheric pressure in the equatorial Pacific Ocean. These changes in the water and atmosphere can affect weather patterns around the globe. The ENSO consists of three phases: The neutral state, and El Niño and La Niña events that occur at irregular intervals (approximately every 2–7 years).

Projected climate changes

How to read the line plots

historical — best estimate
RCP2.6 — likely range
RCP6.0 — very likely range

Lines and shaded areas show multi-model percentiles of 31-year running mean values under RCP2.6 (blue) and RCP6.0 (red). Lines represent the best estimate (multi-model median) and shaded areas the likely range (central 66 %) and the very likely range (central 90 %) of all model projections.

How to read the map plots

Colours show multi-model medians of 31-year mean values under RCP2.6 (top row) and RCP6.0 (bottom row) for different 31-year periods (central year indicated above each column). Colours in the leftmost column show these values for a baseline period (colour bar on the left). Colours in the other columns show differences relative to this baseline period (colour bar on the right). The presence (absence) of a dot in the other columns indicates that at least (less than) 75 % of all models agree on the sign of the difference. For further guidance and background information about the figures and analyses presented in this profile please refer to the supplemental information.

Temperature changes

Air temperature

The **air temperature over Southern Africa is projected to rise by 1.9 to 4.1 °C** (very likely range) by 2080 relative to the year 1876, depending on the future GHG emissions scenario (Figure 3). Under the low emissions scenario RCP2.6, compared to pre-industrial levels, the projected air temperature increase will very likely range between 1.8 and 2.1 °C by 2030, and between 1.9 and 2.2 °C by 2080. Median increases amount to approximately 1.9 °C in 2030, 2.1 °C in 2050 and 2.2 °C in 2080 under RCP2.6. Under RCP6.0, air temperature will increase by between 1.7 and 1.9 °C by 2030, and between 2.9 and 4.1 °C by 2080 (very likely range). Median increases amount to 1.9 °C in 2030, 2.4 °C in 2050 and 3.4 °C in 2080.

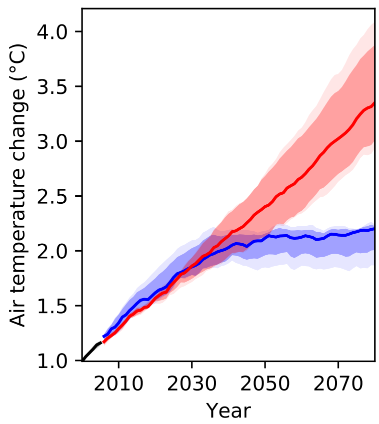

Figure 3: Air temperature projections for Southern Africa for different GHG emissions scenarios.[3]

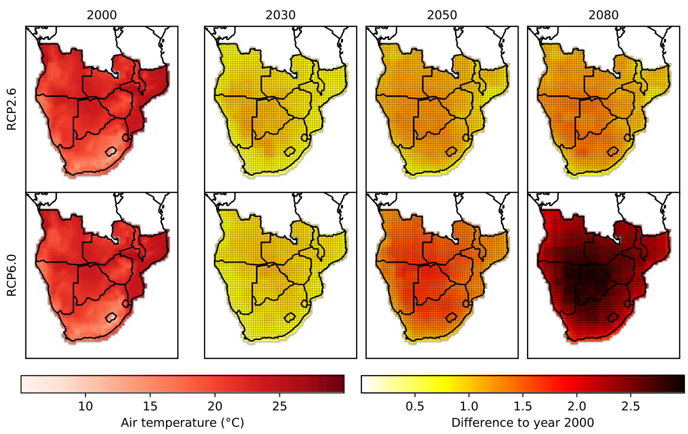

Figure 4: Regional air temperature projections for Southern Africa for different GHG emissions scenarios.

Air temperature increases will affect the entire region (Figure 4). However, their magnitude will vary: The highest values are projected for Botswana, where average temperatures under RCP6.0 will increase by up to 2.9 °C by 2080. Similar temperature increases are projected for eastern Namibia and the north of South Africa. Temperature increases in coastal areas will be comparatively smaller.

3) Note that the baseline for Figure 4 is the year 2000, while for Figure 3, this is the year 1876. Hence, the projected differences are lower for Figure 4 than for Figure 3.

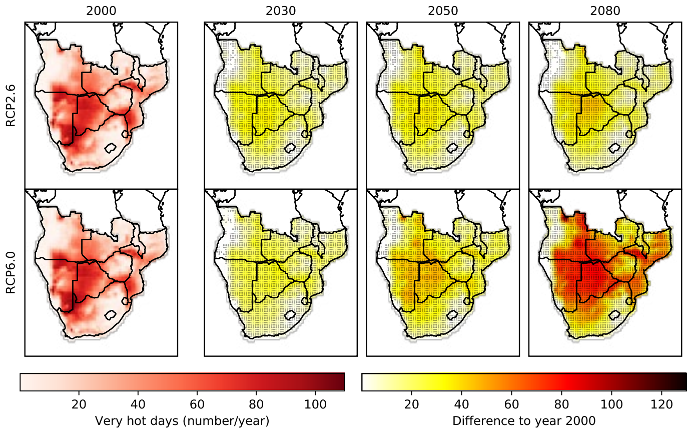

Figure 5: Regional projections of the annual number of very hot days (daily maximum temperature above 35 °C) for Southern Africa for different GHG emissions scenarios.

Very hot days

In line with rising mean annual temperatures, the **annual number of very hot days (daily maximum temperature above 35 °C) is projected to increase** (Figure 5). Especially across the Kalahari Desert, in northern Angola and along the border of Zimbabwe and Botswana, where very hot days are already common, a sharp increase is projected. Under RCP6.0, by 2080, very hot days will increase by **up to 122 days** per year in the north of Angola. The western coastal region will be less affected by extreme heat. Furthermore, some mountainous regions, including the west of Angola and the mountains of Lesotho, will not experience additional very hot days.

Sea level rise

Sea level rise is **not uniform across the globe** but subject to regional differences due to thermal expansion of water and ocean currents, among other factors. Averaged over the entire coastline of Southern Africa, median **increases in sea level rise** amount to 11.4 cm by 2030 and 35.9 cm by 2080 under RCP2.6, compared to the year 2000 (Figure 6). While the median sea level rise under RCP6.0 will increase to around 11 cm by 2030, the long-term median increase will be much higher than under RCP2.6, amounting to over **43 cм by 2080**. However, uncertainty around the magnitude increases with time. Rising sea levels threaten coastal communities and economies and may cause **saline intrusion in coastal waterways and groundwater reservoirs**, rendering water unusable for domestic use and harming biodiversity.

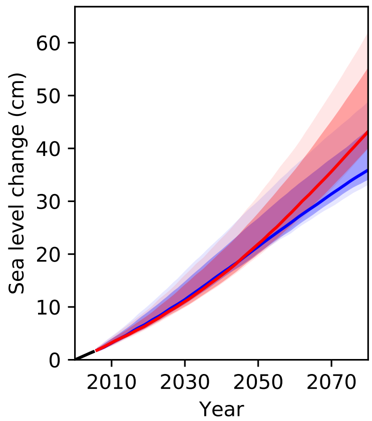

Figure 6: Projections for sea level rise, averaged over the Southern African coastline for different GHG emissions scenarios, relative to the year 2000.

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Uncertainties in climate change projections

Uncertainties are always part of climate change projections. They arise from various factors, including natural variability, uncertainties in GHG emissions scenarios and differences in the models which are used in the projections [19]. Consequently, no future (climate change) projection comes without some level of uncertainty. The levels of uncertainty, however, differ. We present the results of ten different global models. To indicate the uncertainty of the projections we consider model agreement. The more models agree, the higher the certainty; the more they disagree, the lower the certainty. For example, if different models project a similar result under the same scenario, the projected changes demonstrate low levels of uncertainty. However, if they project very different changes (in terms of range and even direction) under the same scenario, then projections are uncertain. Generally, projections regarding temperature-related data are more certain than projections regarding precipitation-related data. Precipitation-related data is subject to higher uncertainty, as many of the atmospheric and surface processes that influence local precipitation patterns are difficult to model in their entirety. For example, while the formation of clouds is an important factor for precipitation, it takes place at a smaller scale than that which is applied in global models in order to model processes at a much larger scale, which is equally relevant for local precipitation.

Precipitation, flood and drought risks

Precipitation

Precipitation projections differ depending on the scenario and **show changes in opposite directions** (Figure 7). Under RCP2.6, median projections project a **decrease in precipitation** from the year 2000 until around 2035, after which precipitation amounts recover by 2050. Eventually, precipitation amounts go back to below-2000 levels. In contrast, under RCP6.0, median model results indicate an increase in mean annual precipitation until 2030, after which precipitation amounts return to year 2000 levels in 2050. Afterwards, precipitation amounts increase again. Overall, high modelling uncertainty in precipitation projections results in a wide range of possible precipitation outcomes, which is shown by the relatively large shaded areas.

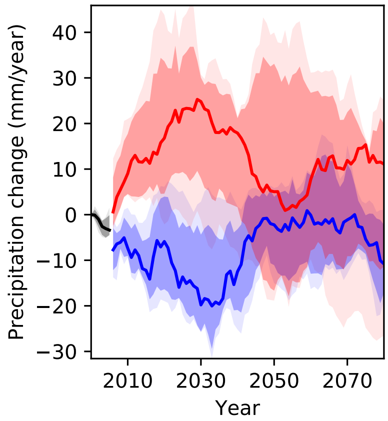

Figure 7: Annual mean precipitation projections for Southern Africa for different GHG emissions scenarios, relative to the year 2000.

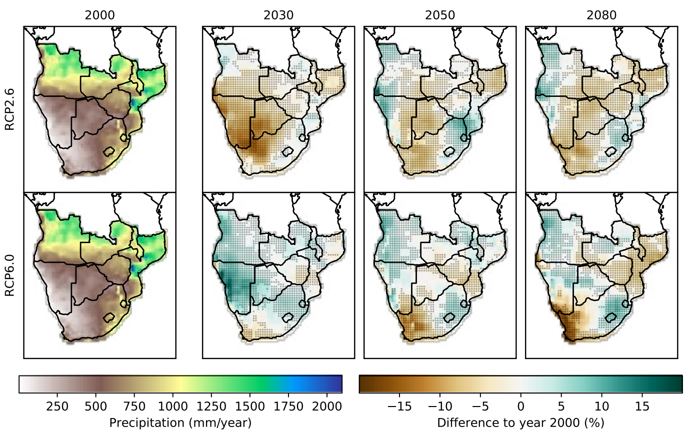

Figure 8: Regional projections of the annual mean precipitation for Southern Africa for different GHG emissions scenarios, relative to the year 2000.

Not only do the amounts of precipitation changes vary, but also their direction and magnitude vary (Figure 8). Overall, **the already dry southwest and centre of Southern Africa are projected to become drier** under both scenarios. A similar trend is projected for most of Zimbabwe and Mozambique. In contrast, **precipitation amounts will increase over the southeast**, including Lesotho, Eswatini and eastern South Africa. The remainder of the region shows a mixed picture of increases and decreases, in addition to uncertainties regarding the direction of change.

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Frequency of heavy precipitation events

In response to global warming, **heavy precipitation events are expected to become more intense in many parts of the world** due to the increased water vapour holding capacity of a warmer atmosphere. At the same time, the number of days with heavy precipitation events is expected to increase. This tendency is also reflected in climate projections for Southern Africa. Despite uncertainties, the overall number of **days with heavy precipitation is projected to increase** (Figure 9). However, looking at different parts of the region, there are marked differences both in the direction and magnitude of change. While most parts of the region will experience more days with heavy precipitation, the frequency of heavy precipitation events is projected to decrease in the southwest under both scenarios.

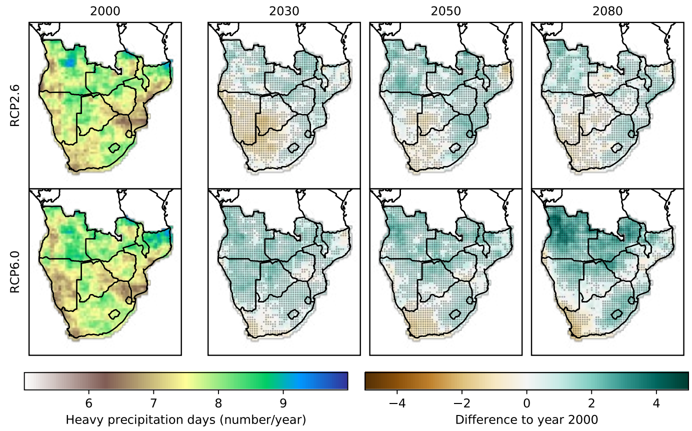

Figure 9: Regional projections of the number of days with heavy precipitation over Southern Africa for different GHG emissions scenarios, relative to the year 2000.

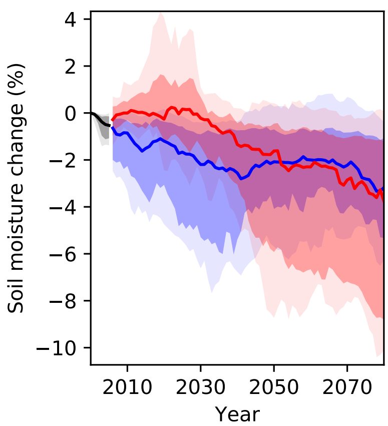

Figure 10: Soil moisture projections for Southern Africa for different GHG emissions scenarios, relative to the year 2000.

Soil moisture

Soil moisture is an **important indicator for drought conditions**. In addition to soil properties and management, it depends on both precipitation and evapotranspiration and therefore also on temperature, as higher temperatures translate to higher potential evapotranspiration. Projections for annual mean soil moisture for a soil depth of up to 1 metre show a **decrease of 3.2 % under RCP2.6 and 3.8 % under RCP6.0** by 2080, compared to the year 2000 (Figure 10). Similar values can be observed throughout the century. However, among the different models underlying this analysis, there is **large year-to-year variability and modelling uncertainty**, with one model projecting no change, two models projecting moderate decreases and one model a stronger decrease in soil moisture. The degree of uncertainty is reflected in the very likely range, which widens towards the end of the century, covering a range of decreases from −0.4 % to −6.3 % under RCP2.6 and −0.1 % to −10.1 % under RCP6.0.

Potential evapotranspiration

Potential evapotranspiration is the amount of water that would be evaporated and transpired if sufficient water was available at and below the land surface. Since warmer air can hold more water vapour, it is expected that **global warming will increase potential evapotranspiration in most regions of the world**. In line with this expectation, hydrological projections for Southern Africa indicate a stronger and more continuous rise of potential evapotranspiration under RCP6.0 than under RCP2.6 (Figure 11). Under RCP6.0, **potential evapotranspiration is projected to increase by 2.7 % in 2030 and by 8.3 % in 2080,** compared to the year 2000. Under RCP2.6, projections show an increase by 3.6 % in 2030 and a preliminary peak of 4.2 % around the year 2042, after which the increases settle around this rate, before slowly increasing again and reaching 4.7 % in 2080.

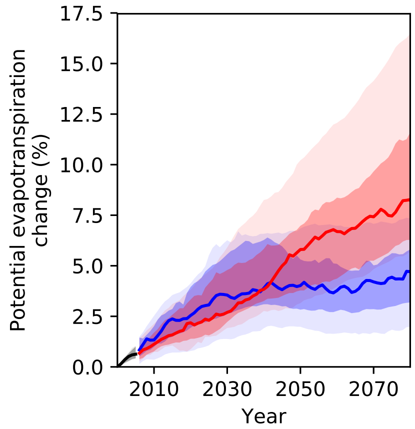

Figure 11: Potential evapotranspiration projections for Southern Africa for different GHG emissions scenarios, relative to the year 2000.

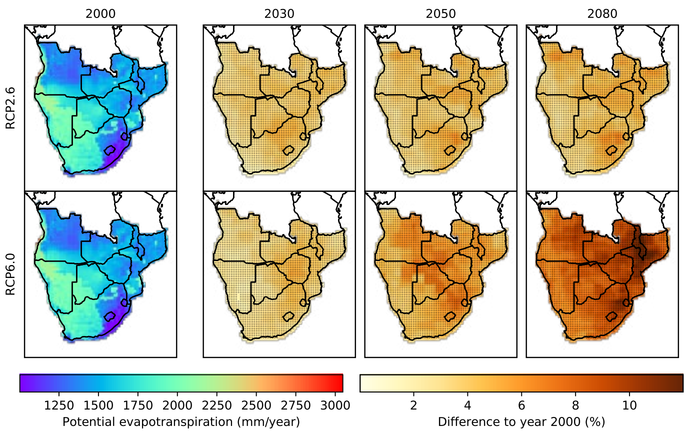

Figure 12: Regional projections of potential evapotranspiration for Southern Africa for different GHG emissions scenarios, relative to the year 2000.

An **increasing trend** in potential evapotranspiration can be observed **all over Southern Africa** and with high certainty (Figure 12). Countries which already experience high rates of potential evapotranspiration, such as Botswana, Namibia and South Africa, will see the lowest percentage increases. However, they will arrive at the highest absolute rates by the end of the century. The **highest percentage increases will take place in Malawi and Mozambique**. Higher evapotranspiration affects the water supply and the amount of surface water available for agriculture. It can reduce the fraction of precipitation that flows over land and into streams and rivers. Long-term shifts in recharge patterns can change groundwater levels and subsequently groundwater surface water interactions and soil moisture.

Sector-specific climate change risk assessment

a. Water resources

Assuming a constant population level, multi-model median projections suggest nearly constant water availability from the year 2000 to 2080 under RCP2.6 and a slightly more variable water availability under RCP6.0 (Figure 13A). Yet, **when accounting for population growth according to SSP2 projections[4], per capita water availability for Southern Africa is projected to decline,** i.e. from around 8,700 m³ in the year 2000 to around 3,400 m³ and 3,700 m³ in the year 2080 under RCP2.6 and RCP6.0, respectively (Figure 13B). **This decline is not primarily driven by climate change, but rather by socio-economic factors.** These factors include population growth, along with increased agricultural production, leading to increased water abstraction for irrigation, drinking water, domestic use and hydropower generation [17]. The decline in water availability highlights the urgency to invest in water saving measures and technologies and cooperation on shared water resources.

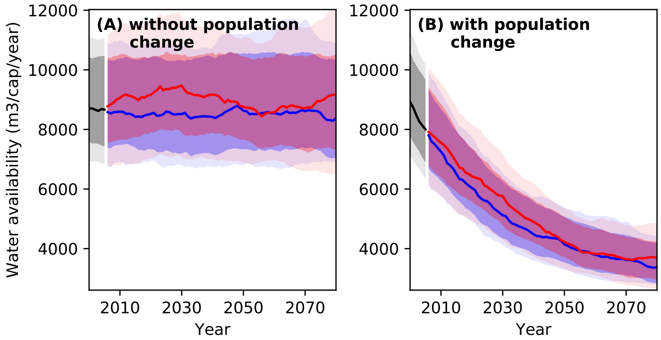

Figure 13: Projections of water availability from precipitation per capita and year with (A) national population held constant at year 2000 level and (B) changing population in line with SSP2 projections for different GHG emissions scenarios, relative to the year 2000.

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4) Shared Socio-economic Pathways (SSPs) outline a narrative of potential global futures, including estimates of broad characteristics such as country level population, GDP or rate of urbanisation. Five different SSPs outline future realities according to a combination of high and low future socio-economic challenges for mitigation and adaptation. SSP2 represents the “middle of the road”-pathway.

Southern Africa's freshwater resources are distributed unevenly over space and time [18]. Most countries in the region are classified as arid and semi-arid, with only the northern parts of Zambia and Angola showing sub-humid to humid climatic conditions [19]. Zimbabwe, South Africa and Eswatini experience low, medium and high water stress, respectively [9]. Figure 14 displays changes of water availability expressed through runoff from precipitation and shows that precipitation amounts across Southern Africa are highly variable. Median projections of water availability from precipitation for RCP2.6 and RCP6.0 differ significantly for the near future. Under RCP6.0, changes in runoff are projected to increase by 6.6 % in 2030, compared to the year 2000, whereas under RCP2.6, projections show a decrease of 2.6 %. Toward mid-century, projections of both scenarios converge and resemble the 2000 runoff, before diverging again towards 2080 (Figure 14). However, there is high modelling uncertainty, which is illustrated by the large shaded areas.

Already today, **Southern Africa has one of the lowest conversion rates of precipitation to runoff water worldwide**, due to high temperatures and rapid evaporation, as well as degraded soils with low vegetation cover [20]. For example, in South Africa, only about 9 % of precipitation translate into runoff [21]. The uneven distribution of water resources can create **tensions between different riparian communities**, in particular between upstream and downstream communities, as water withdrawals further upstream tend to affect downstream riparian communities [22]. One example is the conflict over the Chobe River whose catchment area includes parts of Angola, Botswana, Namibia and Zambia. Although Sedudu Island officially belongs to Botswana, drought-induced declines in water levels have prompted Namibian fishermen to move to the Botswana side of the island. Rising tensions have led to shootings and subsequent arrests of Namibian fishermen by the Botswanan army [23]. Similar disputes arising from the use and ownership of the Orange River and Limpopo River have also led to tensions between countries sharing these rivers [24].

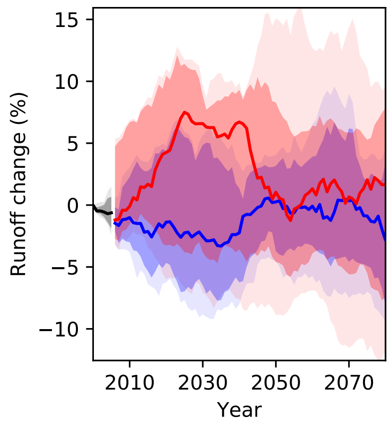

Figure 14: Water availability from precipitation (runoff) projections for Southern Africa for different GHG emissions scenarios.

b. Agriculture

Most of Southern Africa depends heavily on agriculture to sustain rural livelihoods and economic growth. The majority of farming systems in Southern Africa are **cereal-based crop systems**, with **maize** being the **dominant crop**, followed by **sorghum and wheat** [25]. Although **smallholder farmers constitute the bulk of farmers** in the region, in countries like South Africa and Namibia the agricultural sector is dominated by commercial production systems [26]. In South Africa, commercial farming systems outweigh smallholder farming systems at 80 % of agricultural output (International Trade Administration, 2021). Similarly, in Namibia, commercial farming systems cover a larger area than smallholder farming systems, although the latter employ the majority of the population. Around 70 % of the country's population depend directly or indirectly on agriculture for their livelihoods, which is complicated by the country's limited suitability for farming, due to **harsh natural conditions, poor access to markets and high-quality seeds**, among other factors [27]. Unlike Namibia, Angola has an abundance of arable land and diverse climatic conditions that are suitable for producing a variety of agricultural products. Nevertheless, due to a collapse of agricultural production as a result of the civil war, only 10 % of the 35 million hectares of arable land in the country are currently being cultivated [28]. In South Africa, field crops like cereals or legumes, as well as horticultural crops have gained importance. However, in 2021, animals and animal products still accounted for almost 40 % of total agricultural sales [29]. **Livestock is an important component of farming systems** in Southern Africa, mostly including cattle, goats, sheep and chickens [30]. Similarly, in southern Zimbabwe and Zambia, where crop production is marginal, cattle rearing dominates agricultural activities. In Zimbabwe, for example, it is estimated that up to 60 % of rural households own cattle, 70–90 % own goats and over 80 % own chickens [31].

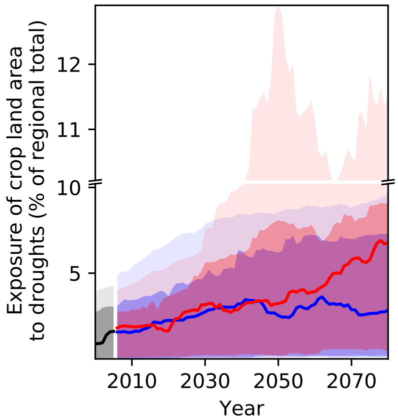

Figure 15: Projections of crop land area exposed to drought at least once a year for Southern Africa for different GHG emissions scenarios.

Agricultural production in Southern Africa is linked to **different global environmental, economic and socio-political factors** [32]. A heavy reliance on climate-sensitive crop production systems and a declining natural resource base, as well as the lack of timely access to input and output markets, contribute to this precarious baseline. In addition, local institutions and traditional social protection systems are often non-existent or not accessible to large parts of the population [33].

Currently, the high uncertainty of precipitation projections (see Figure 7) translates into high uncertainty of drought projections (Figure 15). According to the median and compared to the year 2000, the national **crop land area exposed to at least one drought** per year will slightly **increase under both emissions scenarios** by 2080, with 2.5 % under RCP2.6 and 4.1 % under RCP6.0. While median projections are rather small, the range of projected changes shows a different picture: The very likely range for RCP6.0 indicates that up to 12 % of national cropland could be affected by drought by mid-century.

In terms of **yield projections**, median projections for RCP6.0 indicate a **positive trend** for **cassava** (19 %), **groundnuts** (3 %), **maize** (5 %) and **rice** (2 %), a rather **stable trend** for **wheat** (−1 %) and a **negative trend** for **millet and sorghum** (−5 %) by 2080, compared to the year 2000 (Figure 16). Most crops show similar trends under both emissions scenarios, but the trends under RCP2.6 and RCP6.0 for cassava and groundnuts diverge after 2030. Projections for groundnut yields by 2080 even show a loss of 5 % compared to yields in 2000. Median projections of **wheat yields show high levels of uncertainty,** especially for the high emissions scenario, and no clear trend towards the end of the century.

Although some yield changes may appear small at the regional level, they will likely increase more strongly in some countries and, conversely, decrease more strongly in other countries as a result of climate change. Figure 17 shows that changes in maize yields are highly variable between and within countries. For example, by 2080 and under RCP6.0, the South African province Northern Cape will see increases of up to 99 %, while the province Western Cape will see decreases of up to 76 %. These different changes point to a **shift in crop suitability**, with some regions becoming unsuitable and others becoming suitable for growing different crops. **Farmers will have to adapt to these changing conditions.** Overall, **crop growth and failure depend on a variety of factors** which are projected to change in the future. While higher frequency and intensity of extreme weather events, such as flooding, droughts or heat stress, can have negative effects, other climate-related changes can have positive effects, including increasing levels of water availability, higher temperatures in highland areas or greater concentrations of carbon dioxide, which can facilitate photosynthesis in some crops and spur growth.

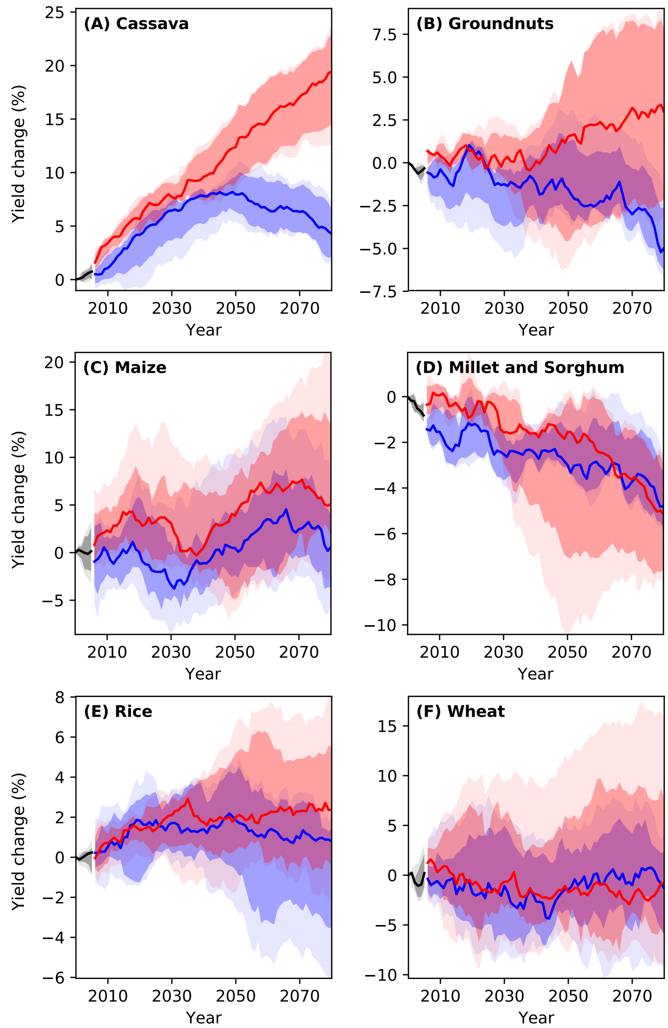

Figure 16: Projections of crop yield changes for major staple crops in Southern Africa for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

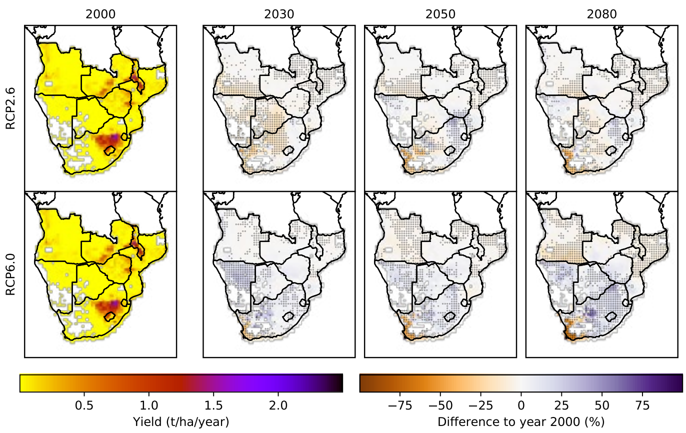

Figure 17: Regional projections of maize yields for Southern Africa for different GHG emissions scenarios assuming constant land use and agricultural management, relative to the year 2000.

Climate impacts on agricultural production can have **differential impacts for men and women**, who have different access to resources and whose tasks in rural households are often gendered [34]. For example, in parts of Zambia, it is common that women travel long distances to fetch water in response to declining water levels in streams and wells, leaving women with less time for other tasks [35]. In addition, women farmers tend to be responsible for feeding their families, which increases their **vulnerability to climate-related crop losses and failures**. Furthermore, women farmers are less mobile and, accordingly, have fewer opportunities for income diversification. While men are able to search for alternative work in other sectors, these **opportunities are rarely available to female farmers** [35].

c. Infrastructure

Climate change is expected to affect the infrastructure of Southern Africa. High precipitation amounts can lead to the **flooding of transport networks**, while high temperatures can cause **roads, bridges and infrastructures to develop cracks and degrade more quickly**. The Rural Access Index, which is defined as the proportion of the rural population living within 2 km of an all-season road, lies between 34–76 % in Southern Africa, depending on the country. While Zambia, Mozambique and Angola achieve the lowest scores with 34–48 %, countries further south like Eswatini (76 %) and South Africa (74 %) achieve the highest scores [36]. Especially during the rainy season, many **inland rural roads are inaccessible**, cutting off villages and communities. Investments will have to be made to build climate-resilient infrastructure, such as roads and railway networks.

Extreme weather events also have **devastating effects on human settlements and economic production sites**, especially in cities like Luanda, Johannesburg or Cape Town, characterised by large populations and high population density. **Informal settlements are particularly vulnerable to extreme weather events**: Make-shift homes are often built at unstable geographical locations including steep slopes or riverbanks, where strong winds and flooding can lead to landslides, contamination of water, loss of housing, injury or death. Dwellers usually have a low adaptive capacity to respond to such events due to high levels of poverty and lack of risk-reducing infrastructures. For example, after heavy precipitation in April 2022, the **eastern part of South Africa experienced heavy flooding**, which led to **448 deaths** and the **displacement of more than 30,000 people** [37]. The flooding caused damage and destruction of houses, health centres, schools, as well as infrastructures, including roads, bridges, and electricity and water infrastructures [37]. It coincided with other challenges including the COVID-19 pandemic and a series of tropical cyclones earlier in the year, forcing people to cope with back-to-back shocks.

While climate change is likely to cause damages to infrastructure, a precise projection of the location and extent of these impacts is difficult to make. Local vulnerability assessments of critical infrastructure are needed. For example, projections of river flood events are subject to high modelling uncertainty, largely due to the uncertainty of future projections of precipitation amounts and their spatial distribution, which affects flood occurrence (see Figure 7). In the case of Southern Africa, median projections show an **increase in national road exposure to river floods** under RCP6.0 (Figure 18). In 2000, 0.12 % of major roads were exposed to river floods at least once a year. By 2080, this value is projected to slightly increase to 0.14 % under RCP6.0 and to remain nearly unchanged under RCP2.6. While the median change appears small, a look at the range of changes shows higher possible changes. For example, under RCP6.0, the very likely range will widen from 0.08–0.16 % in 2000 to 0.10–0.24 % in 2080.

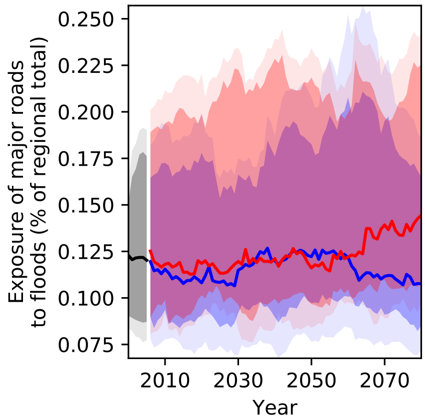

Figure 18: Projections of major roads exposed to river floods at least once a year for Southern Africa for different GHG emissions scenarios.

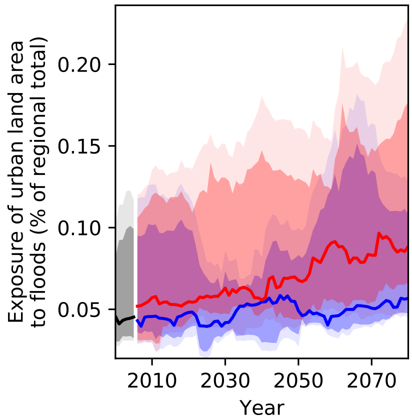

Figure 19: Projections of urban land area exposed to river floods at least once a year for Southern Africa for different GHG emissions scenarios.

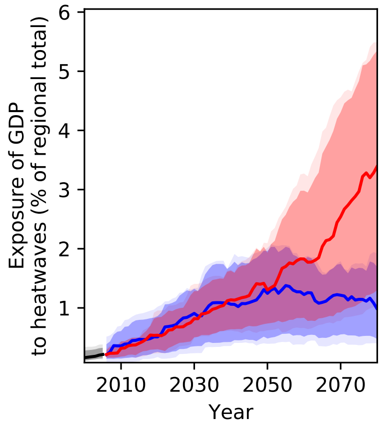

Figure 20: Exposure of GDP in Southern Africa to heatwaves for different GHG emissions scenarios.

The median **exposure of urban land area to river floods** shows a similar picture: Under RCP2.6, it is projected to change slightly from 0.05 % in 2000 to 0.06 % throughout the century, while under RCP6.0, it is projected to increase from to 0.09 % by 2080 (Figure 19). However, the very likely range shows the possible magnitude of changes also in this case: Under RCP6.0, the very likely range will widen from 0.03–0.10 % in 2000 to 0.06–0.23 % in 2080.

The **exposure of the GDP to heatwaves is projected to increase** from around 0.16 % in 2000 to 0.98 % (RCP2.6) and 3.39 % (RCP6.0) by 2080 (Figure 20). It is thus recommended that policy planners start identifying heat-sensitive economic activities and production sites, providing shading of public spaces and integrating climate adaptation strategies such as improved solar-powered cooling systems, increased green infrastructure, cool roof and pavement materials or switching the operating hours from day to night [38].

d. Ecosystems

Climate change contributes to **land degradation and desertification**, posing a serious threat to farming and pastoral communities in Southern Africa. In addition, climate change is expected to affect the ecology and distribution of tropical ecosystems, although the magnitude and direction of these changes are uncertain [39]. Climatic changes can also impact the succession in forest systems, i.e. the natural changes within forests, while concurrently increasing the risk of invasive species, all of which affects ecosystems. In addition to these climatic drivers, low agricultural productivity and population growth might motivate unsustainable agricultural practices, resulting in increased deforestation, fires and land degradation. For example, the rapid destruction caused by the Cape Town wildfire in 2021 was attributed to a combination of hot, dry and windy conditions, which were the most extreme since 1979 and have become twice as likely as a result of climate change [40].

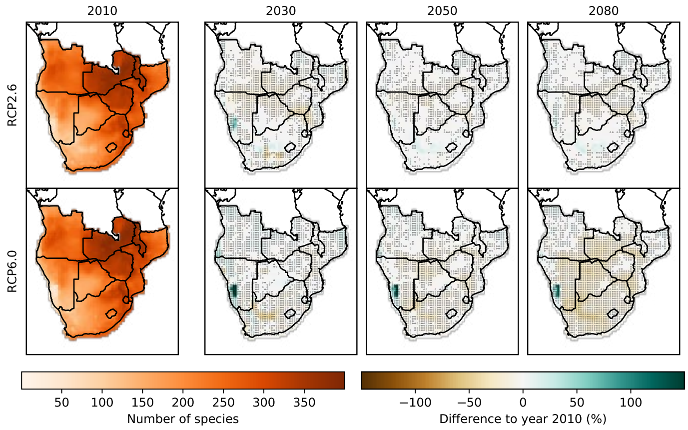

Figure 21: Regional projections of the aggregate number of amphibian, bird and mammal species for Southern Africa for different GHG emissions scenarios.

Shifts in species distribution in relation to climate change are also evident. For example, shifting geographic distributions of fish like anchovy, sardine and hake, and seabirds have been linked to climate change [41], [42]. Additionally, a projected decrease in river flows of the Zambezi River could result in a 22 % decrease in the annual spawning habitat, which would hinder fish migration [15].

Model projections of species richness, including amphibians, birds and mammals, and tree cover for Southern Africa are shown in Figures 21 and 22, respectively. **Trends in species richness differ depending on the region and scenario**. Projections under RCP2.6 are characterised by high modelling uncertainty, particularly over South Africa, Lesotho, Eswatini and the south of Namibia and Botswana. Where models agree on projected impacts, the expected changes are small. RCP6.0, however, shows a different picture: Under this scenario, a long-term **decrease** in species richness is projected for most of the region, except for eastern Mozambique, western Namibia and Angola. While the median for the entire region projects a decrease of 8.3 % by 2080, **South Africa is expected to experience a decrease in species richness of up to 49 %** by 2080 relative to the levels observed in 2010. The only exception to the decrease is **western Namibia**. Here, species richness will increase by up to 249 % by 2030 and 135 % by 2080, compared to the year 2010.

With regard to **tree cover changes**, projections vary depending on the scenario (Figure 22). Under RCP2.6, model results are uncertain and do not allow for an identification of trends. Under RCP6.0, there is greater modelling certainty, although uncertainties still exist across the south of Southern Africa. The average projected decrease in tree cover for the entire region by 2050 and 2080 is 2.8 % and 8.3 %, respectively. However, certain regions are expected to experience an increase in tree cover as well, such as central Angola, where the long-term changes in tree cover are expected to increase by up to 135 %. This increase might be partially explained by rising temperatures in higher altitudes (see Figure 4).

It is important to keep in mind that the **model projections exclude any impacts on biodiversity loss from human activities**, such as land use or poaching, which have been responsible for losses of global biodiversity in the past and are **expected to remain its main driver in the future** [43]**.** High population growth favours cropland expansion and increases the pressure on forests and natural land areas. For example, **Zimbabwe** experienced an **acceleration of deforestation** between 2000 and 2010, reaching 327,000 hectares of cleared forest per year (equivalent to 1.9 % of the country's forested area) [44]. Among the most important drivers of deforestation are **agricultural expansion and mining, as well as fuelwood collection**. High deforestation rates have a particular impact on women, who are often the managers of natural resources like forests, with their livelihoods relying on forest products including for fuel, food and medicine.

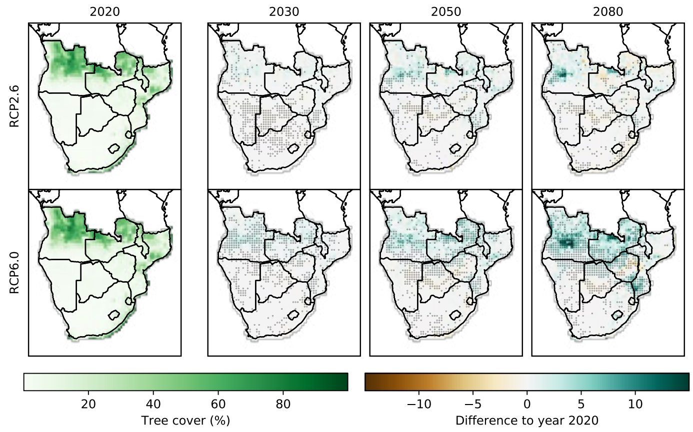

Figure 22: Regional projections for tree cover for Southern Africa for different GHG emissions scenarios.

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e. Human health

Climate change **threatens the health and sanitation sector** through more frequent incidences of heatwaves, floods, droughts and storms, with particular **impacts on vulnerable groups** like children, elderly people, women, chronically ill people and at-risk occupational groups like outdoor workers. Climate impacts on human health and well-being can thus exacerbate existing inequalities [15].

Temperature and precipitation extremes favour the **spread of waterborne diseases**, such as bacterial diarrhoea and cholera. For example, the floods following tropical cyclone Idai in March 2019 caused a major cholera outbreak in Mozambique, with 6,766 cases and 8 confirmed deaths [45]. Rising temperatures and shifting precipitation patterns are also likely to **impact food supply**, thereby increasing the **risk of malnutrition, hunger and death by famine**. For example, an attribution study of the 2007 Lesotho-South Africa drought showed how climate change led to severe crop failures and, in turn, to **food insecurity for around 400,000 people** in Lesotho [46]. Food shortages can be further exacerbated by local and global conflicts. The **civil war in Angola** has severely decreased agricultural production through the combined effects of population displacement and infrastructure damage, transforming a previously self-sufficient country into a heavily dependent food importer. The **war in Ukraine**, on the other hand, has led to increases in global food prices, putting further pressure on rural communities in Southern Africa.

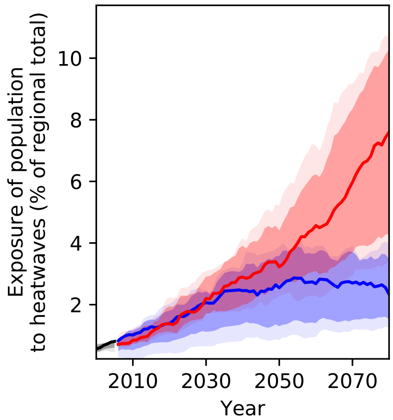

Figure 23: Projections of population exposure to heatwaves at least once a year for Southern Africa for different GHG emissions scenarios.

Furthermore, climate change can **alter the geographic range and transmission period of vector-borne diseases**. In the Southern African region, malaria transmission is projected to increase under the medium (RCP4.5) and higher (RCP8.5) emissions scenarios by 2030, particularly in northern Angola [47]. These **increases will accelerate in the course of the 21st century**, with the sharpest increases projected for western Angola, the upper Zambezi basin and northeastern Zambia. However, in some parts of Southern Africa, malaria prevalence is projected to decrease, due to climate change. For example, under high future emissions (RCP8.5), most of Zambia and Zimbabwe are projected to have almost no malaria transmission by the end of the century [15].

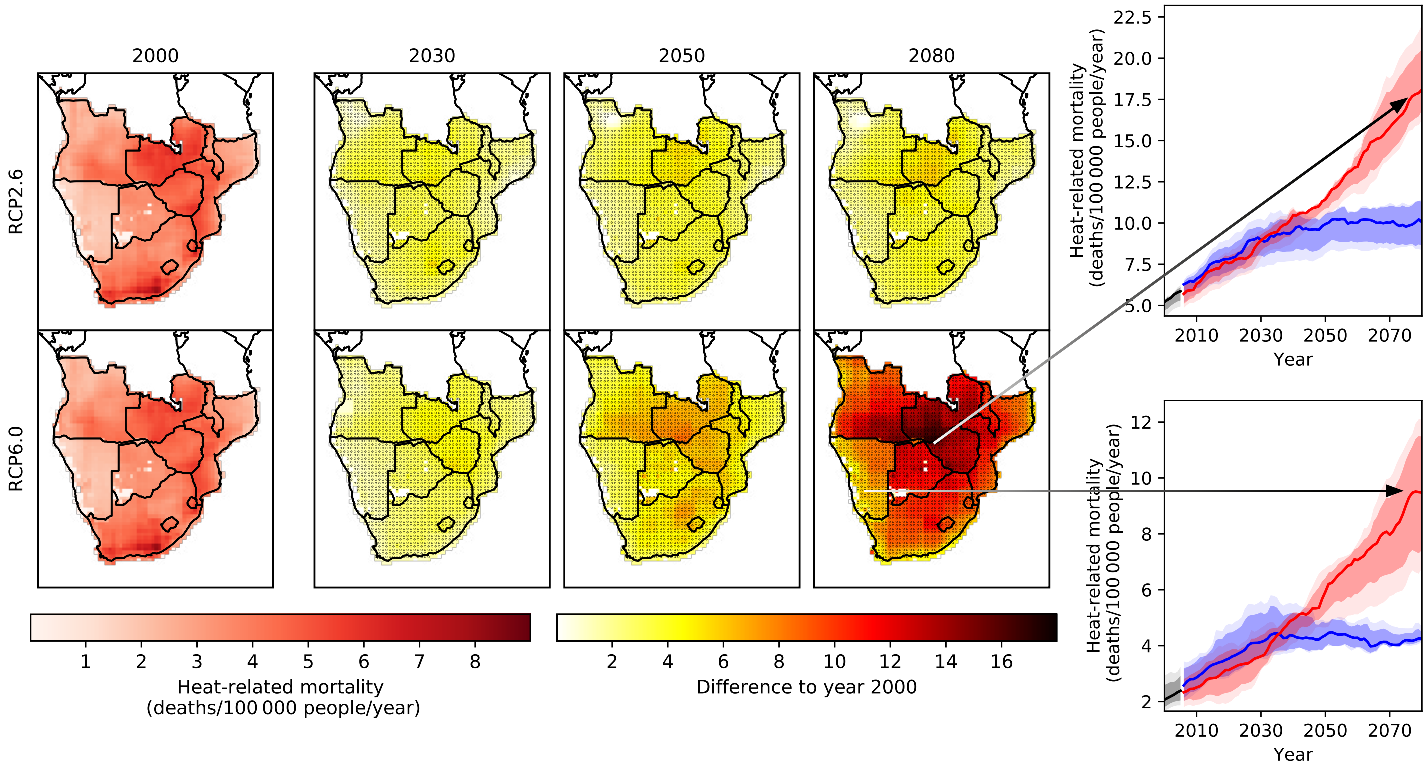

Figure 24: Regional projections of heat-related mortality for Southern Africa and nationally aggregated data for Namibia and Zambia for different GHG emissions scenarios assuming no adaptation to increased heat.

Rising temperatures will very likely result in **more frequent and higher exposure to heatwaves**, which will also increase heat-related mortality. Under RCP2.6, the population affected by at least one heatwave per year will rise from 0.6 % in 2000 to 2.1 % until 2030, and 2.3 % until 2080 (Figure 23). Under RCP6.0, exposure to heatwaves will develop similarly as under RCP2.6 until around 2030. From then on, it will increase more sharply, with around 3.2 and 7.6 % of the population being affected by heatwaves by 2050 and 2080, respectively.

Furthermore, **heat-related mortality is projected to change.** While under RCP2.6, heat-related mortality is projected to increase from 3.9 deaths per 100,000 people per year in 2000 to 6.9 deaths by 2030 and 7.2 deaths by 2080, under RCP6.0, heat-related mortality increases to 6.5 and 13.0 deaths by 2030 and 2080, respectively (Figure 24), provided that no adaptation to hotter conditions will take place. However, this increase is aggregated for the entire Southern African region. **Some countries will see even higher increases in heat-related mortality**: In Zambia, heat-related mortality is projected to amount to 10.1 deaths per 100,000 people per year until 2080 under RCP2.6, and to 18.1 deaths under RCP6.0 until 2080 (Figure 24). In Namibia, heat-related mortality is likely to increase to 4.3 deaths by 2080 under RCP2.6 and 9.5 deaths under RCP6.0.

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