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***Abstract:**
This project addresses knowledge, resource, capacity and networking gaps on the theme: 'Strengthening urban governments in planning adaptation.'
The main objective of this project is to develop an adaptation framework for managing the increased risk to African local government and their communities due to climate change impact. The ultimate beneficiaries of this project will be African local governments and their communities. The guiding and well-tested ICLEI principle of locally designed and owned projects for the global common good, specifically in a developing world context, will be applied throughout project design, inception and delivery.

Additionally, the research will test the theory that the most vulnerable living and working in different geographical, climatic and ecosystem zones will be impacted differently and as such, will require a different set of actions to be taken. Potential commonalities will be sought towards regional participatory learning and wider applicability. The five urban centres chosen for this study, based on selection criteria, include: Cape Town, South Africa, Dar es Salaam, Tanzania; Maputo, Mozambique; Windhoek, Namibia; and Port St. Louis, Mauritius.

Through a participatory process, this project will carry out a desk-top study, long-term, multi-discipline, multi-sectoral stakeholder platforms in five Southern African cities comprising of academics, communities and the local government in order to facilitate knowledge-sharing, promote proactive climate adaptation and resource opportunities available for African cities, develop five tailor-made Adaptation Frameworks and explore regional applicability. A network of stakeholders within each urban centre will be established, feeding into a larger regional network of local authorities and partners in Sub-Saharan Africa, and globally through existing ICLEI global (e.g. the ICLEI Cities for Climate Protection programme), ICLEI Africa and UCLG-A members and networks, ensuring global best practice, roll-out, and long-term sustainability.

Key words: Adaptation, Africa, Climate Change, Local Governments, Participatory Action Research, Policy.

Sub-Saharan African Cities:
A Five-City Network to Pioneer Climate Adaptation through Participatory Research and Local Action

Climate Systems Regional Report: Southern Africa

ICLEI Local Governments for Sustainability

CITIES ADAPT

Adaptation IDRC CRDI DFID Department for International Development

CSAG CLIMATE SYSTEM ANALYSIS GROUP

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Glossary

AAO	Antarctic Oscillation
CO_2	Carbon Dioxide
DJF	December to February
Easterlies	Winds coming from the east
El Niño	Warm phase of ENSO (warm waters in the central Pacific Ocean)
ENSO	El Niño Southern Oscillation
GCM	General or Global Circulation Model
IOD	Indian Ocean Dipole
IPCC	Inter-governmental Panel on Climate Change
JJA	June to August
La Nina	Cold phase of ENSO (cold waters in the central Pacific Ocean)
MAM	March to May
MAP	Mean Annual Precipitation
PCDMI	Program for Climate Model Diagnosis and Intercomparison
SON	September to November
SST	Sea Surface Temperatures
WCRP	World Climate Research Programme
Westerlies	Winds coming from the west

1 The climate of southern Africa

Southern Africa's continental climate is generally hot and rainy in summer with cold and dry winters. This largely results from the atmospheric systems that dominate the regional climate; namely an anticyclonic high pressure system over the continent during winter and an intermittent thermal trough (low pressure) during summer. This summer trough normally sits over the eastern side of the landmass resulting in greater rainfall towards the east and less towards the west, with moisture advected from the tropical Indian Ocean by the northern limb of the Indian Ocean anticyclone. The anticyclones over the Atlantic and Indian oceans tend to shift and merge over the landmass during winter, which largely creates the dry conditions over much of the continent and Madagascar. However, over the southern tip of the continent and Madagascar, mid-latitude westerlies tend to bring colder rain from the south.

While the climate systems governing the weather conditions from season to season are generally the same, there are some variations due to changes in the various drivers of the climate, such as solar radiation and sea-surface temperatures, called forcings. These may result in usually hotter or cooler temperatures, drier or wetter rainy seasons, or change in other variables from year to year. This natural variability is part of the climate system. Climate change is a permanent change to the climate system over a period due to factors such as changes in solar radiation, greenhouse gas composition and concentration, planetary orbits etc. Short term climate change (over 100s of years) is generally unprecedented in the history of the planet, which makes the current era of global warming a serious threat to climate. Climate change is thus a change to the long term climate means and generally is manifest through changing temperatures and rainfall (as well as many other parameters), if not in actual value then in nature.

The problem of quantifying climate change in Africa exists partly because of the complexity of regional climates in Africa and the associated geographic features. African seasons in the northern and southern hemispheres are out of phase and this leads to the wet season in Northern hemisphere corresponding to June-September (summer) while this period signifies the dry season in the summer season in the Southern Hemisphere. Surface observations in Africa are poor, but this network indicates that temperatures have warmed through the 20th century, while drying has occurred over large areas.

In the case of the Sahel, scientists have developed two possible causes for decadal trends in below normal rainfall: (1) internal processes such as desertification, deforestation and higher aerosol loading from the Sahara, and (2) external factors such as the impacts of global sea surface temperature anomalies or trend and anthropogenic climate change.

For understanding climate change it is often useful to understand the weather producing systems which, as a long term average, define the regional climate. This is because climate change will alter the mean strength and position of these systems and it is partly through this process (as well as increases in the radiative balance of the atmosphere) that regional rainfall and temperatures will be changed. Furthermore, understanding this process-based change allows us to examine the consistency of the different models used to predict climate change.

Drivers of climate variability

Natural climate variability plays an important role in defining the climate of the Southern African region on inter-annual (year by year) timescales. Several important drivers of this variability include El-Niño Southern Oscillation (ENSO), the Antarctic Oscillation (AAO) and the Indian Ocean dipole (IOD).

ENSO has several definitions but is generally associated with warm Sea Surface Temperatures (SST) in the central Pacific during its negative phase (this warm phase is referred to as an El-Niño event) and cold SST during its positive phase (La-Nina event). These events are states of the ocean which can affect the atmospheric circulation. Summer droughts are often associated with El-Niño events, especially over the south eastern parts of the continent, with above normal rainfall over the same regions during a La Nina. These associations are reversed over east Africa where an El- Niño event is associated with above normal rainfall, which could cause floods, and La Nina episodes often associated with droughts.

The AAO describes an oscillation of high and low pressures over the Antarctic continent and mostly affects the atmospheric dynamics south of 30˚S. However, this means that storms embedded in the westerlies, which bring the winter rainfall to the south of the region, are potentially affected by changes in this large-scale phenomenon.

SSTs in the Indian Ocean, which are sometimes associated with El-Niño, also exert a strong influence on the regional climate. Warm SSTs in the Indian Ocean can lead to drier conditions inland (due to the offshore displacement of dominant rainfall producing systems) and it is notable that SSTs have been increasing over the Indian Ocean since the late 1970s, a process which is expected to continue with climate change.

Whilst it is important to understand that climate change may change the association between these large-scale drivers of climate variability and regional climate (especially rainfall), they will continue to provide the dominant sources of variability during the next 10 years, or perhaps more. For the short term it might therefore be more important to ask how continuous and accelerating climate change might affect the influence of these drivers on regional climate and how extreme climate events of drought and flood may change. Currently we are not able to answer this question for specific regions without running thousands of climate simulations, which is beyond the scope of this report. However, by evaluating how the dynamics of the climate may change we can begin to think what changes in regional weather patterns we may expect to see.

Tropical cyclones

A **tropical cyclone** is a storm system characterized by a large low-pressure centre with strong winds and heavy rain. Tropical cyclones strengthen when water evaporated from the ocean is released as the saturated air rises, resulting in condensation of water vapour contained in the moist air. Tropical cyclones are typically generated in areas where the ocean surface temperature is greater than 27˚C, and in a latitude band between 5-30˚S. In the southern hemisphere they move SW from the equatorial region, in Africa specifically towards Mozambique and the Mozambique channel. Approximately 10 cyclonic 'events' develop each year over the southern Indian Ocean and they normally travel in a westerly direction, then head southwards and eventually merge with the westerlies at approximately 35˚S. Most events form east of Madagascar and travel towards Madagascar, often dissipating upon reaching the island, though some (40%) re-generate over the

Mozambican Channel[1]. Highest wind speeds tend to be over the south-eastern region of the 'eye' or centre with most cyclones developing wind speeds of up to 25 m/s. However, wind speeds of more than 50 m/s have been measured[2].

Monsoons

Monsoons may be considered as large-scale sea breezes, due to seasonal heating and the resulting development of a thermal low over a continental landmass. They are caused by differential warming between land and sea masses which occurs because heat in the ocean is mixed vertically through the action of wind and turbulence, whereas the land surface conducts heat slowly, with the solar radiation penetrating less than a metre. The specific heat capacity of liquid water is higher than that of the land; consequently the air over the land warms faster and gets hotter than the air over the ocean. The hot air over the land tends to rise, creating an area of low pressure. This creates a steady wind blowing toward the land, bringing in the moist oceanic surface air. As the moist air is lifted upwards by mountains, surface heating or convergence at the surface, it cools, condenses and causes precipitation, which is sometimes very intense.

In winter, the land cools off quickly, but the ocean retains heat longer. The cold air over the land creates a high pressure area which produces a breeze from land to ocean. Monsoons are much larger in scale, stronger and seasonal than the local scale sea and land breezes
Most summer monsoons have a strong tendency to produce heavy rainfall rain but the intensity and duration varies from year to year. Winter monsoons, on the other hand, tend to cause subsidence and drought.

The East African monsoons may be considered an extension of the South Asian monsoonal system, but they possess a relative dryness, caused by a low-level divergence over eastern Africa. Most rainfall in the region therefore occurs during periods between the monsoons, and total rainfall in East Africa is relatively low. Over most of the region it is strongly concentrated during two short seasons and it is highly variable from year to year, both in total amount and in time of occurrence.

2 Global and regional climate trends

It is widely recognized that there has been a detectable rise in global temperature during the last 40 years and that this rise cannot be explained unless human activities are accounted for[3]. The regional distribution of temperature increases is not however uniform and some regions have experienced greater change than others, especially the interior of continental regions such as southern Africa (see Figure 1). This is consistent with detected increases in annual temperatures found over southern Africa since 1900[4]. Additionally these changes in temperature are associated with

[1] Olivier, J., 1991. Tropical cyclones in the south-western Indian Ocean and their impact on South African rainfall. Research Thesis, Department of Geography, University of Stellenbosch
[2] Meteo France, 2001. Saison Cyclonique 1999–2000. Direction Interregionale de la Reunion
[3] IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, New York, US, Cambridge University Press.
[4] Hulme, M., R. Doherty, T. Ngara, M. New and D. Lister (2001). African Climate Change: 1900-2100. *Climate Research* 17(2): 145-168.

decreases in cold extreme climate events accompanied by increases in hot extreme climate events[5]. Furthermore, the global average temperature indicates an increasing rate of change, such that temperature is rising quicker during the latter half of the 20th century (see Figure 1). Importantly, this increase in the rate of change is expected to continue, potentially resulting in more rapid changes of climate in the future.

Box 1: What is climate change?

Climate change refers to a change in the average weather experienced in a particular region or location. The change may occur over periods ranging from decades to millennia. It may affect one or more seasons (e.g. summer, winter or the whole year) and involves changes in one or more aspects of the weather e.g. rainfall, temperature or winds. It's causes may be natural (e.g. due to periodic changes in the earth's orbit, volcanoes and solar variability) or attributable to human (anthropogenic) activities e.g. increasing emissions of greenhouse gases such as CO_2, land use change and/or emissions of aerosols. In contemporary society and in the context of this report the term 'Climate change' often refers to changes due to anthropogenic causes.

Changes in rainfall are typically harder to detect due to its greater variability, both in time and space. Even so, changing rainfall patterns have been detected for many parts of the globe, including moderate decreases in annual rainfall over southern Africa. Where records are of sufficient length there have been detectable increases in the number of heavy rainfall events[6] and within the southern hemisphere there is evidence for a moistening of the tropics and subtropics[7]. This is consistent with regional studies over continental southern Africa which have shown trends for an increasing length of the dry season and increases in average rainfall intensity[4]. This has important implications for the seasonality of regional rainfall and together suggests a shorter but more intense rainfall season.

Besides changes in temperature and rainfall, other aspects of global change are notable[5]:

- Increases in intensity and spatial extent of droughts since the mid-1970s;
- Decreases in northern hemisphere snow cover;
- Increases in the duration of heat waves during the latter half of the 20th century;
- Shrinking of the arctic sea ice pack since 1978;
- Widespread shrinking of glaciers, especially mountain glaciers in the tropics;
- Increases in upper-ocean (0-700m) heat content;
- Increases in sea level at a rate of 1.8 mm yr^{-1} between 1961 and 2003, with a faster rate of 3.1 mm yr^{-1} between 1993 and 2003.

[5] New, M., B. Hewitson, D. B. Stephenson, A.Tsiga, A. Kruger, A. Manhique, B. Gomez, C. A. S. Coelho, D. N. Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M. L. Mdoka and R. Lajoie (2006). Evidence of trends in daily climate extreme climate events over southern and west Africa. *Journal of Geophysical Research* 111. D14102, doi:10.1029/2005JD006289

[6] Solomon, S., D. Qin, M. Manning, R. B. Alley, T. Berntsen, N. L. Bindoff, Z. C. A. Chidthaisong, J. M. Gregory, G. C. Hegerl, M. Heimann, B. Hewitson, B. J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T. F. Stocker, P. Whetton, R. A. Wood and D. Wratt (2007). Technical Summary. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S. Solomon, D. Qin, M. Manning et al. Cambridge, UK. New York, US, Cambridge University Press

[7] Zhang, X., F. W. Zwiers, G. C. Hegerl, F. H. Lambert, N. P. Gillett, S. Solomon, P. A. Stott and T. Nozawa (2007). Detection of human influence on twentieth-century precipitation trends. *Nature* 448: 461-465

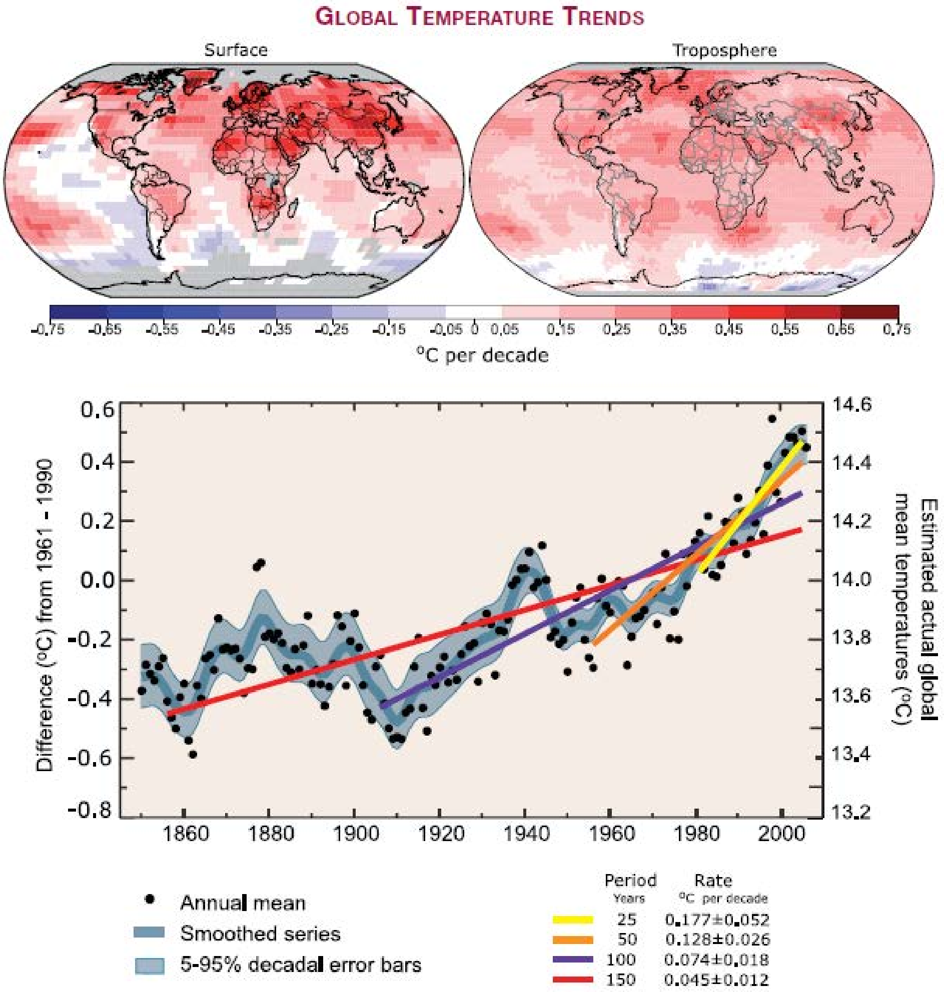


Figure 1: Distribution of global temperature trends (1979-2005) for the surface (left) and troposphere (right) from satellite records. Below: the average global temperature since 1850 indicating the increased rate of change during the later part of the 20th century. (Source: IPCC, 2007)

Box 2: What causes climate change?

Anthropogenic emissions of greenhouse gases (the main cause of anthropogenic climate change) have increased steadily since the industrial revolution. The rate of emissions, however, have been steadily increasing over time, and computer models of the earth's climate system (including both natural and human causes) are unable to simulate recent warming unless they include anthropogenic emissions of greenhouse gases. Computer models of the earth's climate which include only natural forcings (e.g. solar variability due to both internal and orbital variations, volcanic activity etc.) simulate a cooling of the earth after 1960, which is at odds with the observed warming (see Figure 1). This has led the Intergovernmental Panel on Climate Change (IPCC) to conclude recently that most of the warming of the last 50 years is attributable to human activities.

There is therefore compelling evidence for climate change at the global level, attribution to human activities, as well as its effects on continental southern Africa. However, understanding how global climate change may affect individual countries and small regions within a country is still a matter of research and is inherently linked to issues of uncertainty (see Box 3). So whilst the observed global level changes serve to highlight that climate change is a reality and that we have confidence in continuing and potentially accelerating change, it is necessary to explore how local climates may already be changing as well as how they are expected to change in the future.

Box 3: Understanding uncertainty and risk

The issue of uncertainty is crucial to understanding past and future climatic change, especially when designing adaptation strategies that will benefit both present and future socioeconomic situations. Uncertainty does not mean that we have no confidence in our projections of future climate. Indeed all climate projections, including seasonal forecasts, are couched in terms of the probability of particular climate conditions occurring in the future. This is a framework within which humans often operate, allowing an assessment of future risks, e.g. consideration of financial and investment opportunities.

To be able to assess risk, one needs to consider all sources of information. It is therefore essential that a probabilistic framework is used to develop projections which should incorporate different sources of information. The IPCC define four sources of uncertainty that currently limit the detail of the regional projections3:

1. Natural variability. Due to the limiting factor of observations (both in time and space) we have a limited understanding of natural variability. It is difficult to characterise this variability and the degree to which it may exacerbate or mitigate the expected background change in climate. This variability itself may change due to anthropogenic factors, e.g. increases in the frequency of droughts and floods;
2. Future emissions. Much of future projected change, at least in terms of the magnitude of change, is dependent on how society will change its future activity and emissions of greenhouse gases. Even so, the world is already committed to a degree of change based on past emissions (at least another 0.6ºC warming in the global mean temperature). Human responses to managing emissions may result in a projected global mean temperature change of between 1.5º and 5.6ºC;
3. Uncertainty in the science. This is further complicated within Africa because of limited understanding of the regional dynamics of the climate of the continent. There may be aspects of the regional climate system, which could interact with globally forced changes to either exacerbate or mitigate expected change e.g. land-use change. One consequence is the possibility of rapid nonlinear change, with unforeseen and sudden increases in regional impacts;
4. Downscaling – the term used to define the development of regional scale projections of change from General Circulation Models (GCMs). Downscaling tools can introduce additional uncertainty e.g. between downscaling using regional climate models and statistical techniques. Usually this uncertainty limits the confidence in the magnitude of the projected change with the pattern and sign of change often interpreted with greater certainty.

3 Detailed regional climates

3.1 Namibia

Figure 2: Map of Namibia (Source: www.theworldatlas.net)

Namibia is the most arid country in the region – 92% of area is hyper-arid, arid or semi-arid. Coastal desert exists along the entire length of Atlantic coastline, including Namib Desert; unsuited to agriculture. The inland plateau region, including escarpment, highland and mountain regions, covers more than half of the country.

The Kalahari Desert extends south and east of the plateau. Rainfall is sparse and highly variable temporally and spatially. Most rainfall evaporates immediately and evapotranspiration[8] exceeds rainfall in most areas. **Figure 3** shows the long term averages for Temperature and Precipitation for the country.

The temperatures generally increase from the coastal regions towards the East, but the highlands' cooler winter temperatures reduce their averages. The rainfall shows a similar west to east increase but inland there is a south to north increase as well.

[8] Evapotranspiration is the sum of all evaporation from the surface of water and the transpiration from vegetation

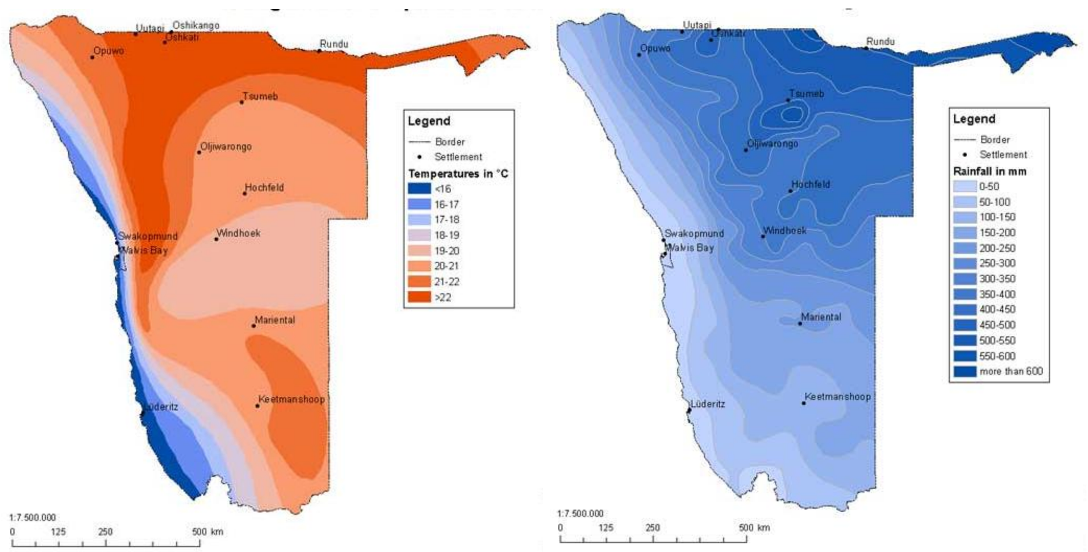


Figure 3: Annual average temperature and Precipitation (www.dea.met.gov.za)

Namibia possesses three distinct climatic zones:

- The north-east savannah zone has an intermittent moist sub-tropical climate. Rainfall can be expected between October/November to March/April. The Mean Annual Precipitation (MAP) is concentrated in a couple of heavy showers and not distributed in regular intervals over the entire rainy season. With the exception of the border rivers, Okavango and Kunene all other rivers are periodic. The MAP ranges from approximately 450 mm to 600 mm. It is in this region that the arable land of Namibia is located and where the majority of agriculture (mostly millet) takes place.
- The second climatic zone occupies the largest part of Namibia. It has a semi-arid dry climate with generally dry rivers with episodic run-offs. The precipitation in this semi-arid tropical climate is highly irregular. This region stretches from the Kaokoveld in the south towards the South-East-Kalahari at the Botswana border. In this area night frosts can be expected during the winter months. The general altitude of this central plateau is above 1.000 m. The MAP ranges from approximately 200 mm to 450 mm.
- The third climatic region is situated in the south-west of the central semi-arid tropical zone. This warm-moderate subtropical zone region has a distinct semi-desert to desert climate. These areas have 11 to 12 arid months each year. Only in exceptionally rainy seasons does this region receive a mean annual precipitation of between 100 mm and 200 mm. Under normal circumstances the MAP is 100 mm, while only 50 mm falls in the Namib and the Orange River valley. The Orange river is the only permanent river in the region.

Namibia: Local Climates

Namibia's climate is characterized by hot and dry conditions and sparse and erratic rainfall. Within Africa the climate is second in aridity only to the Sahara Desert and 92 percent of the land area is defined as hyper-arid, arid or semi-arid. Rainfall patterns are characterized by their high temporal and spatial variability. Conventional statistical descriptors such as mean and even median are often difficult to use and estimates of rainfall characteristics and patterns based on point measurements are problematic.
Mean annual precipitation: 285 mm.

Of the total rainfall: 83 % evaporates, 14 % is used up by vegetation, 1 % recharges groundwater and only 2 % becomes runoff and may be harnessed in surface storage facilities.

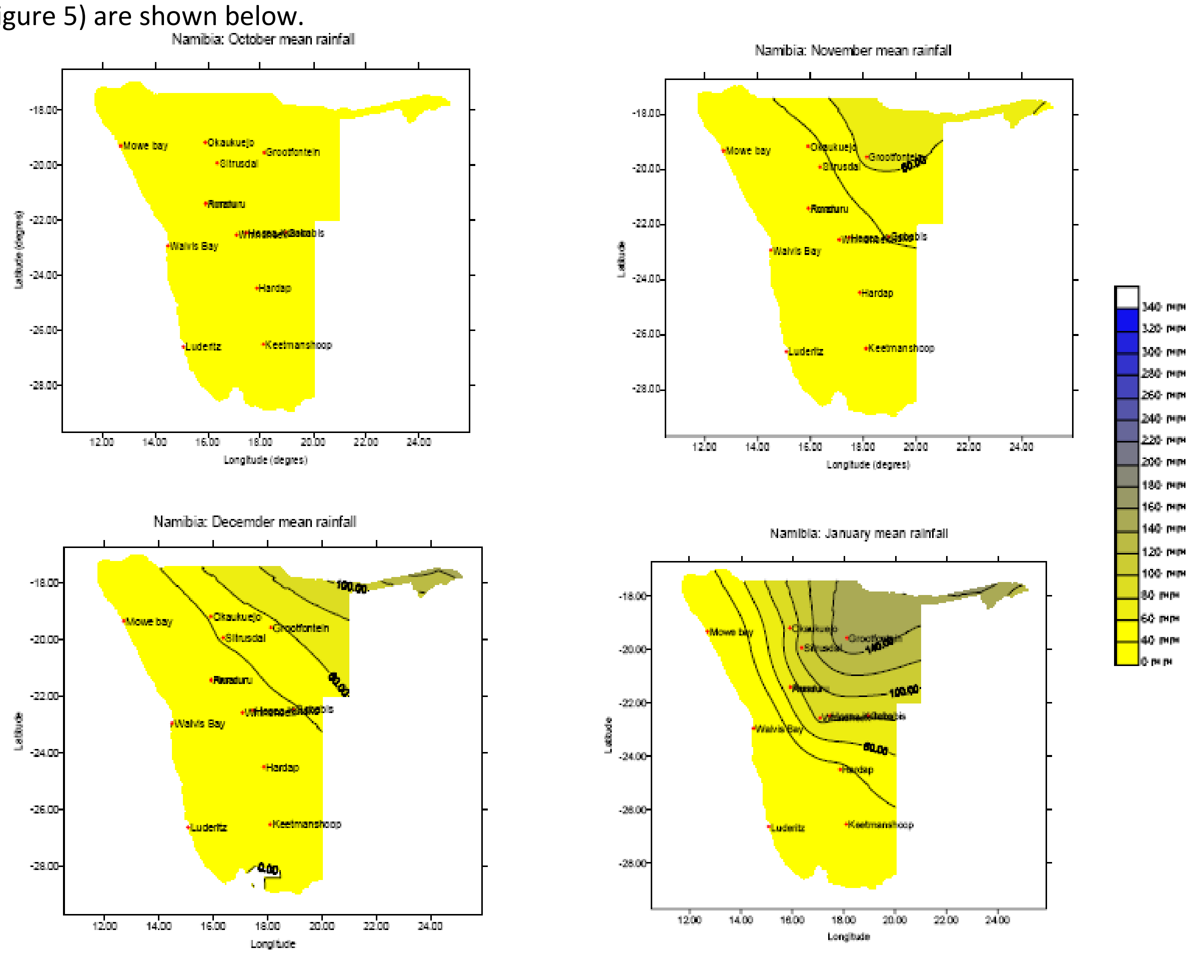
- North-east savannah zone: Rainfall between October/November to March/April. The Mean annual precipitation (MAP) ranges from approximately 450 mm to 600 mm
- Kaokoveld in the south towards the South-East-Kalahari: The MAP ranges from approximately 200 mm to 450 mm.
- South-west of the central semi-arid tropical: 11 to 12 arid months each year. In exceptionally rainy seasons the region receives a mean annual precipitation of between 100 mm and 200 mm. Under normal circumstances the MAP is 100 mm, while only 50 mm falls in the Namib and the Orange River valley.

Mean annual temperatures are below 16 °C along the southern coast, between 20 °C and 22 °C in large parts of the country's interior and the eastern parts, and above 22 °C in the north. Temperatures are moderated by the cold Benguela currents along the coast. In Windhoek average temperature ranges are from 6 °C to 20 °C in July to 17 °C to 29 °C in January.

Net evaporation can be as high as 3700 mm per year. In the coastal plateau the average monthly evapotranspiration always exceeds the rainfall by a factor of up to five.

Namibia: Long Term Means

The rainfall season variation (Figure 4) and long term climatological means for 6 Namibian cities (Figure 5) are shown below.



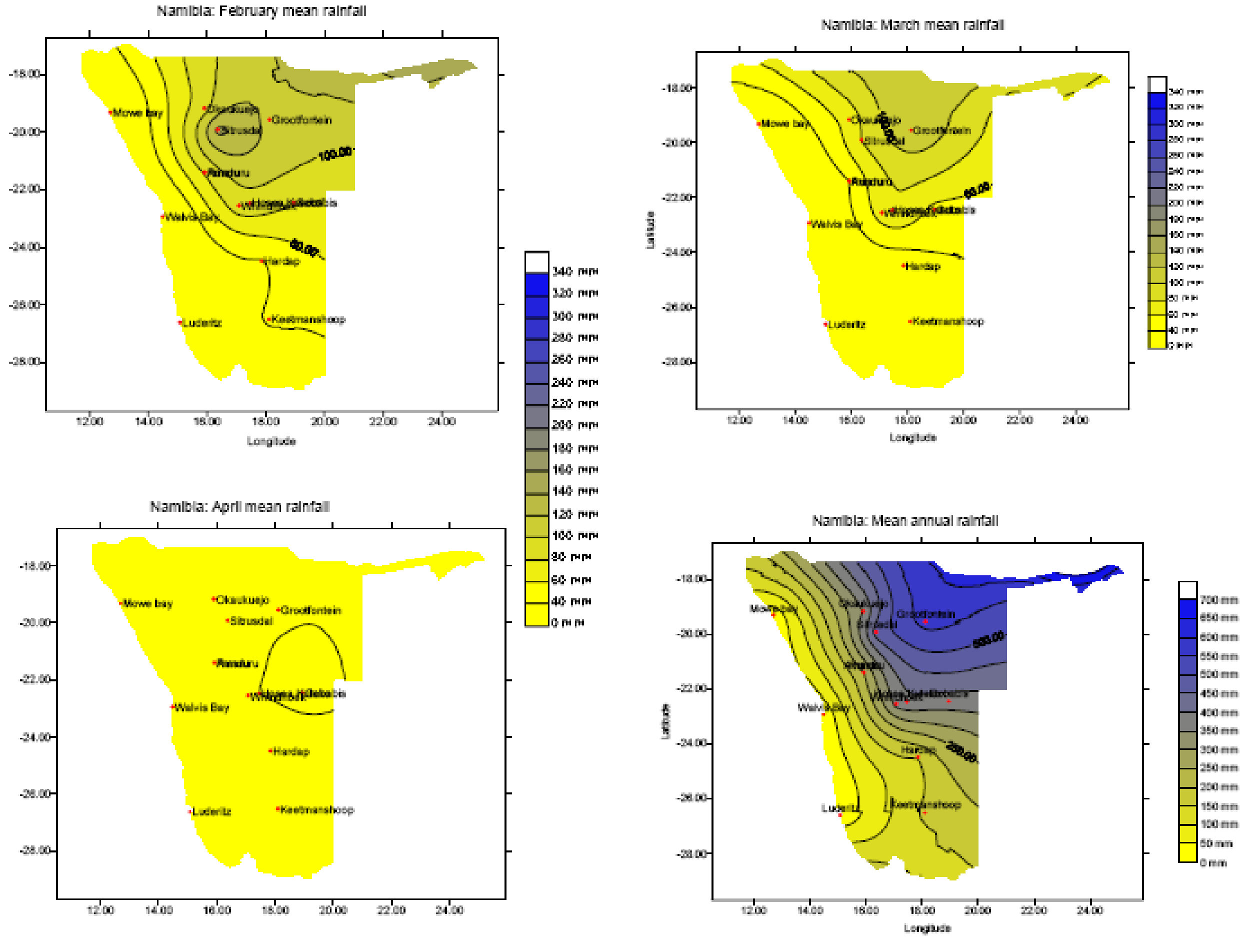
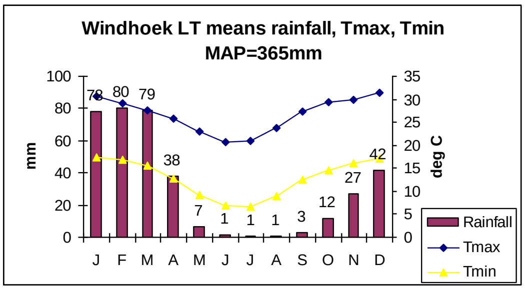
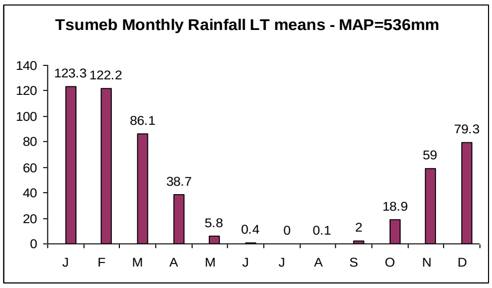


Figure 4: Rainfall variation in Namibia for the October to April rainy season (Source http://209.88.21.36/Atlas/Atlas_web.htm)

Windhoek

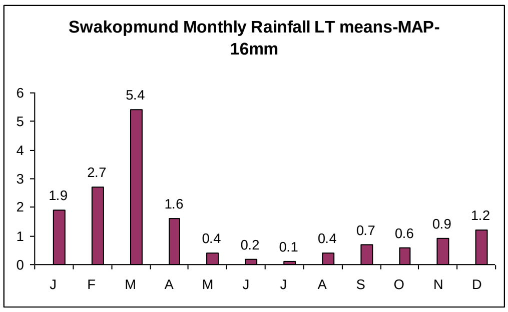


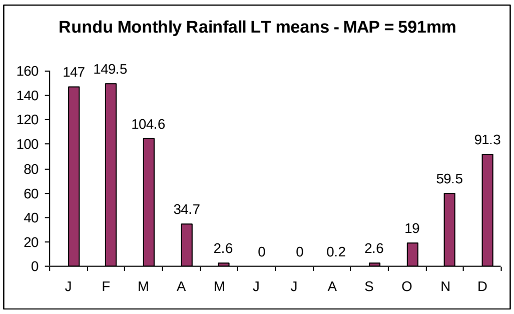
Tsumeb



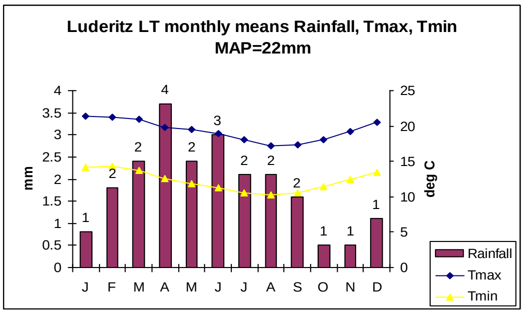
Swakopmund

Rundu





Luderitz



Keetmanshoop

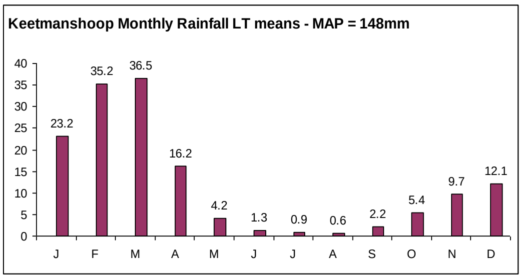


Figure 5: Meteorological patterns in main cities in Namibia – LT = long term means averaged over at least 30 years

Namibia: Variability

Rainfall patterns are characterized by their high temporal and spatial variability. Conventional statistical descriptors such as mean and even median are often difficult to use and estimates of rainfall characteristics and patterns based on point measurements are problematic. The Coefficient of Variation of precipitation in percentage varies from 65% in a rainy month to 513% in a dry month.

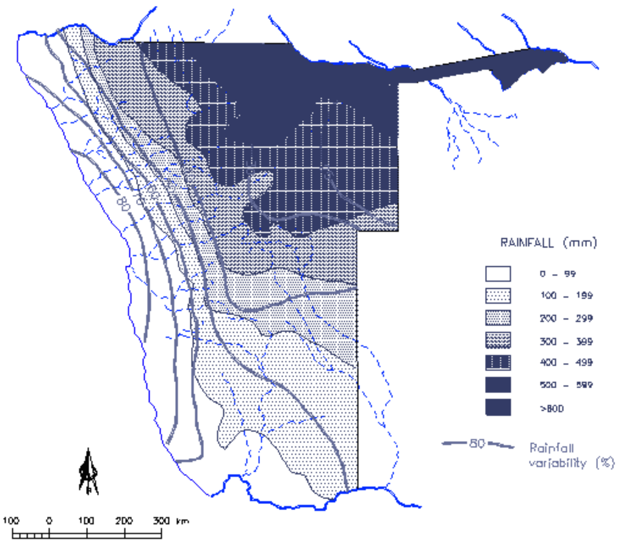


Figure 6: Mean Annual Rainfall and rainfall variability in Namibia

(Source: Population Development Environment Project CD-rom IIASA (Feb 2001): http://www.iiasa.ac.at/Research/POP/pde/Maps/na-rainfall.html)

Namibia: Seasonality of rainfall

With the exception of Luderitz which experiences rare cold frontal rainfall in winter, all stations receive summer rainfall between October and May.

Namibia: Threats

A study by the World Bank on the impact of **sea level rise** on developing countries worldwide states that sub-Saharan Africa has the least impact of all regions. In terms of the proportion of the country area impacted by sea level rise, Namibia is ranked 22 out of 29 coastal countries in sub-Saharan Africa. It is the vulnerability of Walvis Bay to the impacts of sea level rise that contributes most to the World Bank ratings of concern on Namibia. Low-lying Walvis Bay, with an elevation of less than 2m above mean sea level, is the most vulnerable to climate change influences such as sea level rise and extreme tidal characteristics.. An earlier study on the impacts of climate change indicates the possibility of inundation, water logging and flooding of the town, particularly if the protection from the Pelican Point sand spit is reduced[9].

Temperature increases in an already hot country will threaten existing water supplies and the viability of agriculture. In the wetter northern part of the country the risk of malaria outbreaks is likely to increase and health and sanitation infrastructures will be under greater strain.

3.2 South Africa

Figure 7: South Africa (source http://www.suncape.com/maps.php?ln=en)

Based on annual rainfall (Figure 8), three general climate zones can be distinguished

- The eastern parts of the country, which are summer rainfall areas with an annual precipitation of 500 mm and more;

[9] Brundrit, G B (1995). Trends of southern African sea level: statistical analysis and interpretation. South African Journal of Marine Science 16: 9-17.

- The central and the western parts of the great plateau, which are semi-arid to arid and are characterized by late summer rains, varying from less than 100 mm to approximately 500 mm;
- The Cape fold mountains and the area between them and the sea have a winter rainfall season in the west and rainfall throughout the year in the more southeasterly parts. Rainfall in this region varies from about 300 mm to more than 900 mm.

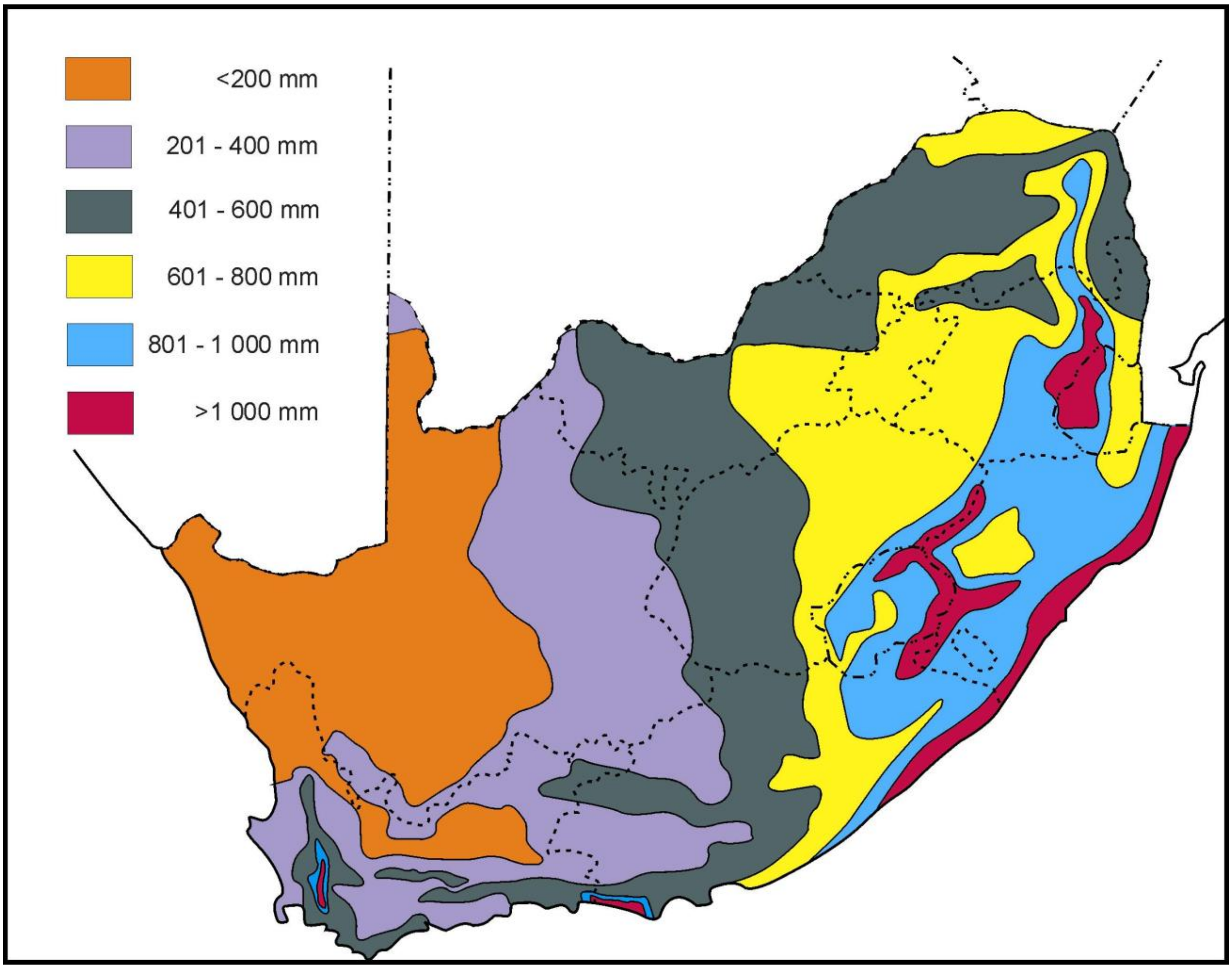


Figure 8: Average Precipitation – South Africa (source www. hoeckmann.de)

South Africa: Local Climates

South Africa can be divided in 11 climatic regions (see Figure 9)
The average annual rainfall is 495 mm (<100 mm/year in the western deserts to 1200 mm/year in the east). Only 35 percent of the country has a precipitation of 500 mm or more, while 44 percent has a precipitation of 200-500 mm and 21 percent has a precipitation of less than 200 mm.
Figure 9 shows the seasonality variation during the two rainy seasons; winter in the SW and eastern coastal regions, and summer for the eastern half of the country.

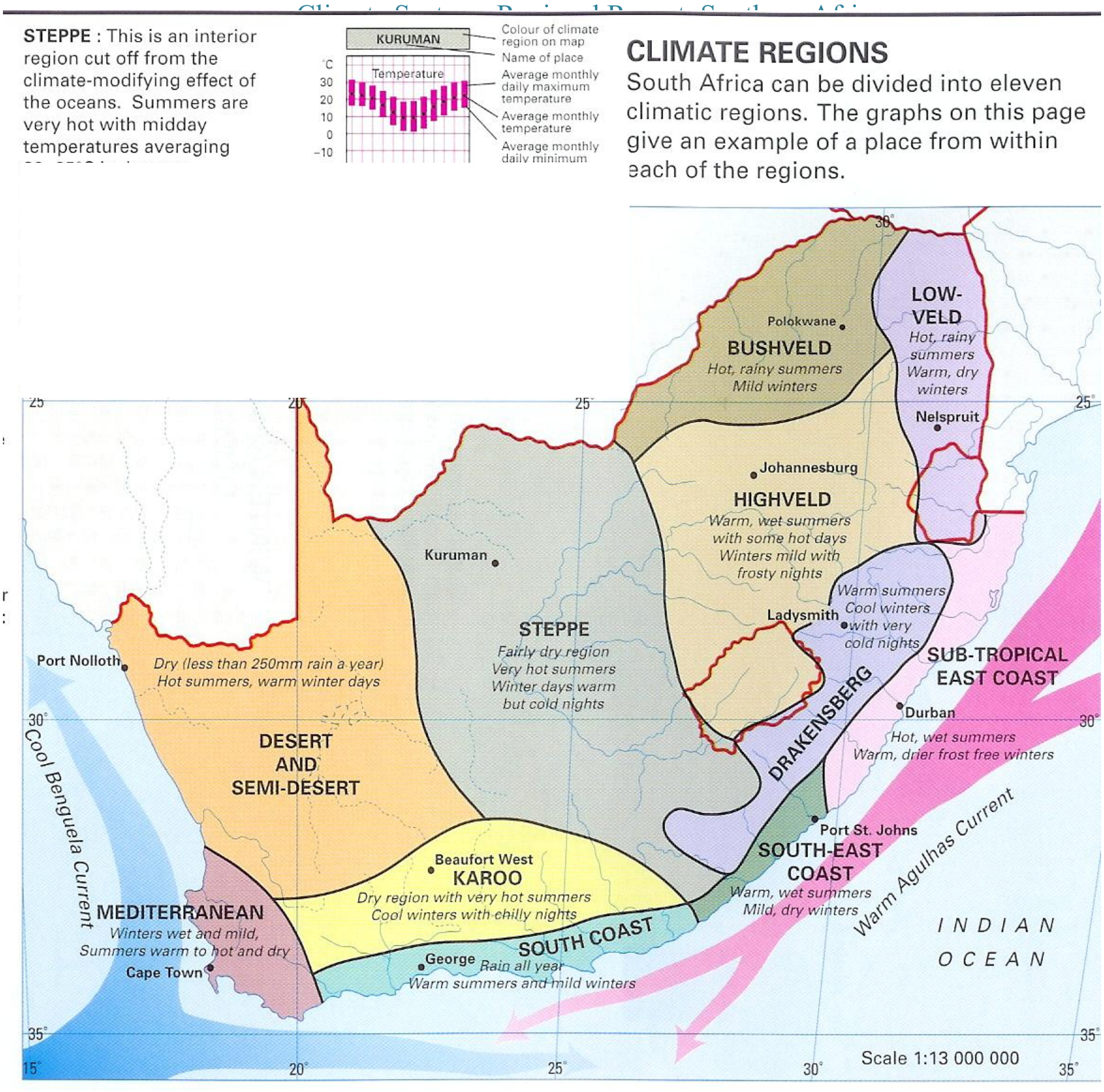


Figure 9: Climatic regions of South Africa (source

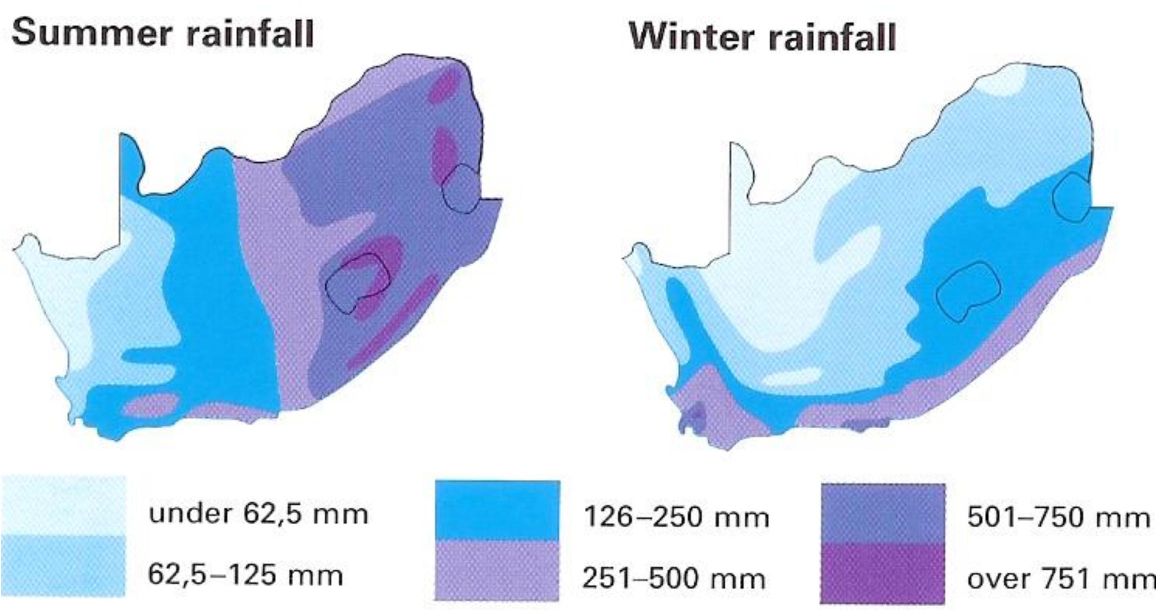


Figure 10: Rainfall seasonality (source

Summer temperatures vary from 15 ºC at night to 30 ºC at noon (October to March) and winter temperatures: between 0 ºC at night and 18 ºC at noon (April to September). Winter temperatures in the interior often drop below zero and frost is common.

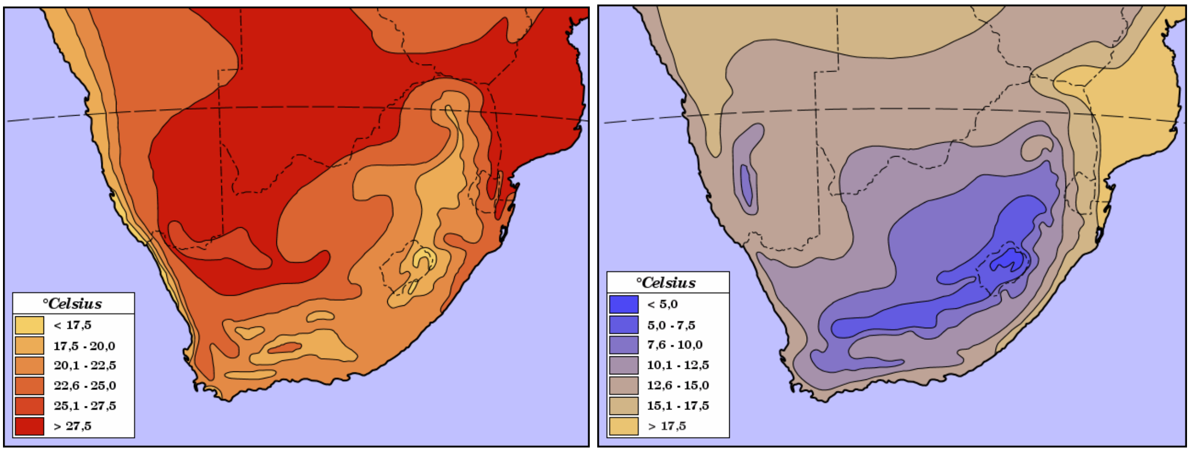
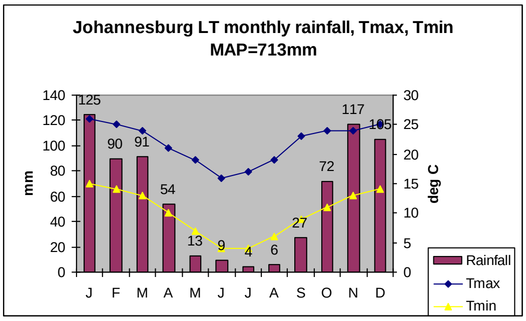


Figure 11: Average Temperature January and July– South Africa (Source http://www.suncape.com/maps.php?ln=en)

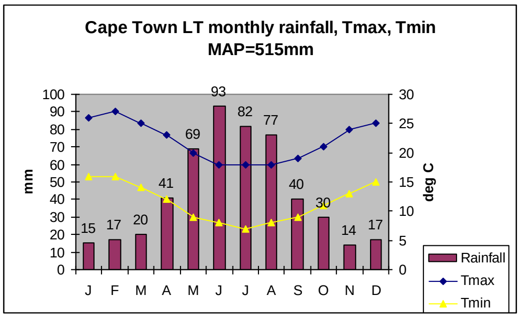
South Africa: Long Term Means

The variation of climate within the borders of South Africa is reflected by the individual values for 6 locations shown in

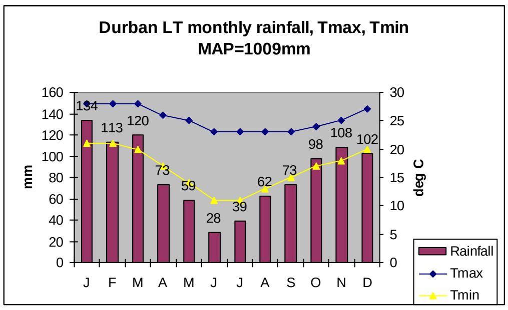
Johannesburg



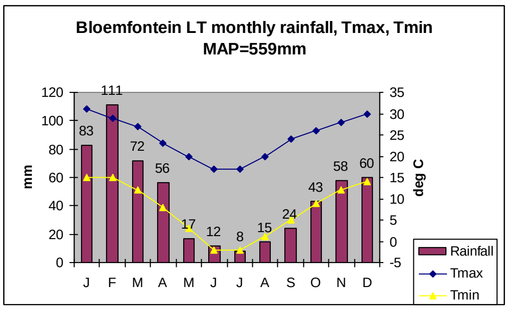
Cape Town



Durban

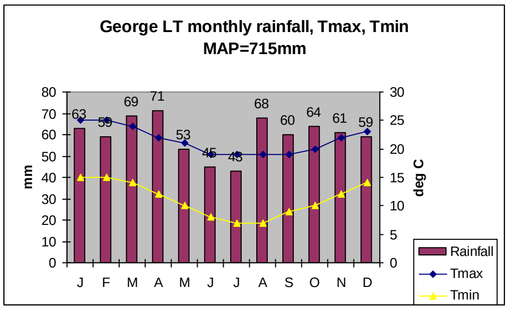


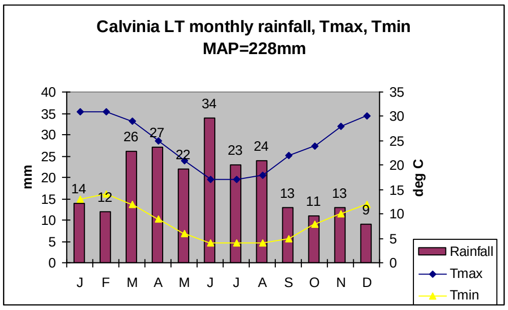
Bloemfontein



George

Calvinia





South Africa: Variability

The variability of rainfall increases from East to west and corresponds in most cases with decreasing rainfall (see Figure 12) Variability is defined as the extent to which any particular year's rainfall will vary from the long term mean (thus, a 50% variability means that in that place for any particular year the rainfall is likely to be in a range of 50% more or less than the long term average).

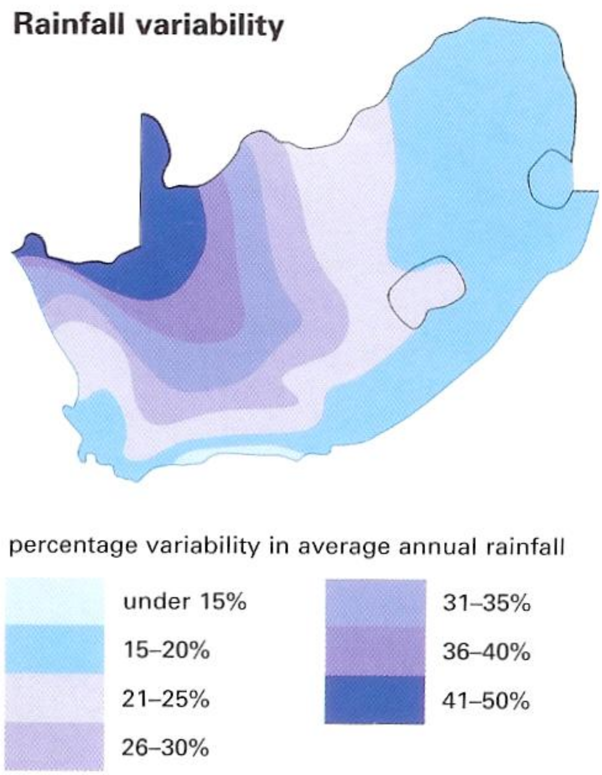


Figure 12: Rainfall variability (Source

South Africa: Seasonality of rainfall

80% of the country experiences predominantly summer rainfall, 10% Winter rainfall and less than 10% rain throughout the year (the Southern coastal region).The seasonality and high unreliability of rainfall results in dry periods during which the food security problem increases for many households. Droughts are experienced on average in 3 out of every 10 years.

South Africa: Threats

Increases in temperature and changes to rainfall pose the greatest threat to agriculture and water supplies in the region. Crop suitability and yields are both expected to change in the future and adaptation options will have to include alternatives and demand reduction (in the case of water).

3.3 Mozambique

The country can be divided into four main land zones:

(a) From the coast to the interior, the plains lie at an elevation of under 200 m and cover more than 40% of the land area. North of the Zambezi River, the plains are between 60 km and 100 km wide. In the Zambezi Valley the plains extend upstream about 600 km. South of the Zambezi River the plains are up to 100 km wide. The coastal area is divided into different sections. The northern part is composed of craggy coasts. In the Zambezi Delta and in the southern area, beaches interrupt mangroves.

(b) A lower and middle plateau, covering about 30% of the land area, extends from the plains in the west (elevation 200 m to 500 m). The biggest area is located in the north of the country.

(c) The middle plateau (elevation 500 m to 1000 m) covers approximately 26% of the land area and is located in the western part of northern and middle Mozambique.

(d) The remaining area is mountainous (with elevations above 1000 m) and accounts for about 5% of the land area. The mountains of Alto Niassa, Alta Zambézia and Agonia are of importance. The highest point in Mozambique is Monte Binga at 2436 m.

Figure 13. Map of Mozambique (source: http://www.thecommonwealth.org)

The climate varies from tropical and sub-tropical in the north/central regions, to semi-arid and arid climates in the south. Rainfall varies widely from the coast (ave 800-1000 mm) decreasing inland to 400 mm at the border with SA and Zimbabwe. rainfall **decreases** from the north/central regions (1000-2000 mm, NE monsoon) to the southern inland (500-600 mm). There are distinct rainy and dry seasons. The north/central region is most suited to rainfed agriculture. The length of the growing period is highly variable through the country (90-270 days). 4.2 million ha (5%) is arable land, 56% is used for pasture.

Mozambique: Local Climates

The climate can be described as semi-arid and subtropical in the **south** and tropical in the **north (s**ee Figure 14). It is strongly influenced by altitude, proximity to the sea and the latitude. The country is affected by seasonal air circulation of the Indian Ocean and is characterized by one rainy and one dry season per year. The southern part of the country is generally drier than the north and has strong fluctuations in temperature and precipitation, with the heaviest rainfall from October to March.

The rainy season is from October to March. Annual average precipitation is 1032 mm. Rainfall varies between 1400 mm a year near the Zambezi Delta to about 300 mm a year in the lowlands of the southern interior. Mountainous areas have around 2000 mm of rainfall. The driest areas of the country lie in the interior of Gaza Province.

The average temperature along the coast is 18 ºC in the extreme south, while in the hot season most coastal areas average 28 ºC. The hottest region is the interior Zambezi valley. The coldest temperatures are usually recorded in one of the western mountain ranges, where frosts are common during winter..

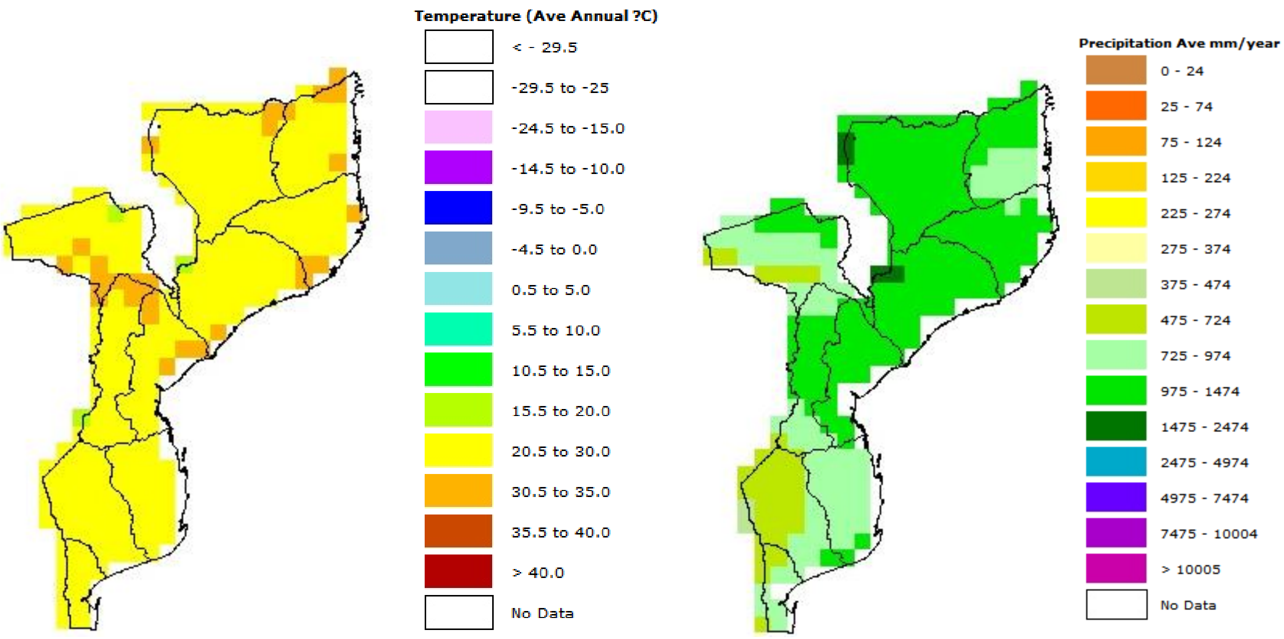
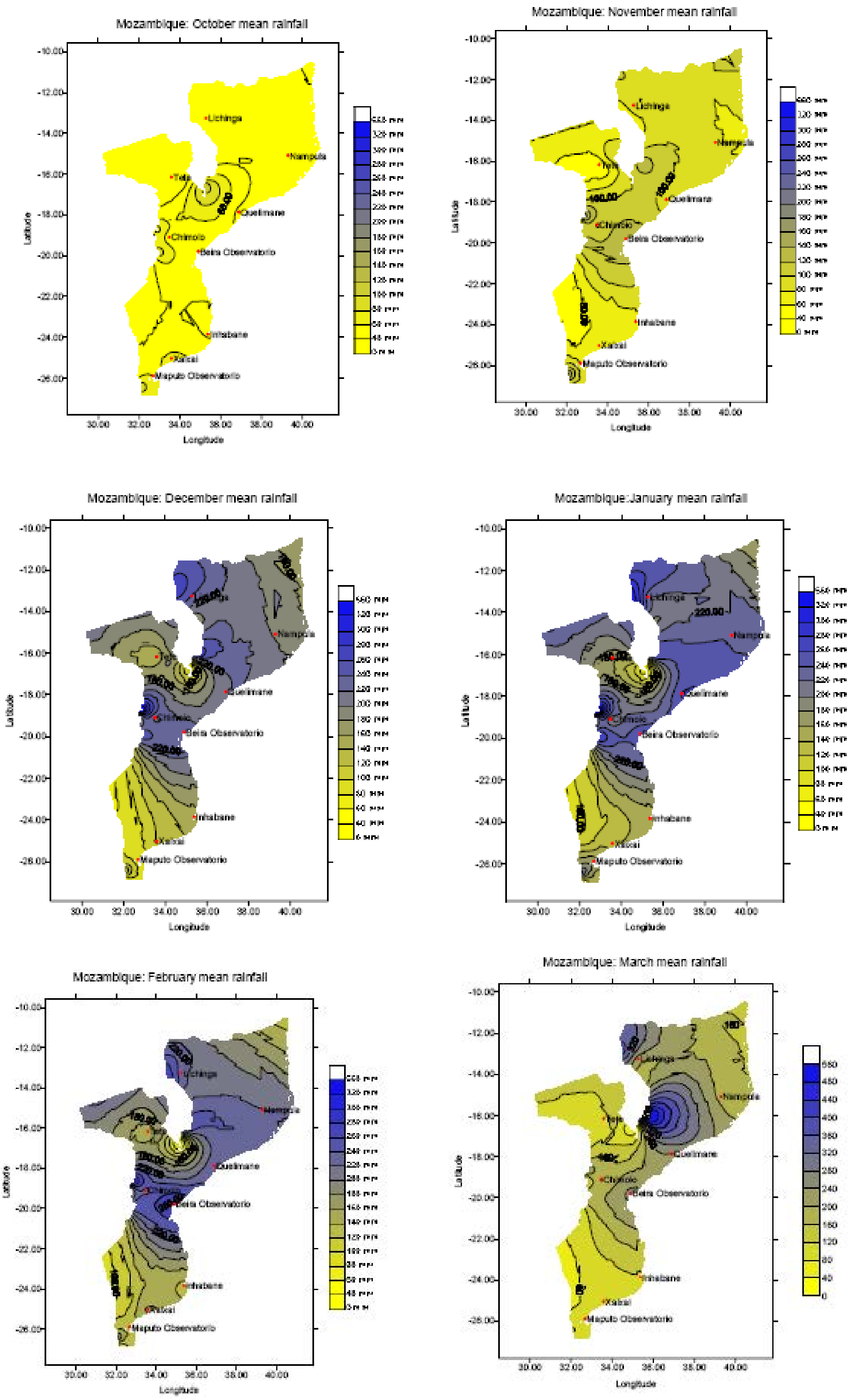


Figure 14: Average Temperature and Precipitation for Mozambique. Source: FAO[10]

[10] Food and Agriculture Organization of the United Nations (2007). http://www.fao.org

Figure 15 shows the variation of rainfall during the rainy season.



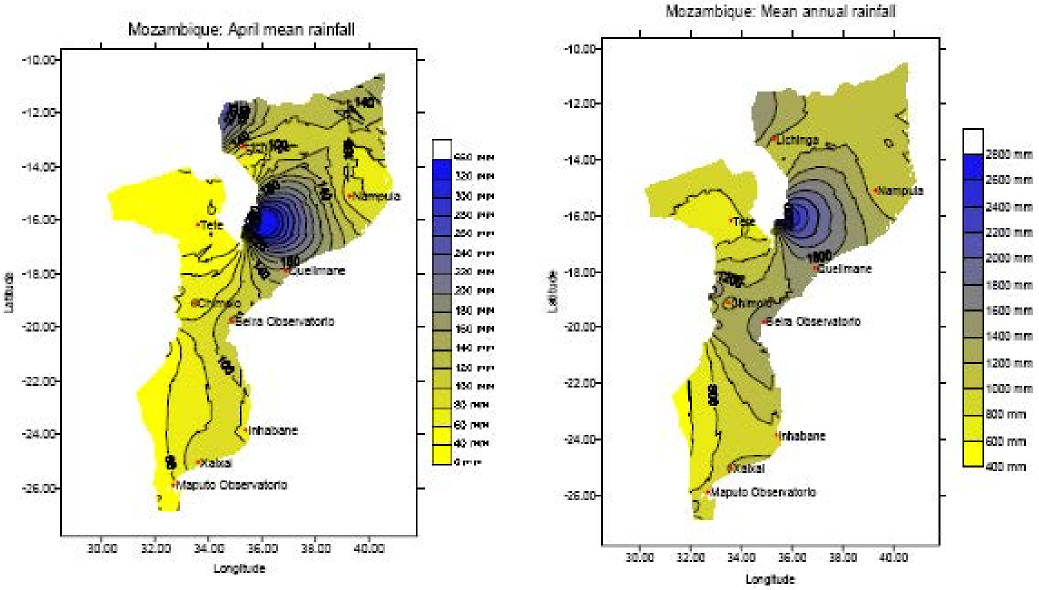


Figure 15: Seasonal rainfall variation from October to April (Source http://209.88.21.36/Atlas/Atlas_web.htm)

Mozambique: Long Term Means

Mean annual precipitation of major centres (see Figure 16)

Maputo	778mm
Zumbo	774mm
Cobue	1212mm
Palma	1020mm
Nampula	1059mm
Beira	1502mm

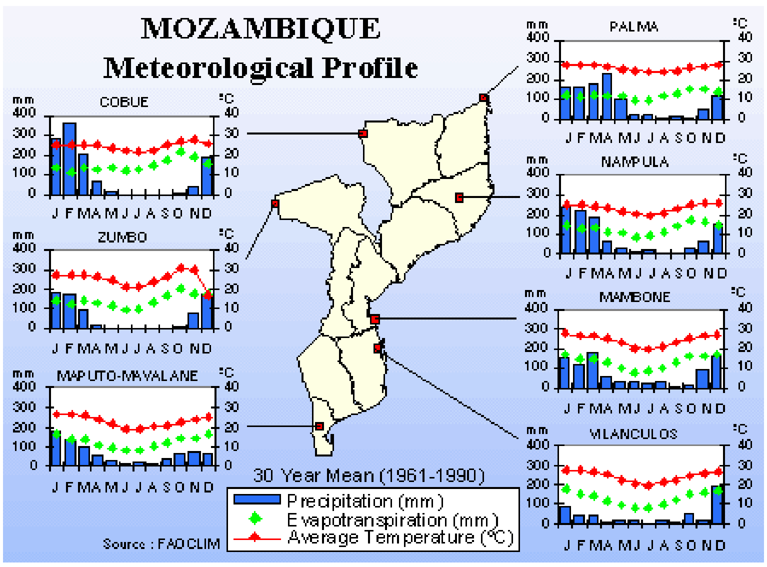


Figure 16: Meteorological patterns in main cities in Mozambique, average 1961-90.

(©1999-SADC/FSTAU-FAO/GIEWS).

Mozambique: Variability

The climate of Mozambique means that the risk of harvest loss in rainfed agriculture exceeds 50 percent in all regions south of the Save River, and can reach up to 75 percent in the interior of the Gaza province. The centre and north regions of the country have more appropriate conditions for rainfed agriculture, where the probability of good harvests during the rainy season is 70-95 percent. The north of the Manica province and the south of the Tete province regions are excluded from this Centre-North region, as they have a risk of harvest loss in rainfed crops of usually more than 50 percent. Other environmental constraints to agriculture are shown in Figure 17

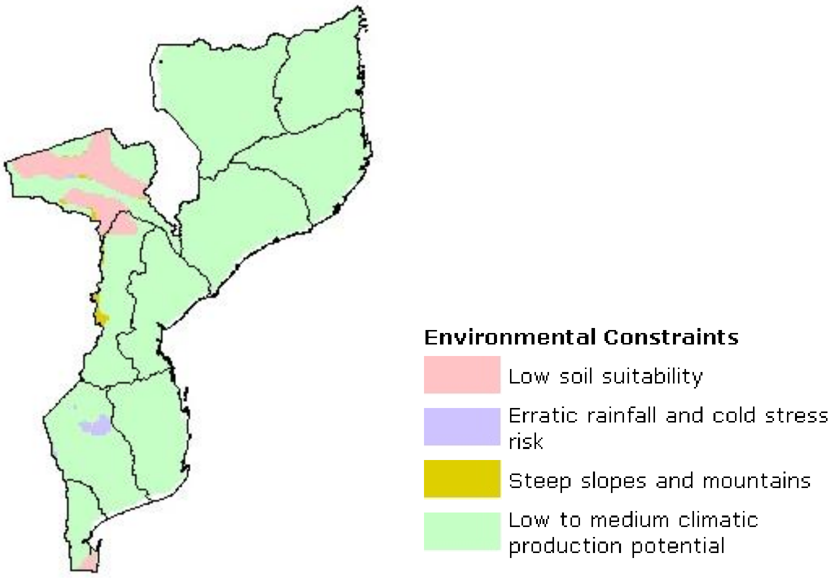


Figure 17: Environmental constraints in Mozambique (source: FAO[11])

Rainfall variability varies between 575 in December to 134% in September.

Mozambique: Seasonality of rainfall

The entire country experiences summer rainfall, but there are significant winter events in some regions. The northern regions experience a longer rainfall season lasting until May

Mozambique: Threats - Extreme climate events

Mozambique is vulnerable to climatic hazards such as floods, droughts and cyclones. The vulnerability of the human population to outbreaks of diseases is exacerbated by extreme climatic events.

[11] Food and Agriculture Organization of the United Nations (2007). http://www.fao.org

Tropical cyclones have become more frequent in recent years leading to devastating flood events. In 2000 and 2001 major floods led to the displacement of several hundred thousand people. This had specific health outcomes, especially in terms of water-borne diseases. For example, the floods were shown to have directly increased the incidence of cholera , while a study in 2002 comparing the number of cases of malaria after the Mozambique floods of 2000 with the number of cases in 1999 and 2001, though not conclusive, seems to indicate a huge increase in incidences of malaria. Malaria is the primary cause of mortality among children, causing 15 to 30% of all under-five deaths.

In recent years, insufficient rains, particularly in the south, have resulted in reduced crop production. Recent findings from a national food and nutritional survey showed that conditions in the drought-affected southern provinces, that also have the highest HIV/AIDS prevalence, have deteriorated. Assessments indicate that up to 800,000 people would be in need of food aid until March 2006 . In other provinces not affected by floods and cyclones, a series of natural and manmade disasters, including strong winds, heavy rain and flooding, caused damage to property and livelihoods.

Prolonged periods of drought (severe drought struck the country in 1974, 1983 and 1984, and in 1992); severe floods (the last were in February/March 2000, and since the rainy season in late 2000); devastating cyclones.

The severe 2000 floods in southern and central Mozambique affected, for instance, about 150,000 hectares of crop production. Livestock losses were estimated at about 30% of the total cattle stock in the three southern provinces (Gaza, Inhambane and Maputo Province). Extensive losses of small animals, such as goats and chickens, were reported. Oxfam reported that 522,000 people were displaced or in areas cut off by flooding.

3.4 Tanzania

Figure 18: Tanzania

Source: theworldatlas.net

Mainland Tanzania falls into three major geographical zones—a narrow lowland coastal strip along the Indian Ocean; a vast interior plateau; and a number of scattered mountainous regions. The coastal zone (10–40 mi/16–60 km wide) receives considerable rainfall and has much fertile soil. The plateau (average elevation: 3,500–4,500 ft/1,070–1,370 m) extends over most of the interior and is cut in two places by branches of the Great Rift Valley. The western branch contains Lake Tanganyika and the eastern branch runs through central Tanzania about 500 ft (150 m) below the level of the plateau; the two branches merge just north of Lake Nyasa. The plateau receives little rainfall, but in most parts there is enough to support agriculture.

Tanzania has four distinct climatic zones: hot, humid tropical coastal plains; the arid central plateau; high, moist and humid lake regions; and the temperate highlands. There are two rain seasons in most of the country: the long season from mid-March through to May, the short rain season falls during November, December and January. The heavy rains fall in April and May, From December to March, when the northeast monsoon blows, it is hot and comparatively dry. In the south there is one rainy season, from November to March. Long term means for temperature and rainfall are given in Figure 19

Rainfall varies from over 1500mm per year on the coastal plains and humid lake regions to less than 600mm over the central plateau. One third of the country has rainfall of over 1000mm/a, and one third less than 800 mm/a.

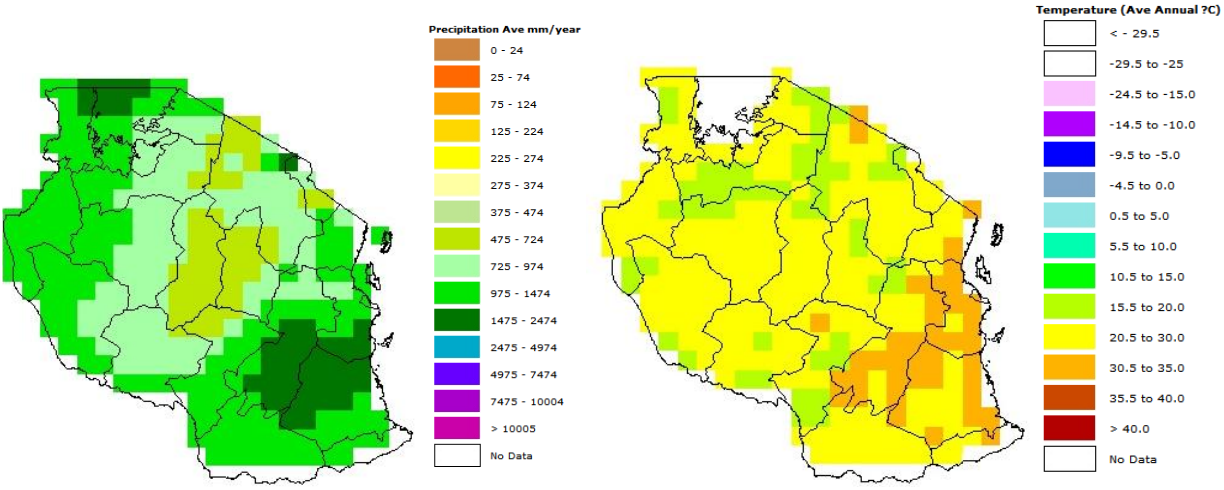


Figure 19: Average Precipitation and temperature of Tanzania (Source: FAO[12])

Tanzania: Local Climates

The climate on the offshore islands of Tanzania is tropical, but the heat is tempered by sea breezes that are constant throughout the year, except during the rainy seasons. The coolest months are from June to October, and the warmest are December to March.

The climate along the coast: Coastal Region, Dar-Es-Salaam, Lindi, Mtwara, and Tanga, and the off-shore Islands of Mafia, Pemba, and Unguja is tropical with relatively high humidity. The average temperature, which is moderated by the sea breeze, especially on the islands, ranges between 27 and 29ºC.

In the Central, Northern and Western Region: Around Mwanza Kagera, Kigoma, Shinyanga and Tabora, the climate is modified by highland plateau; low humidity with temperatures ranging between 20 and 27ºC during the cooler months of June through August. The temperature can reach as high as 30ºC and higher between the months of December and March.

Northeast and Southwest Regions: In the mountainous areas of the Arusha, Kilimanjaro and Mara region, and Mbeya, Rukwa, Iringa and Ruvuma, and Makonde Plateau (Newalla, Masasi, Nachingwea and Tunduru) , the temperature occasionally drops below 15ºC at night during the months of June and July. In the area around Rungwe mountains the temperature can reach as low as 8 or 6ºC.

Central Area: A large part of central regions (Dodoma and Singida) is semi-arid, receiving less than 500mm of rain annually. In contrast, the mountainous area in the north-east and south-west receive over 2000mm. of rain annually. Along the coast (Dar es Salaam, Tanga, Lindi, Mtwara and Coastal Region) rainfall ranges between 1000 and 1900mm.

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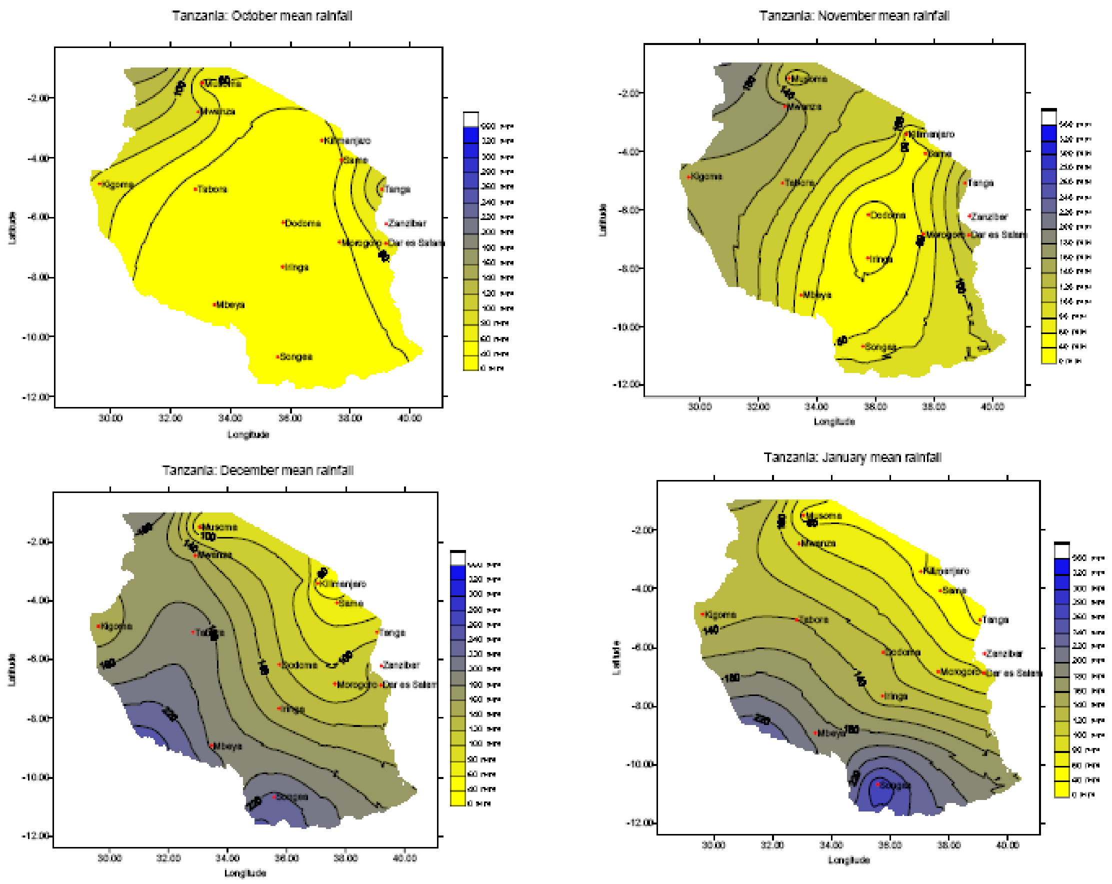
[12] Food and Agriculture Organization of the United Nations (2007). http://www.fao.org

Tanzania: Long Term Means

Seasonal rainfall varies across the country with the wettest month in April (Figure 20). Individual climatic means for 5 main cities are given in



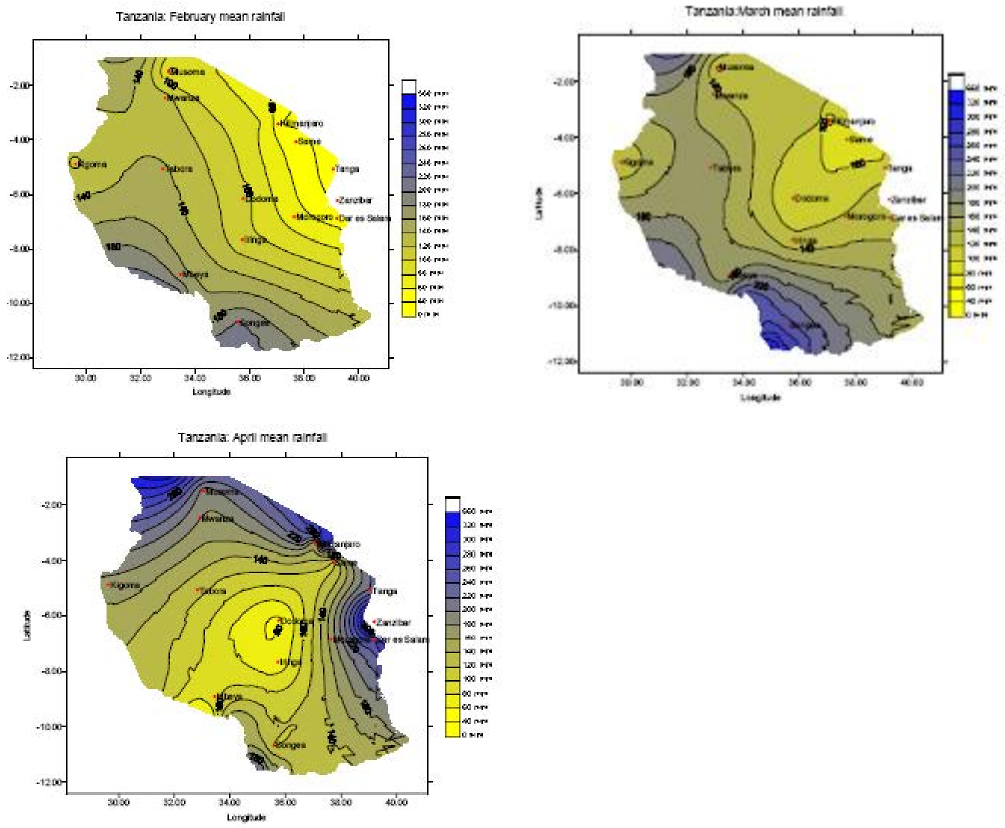
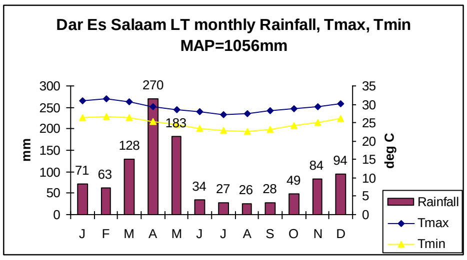
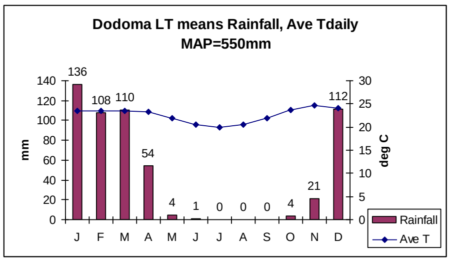


Figure 20: Seasonal variation of rainfall from October to April (source http://209.88.21.36/Atlas/Atlas_web.htm)

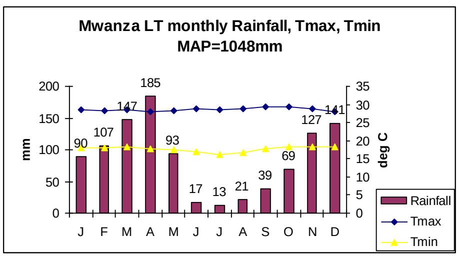
Dar Es Salaam



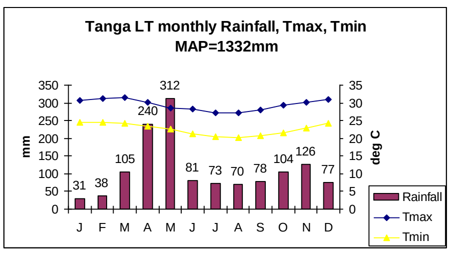
Dodoma



Mwanza



Tanga



Arusha

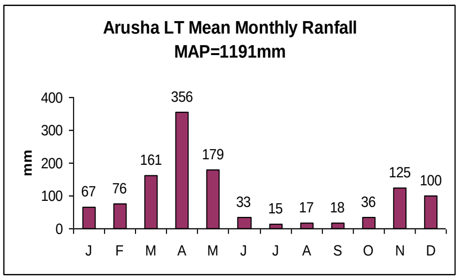


Figure 21: Long term climate means for 5 cities

Tanzania: Seasonality of rainfall

Over most of the country there is a single rainy season with the heaviest falls between November and April; the period May to October is dry and sunny. The coastal region is an exception in that it gets some rain in all months, with the main rain falling between March and May. The southern coastal district is occasionally affected by heavy rain and strong winds associated with tropical cyclones in the south Indian Ocean.

Tanzania: Threats

Extreme events are likely to pose the greatest climate change threat to Tanzania; they are likely to take the form of drought, floods and tropical storms – all of which are expected to become more frequent, intense and unpredictable (IPCC 2007). Already droughts during the last decade have caused famines in most districts.

3.5 Mauritius

Figure 22 Map of Mauritius main island (Source: http://goafrica.about.com/library/bl.mapfacts.mauritius.htm)

Mauritius consists of a few islands, but here the main inhabited (and largest) island is used (Figure 22). It has an area of approximately 600km^2. As such there are no distinct climatic regions, though rainfall varies across the island with highest levels recorded in the high-lying areas. Located between the Equator and the Tropic of Capricorn, Mauritius enjoys a mild tropical maritime climate throughout the year. The country has two seasons: a warm humid summer extending from November to April and a relatively cool dry winter from June to September. The month of October and May are commonly known as the transition months.

Mean summer temperature is 24.7 degrees Celsius and mean winter temperature is 20.4 degrees Celsius. The temperature difference between the seasons is only 4.3 degrees Celsius.

The warmest months are January and February with average day maximum temperature reaching 29.2 degrees Celsius and the coolest months are July and August when average night minimum temperatures drops down to 16.4 degrees Celsius.

Long term mean annual rainfall (1971-2000) over the Island is 2010 mm. The wettest months are February and March. The driest month is October.

Mean summer rainfall (1971-2000) is 1344 mm, which is 67% of the annual amount over the Island. Mean winter rainfall (1971-2000) is 666 mm. Although there is no marked rainy season, most of the rainfall occurs in summer months.

The Island receives 6.5 to above 8 hours of bright sunshine daily. In summer months around 6.0 hours of bright sunshine are received over the high grounds, whereas the coastal regions are exposed to 7.5 to over 8.0 hours of bright sunshine. In winter months, the Central Plateau receives around 5.0 hours of bright sunshine whereas the coast receives above 7.5 hours of bright sunshine.

Temperatures in the interior of the island are generally 3 to 5°C cooler than at the coast. The rainy season is from January to May with the possibility of tropical cyclones between January and March.

Mauritius: Long Term Means

Figure 23 shows long term monthly means of temperature, humidity, wind, sunshine hours and rainfall.

MONTH	TEMPERATURE				HUMIDITY	WIND		SUNSHINE		RAINFALL LTM	NO OF DAYS WITH	NO OF DAYS WITH
	Mean Max 1971-2000	Highest Max Recorded	Mean Min 1971-2000	Lowest Min Recorded	%	Mean Wind Speed Km/h	Highest Gust Km/h	Daily Hrs per day	Mean Monthly	1971-2000	RAINFALL > 1 MM	RAINFALL > 5 MM
January	29.8	35.9	23.0	17.7	81	11.4	219	7.7	239.7	236.6	16	8
February	29.5	34.4	23.1	17.4	83	9.5	209	7.1	198.7	266.6	16	10
March	29.1	33.4	22.7	15.9	83	9.5	169	6.9	212.9	203.1	17	8
April	28.2	32.8	21.8	15.0	83	9.5	153	6.5	194.1	211.5	17	8
May	26.8	30.6	20.2	13.3	81	11.4	69	6.6	203.2	153.4	14	6
June	25.2	30.4	18.7	11.5	78	11.4	105	6.1	182.1	95.2	14	5
July	24.2	27.7	18.1	11.0	77	13.3	87	5.5	170.9	100.2	16	5
August	24.2	28.8	17.8	11.0	78	15.2	89	5.9	181.4	87.9	15	5
September	25.1	29.1	18.0	11.7	77	13.3	82	6.7	200.8	59.6	10	3
October	26.4	29.9	19.2	11.0	77	11.4	69	7.6	236.3	60.1	9	3
November	28.0	32.6	20.4	12.2	78	11.4	92	8.8	265.4	76.9	10	4
December	29.2	33.8	21.9	16.1	80	11.4	221	8.4	259.7	171.8	12	6

Note: LTM = long term mean
Temperature in measured in degrees celsius
Rainfall is measured in millimetres

Figure 23: Long term Climate means for Port Louis (Source: Mauritius Meteorological Services

Mauritius: Recent Climate Trends

Temperature

Mean annual temperature has increased by 0.6°C since 1960, an average rate of 0.13°C per decade. This increase in temperature is most rapid in JFM (0.16°C per decade) and least rapid in OND (0.10°C per decade).

There is insufficient daily temperature data available from which to determine trends in daily temperature extreme climate events.

Precipitation

The large inter-annual and inter-decadal variations in rainfall in this part of the world mean that it is difficult to identify long term trends. Whilst there is no evident trend in annual rainfall, OND rainfall has declined over the period 1960 to 2006, at an average rate of 7.7mm per month (8.7%) per decade.

There are insufficient daily rainfall observations available to identify trends in daily rainfall extreme climate events.

Mauritius: Extreme climate events

Mauritius is particularly vulnerable to hydro-meteorological hazards such as torrential rain and storm damage arising from high waves, storm surge, tropical cyclones, climate change, sea-level rise and tsunamis. The most serious impacts of these severe natural phenomena are upon the coastal zone, an important asset which contributes significantly to the economic development of the country through tourism. Remote sensing devices such as satellites and radar are extensively used for the detection and monitoring of some of these phenomena.

Large wave heights in the Indian Ocean around Mauritius are common because of strong winds generated by tropical cyclones and the low pressure cells in the roaring forties. Such heavy sea conditions are often responsible for ships failures and sinking. Model output covering the coastal south west Indian Ocean is not always accurate due to lack of in-situ real-time data and these forecast do not cater for risk of freak/rogue waves.

Analysis of data from Mauritius Meteorological Services does not show any increase in the number of storms in the South West Indian Ocean tropical cyclone basin. However, there seems to be an increasing trend in the number of storms reaching tropical cyclone strength (winds above 165 km/hr). The powerful winds that are associated with these storms cause widespread damage.

4 Changes in the future climate of southern Africa

General Circulation models (GCMs) are the fundamental tool used for assessing the causes of past change and projecting change in the future. They are complex computer models, which represent interactions between the different components of the climate system such as the land surface, the atmosphere and the oceans. In making projections of climate change, several GCMs and scenarios of future emissions of greenhouse gases are used to predict the future (see Box 4 and Box 5). This leads to a suite of possible futures, each of which is a valid representation of what the future climate may be. That there is a range of future possibilities is an important concept to understand clearly as it means that we can only suggest futures that may be more *likely* than others.

Box 4: Is one GCM better than another at projecting future change?

Whilst some GCMs are better at simulating the present observed climate, this does not necessarily mean that they are better at simulating future *change*. Evaluating one GCM against another is also not an easy task; whilst one GCM may better simulate monthly mean rainfall and temperature it may not better simulate the daily frequency or diurnal cycle of rainfall. Another problem when trying to use a single GCM is that only a limited number of future scenarios can be used and this can sometimes create the impression of a narrowly determined future, which may not fully span the range of potential future change. It is therefore recommended that future change is expressed either as a range of future change or as an average statistic (e.g. median) with some measure or recognition of the spread of possible future states.

GCMs typically work at a spatial scale of 200-300km, with the scales at which they have skill, i.e. at which they can usefully project the future, typically greater. Whilst this problem is greatest for projections of rainfall, it limits the application of GCM projections for assessments of change at the local scale. Therefore, the technique of 'downscaling' is typically used to produce projections at a finer spatial scale. Downscaling works because the GCMs are generally good at projecting changes in atmospheric circulation (high and low pressure) but do a poor job of translating that information into changes in rainfall. Given the scale of this review downscaling is not feasible for the whole region and we focus on the information given by the GCMs.

Box 5: What is a scenario?
Scenarios describe potential futures, which can be based on changes in the climate system, socio-economic circumstances or other potential future changes. In the context of climate change the IPCC published its Special Report on Emissions Scenarios (SRES) which describe a range of possible scenarios based around four 'storylines': A1, B1, A2 and B2. These storylines assume different paths of development for the world, greater weight being given to environmental (B family) or economic (A family) considerations, and more global (A1, B1) or regional (A2, B2) development. Each of these scenarios has an associated emissions pathway for the period 2000-2100. These emission pathways describe the amount of greenhouse gases (and other atmospheric gases) emitted through human activity in the future. General Circulation Models (GCMs) can then use these future emissions (which define changes in the concentration of these gases in the atmosphere) to model the future climate.

All the GCMs used in this report were used in the IPCC 4th assessment report. We use GCMs forced with both the SRES B1 (assumes society will reduce its use of fossil fuels and increase clean technology, as well as an emphasis on social and environmental stability) and A2 emissions scenarios[13] (which assumes that society will continue to use fossil fuels at a moderate growth rate, there will be less economic integration and populations will continue to expand). Details of the GCMs used for each scenario are provided in Table 1.

Originating Group(s)	**Country**	**I.D.**	**B1 scenario**	**A2 scenario**
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0	Yes	Yes
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T63)	Yes	Yes
Météo-France / Centre National de Recherches Météorologiques	France	CNRM-CM3	Yes	Yes
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.5	Yes	Yes
Meteorological Research Institute	Japan	MRI-CGCM2.3.2	Yes	Yes
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM	Yes	Yes
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0	Yes	Yes
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1	Yes	Yes
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	Germany/ Korea	ECHO-G	Yes	Yes
Institut Pierre Simon Laplace	France	IPSL-CM4	Yes	Yes
Instituto Nazionale di Geofisica e Vulcanologia	Italy	INGV-SXG	No	Yes
Institute for Numerical Mathematics	Russia	INM-CM3.0	Yes	Yes
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(med res)	Yes	Yes
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadCM3	Yes	Yes
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadGEM1	No	Yes

13 IPCC (2000) IPCC special report emissions scenarios: Special report of IPCC working group III. Intergovernmental panel on climate change. pp 20.

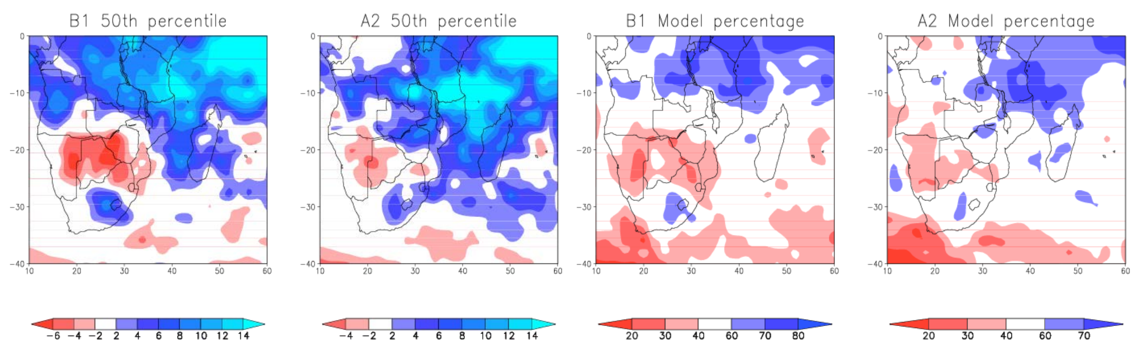
Table 1: GCMs used to derive the projected climate change (from the 1960-2000 baseline period) by 2040-2060[14]

Rainfall

Figure 24 to Figure 27 shows the median change in rainfall from the available GCMs for each scenario and for each of the 4 seasons: December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON). Also shown in each figure are the percentage of models which agree on a positive change in rainfall i.e. high percentages (>80%) indicate that the 13(B1)/15(A2) models mostly tend to suggest an increase in rainfall, whereas low percentages (<20%) indicate that the models mostly tend to suggest a decrease in rainfall. Percentages close to 50% e.g. 40-60% suggest that the different models disagree on the sign of change i.e. whether it will be positive or negative. This is one way of representing uncertainty in the model projections and this information can be combined with the median (50th percentile) estimates to suggest where the models are confident of +ve/-ve change.

It is notable that there are only subtle differences between the B1 and A2 scenarios, which suggests that for this mid-century period the choice of assumed emissions scenario makes little difference to the projected changes in rainfall, at least when considering a range of GCMs. Given that some differences may be due to the different GCM sets used in each scenario, it is advisable that little attention is paid to the differences between the scenarios.
Figure 24 suggests that during DJF, the main summer season, there is a tendency for the models to suggest drying over central southern Africa (though this is usually simulated by less than 70% of the GCMs), with slightly more consistently simulated increases further north over East Africa. Similar tendencies are noted during MAM (Figure 25), though with slightly more consistently simulated decreases in rainfall towards the south west of the continent. In all cases it should be noted that small and isolated regions (e.g. small patches of blue in the A2 model consistency figure for DJF) should be ignored as they represent only 1 or 2 GCM pixels, at which scale it is debateable if the GCMs have sufficient skill.

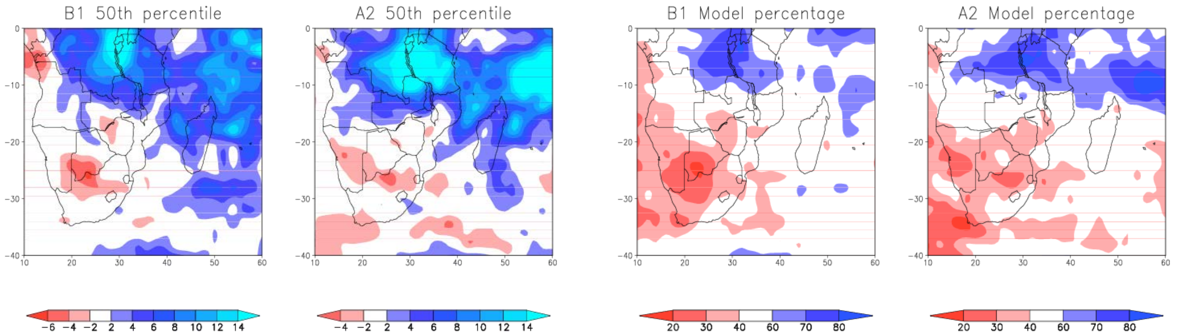
During JJA most models are simulating a decrease in rainfall over most of the region, though these changes are small and it is the dry season in most countries, so the impact of this change in rainfall is likely to be minimal. Perhaps a more important change is the consistently simulated decreases in rainfall during SON (Figure 27) across much of the southern African region. This is the period incorporating the start of the rains and suggests a reduction in early season rainfall.



[14] http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

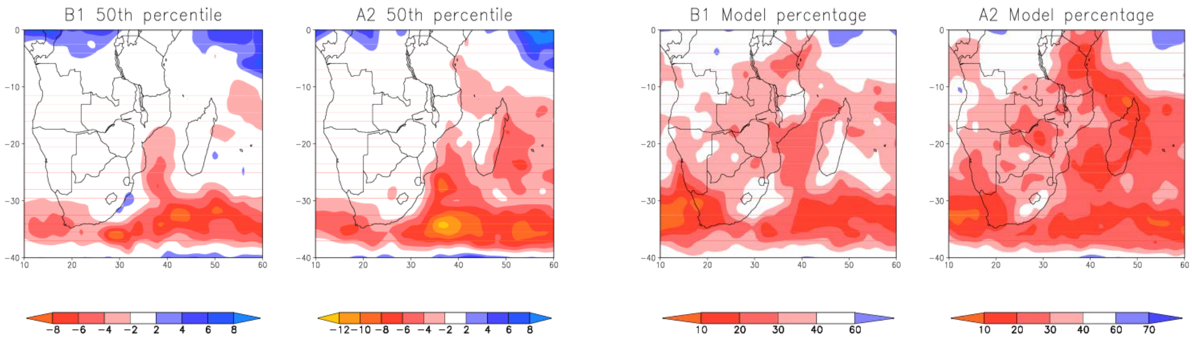
(a) (b)

Figure 24: DJF season: a) Median change in average rainfall by 2040-2060 (mm month^{-1}); b) Percentage of models suggesting an increase in rainfall



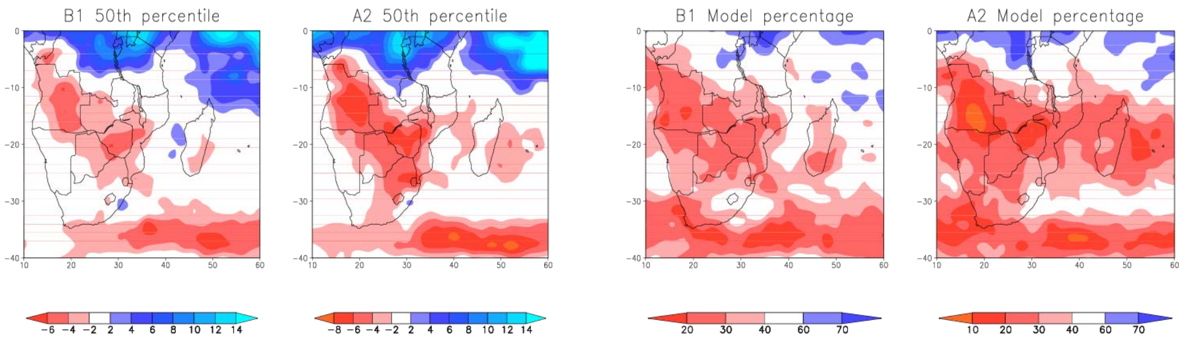
(a) (b)

Figure 25: MAM season: a) Median change in average rainfall by 2040-2060 (mm month^{-1}); b) Percentage of models suggesting an increase in rainfall



(a) (b)

Figure 26: JJA season: a) Median change in average rainfall by 2040-2060 (mm month^{-1}); b) Percentage of models suggesting an increase in rainfall



(a) (b)

Figure 27: SON season: a) Median change in average rainfall by 2040-2060 (mm month^{-1}); b) Percentage of models suggesting an increase in rainfall

Temperature

Figure 28 shows the median change in average surface temperature from the GCMs for each season and for the B1 and A2 scenarios. Because all models indicate an increase in temperature we do not show the model consistency as we did for rainfall. It can be seen that temperatures are expected to rise between 1 and 3°C over most land areas by approximately 2050. Increases are greatest under the A2 emissions scenario and towards the arid regions in the southwest of the continental landmass, which are also the regions which are suggested to receive the lowest increases (or decreases) in average rainfall in the future.

Temperatures in coastal cities can be expected to be close to that of the surrounding maritime air masses, though they will be influenced by the temperature over land which is higher e.g. Berg winds in Cape Town (winds which bring hot and dry air from the continent) may endure higher temperature increases than onshore winds from the ocean. In the case of small Indian Ocean island states such as Mauritius it may be expected that the temperature increase will be the same as the surrounding oceans, modified by the local topography of the island. However, neither these islands nor their topography are simulated by the GCMs used in this study.

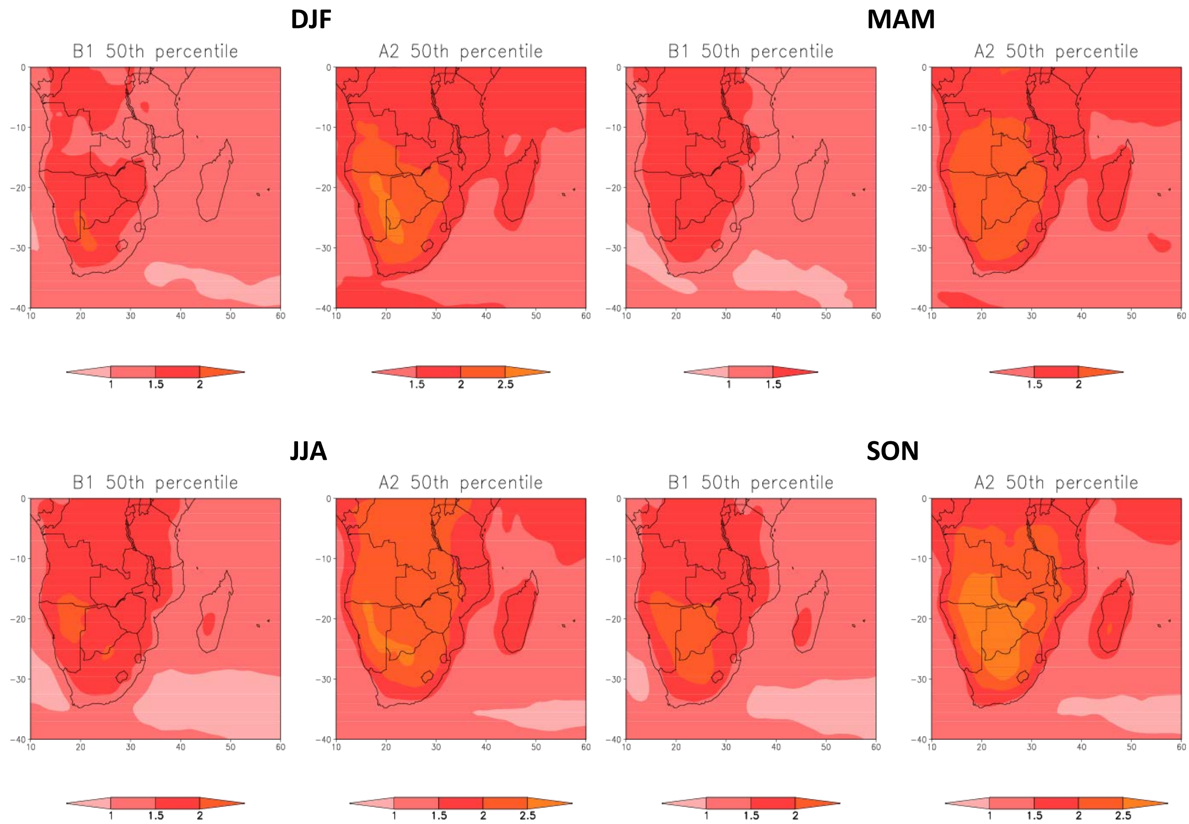


Figure 28: Median change in average temperature (K) by 2040-2060, relative to the 1960-2000 period. B1 scenario left and A2 scenario on the right.

Winds

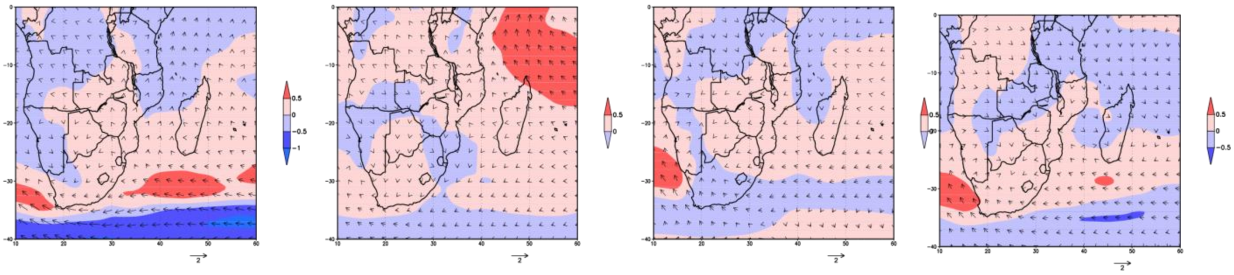


Figure 29: Median changes in 10m wind direction and wind speed (by 2040-2060, relative to 1960-2000), simulated by the 15 GCMs in the A2 scenario.

Figure 29 indicates the median change in surface (10m) wind direction and speed simulated by the 15 GCMs under the A2 emissions scenario. We only show the A2 emissions scenario as the changes look similar in the B1 scenario (though slightly smaller) and do not significantly alter the following discussion. During DJF changes are mostly for an increase in easterly wind flow south of 30°S which decreases the normal westerly flow in the far south and increases the easterly flow further north (south of Madagascar and offshore of Cape Town). These changes are linked to changes in the regional dynamics, namely a decreasing influence of the westerlies and retreat of mid-latitude storms in the south and an increase in the strength of the high pressure anticyclones over the Indian and Atlantic Oceans (notice the increase in offshore flow off Cape Town).

During MAM the main feature is an increase in the southeast monsoon over the tropical Indian Ocean, which increases the advection of warm moist air over east Africa and contributes to the increases in rainfall seen in Figure 25. The most significant feature in the JJA and SON seasons is the increase in the strength of the Atlantic high pressure system resulting in increased offshore flow near Cape Town. In both seasons there is also an indication of reduced westerly flow to the south, though this is a small change and is likely less consistently simulated by the GCMs.

Changes in tropical cyclones

Tropical cyclones are very difficult to simulate even under current climatic conditions and their future prediction is hampered by the coarse resolution of the GCMs, which are unable to capture many of the features which are important for cyclogenesis e.g. wind shear between the lower and upper atmosphere, the dynamics of the eye of a cyclone and the underlying ocean[15]. This results in only small depressions being simulated by GCMs and it is necessary to use statistical or statistical/dynamical models to obtain information on expected changes in tracks, frequency and intensity. This is still an evolving science and continues to be debated at the global level. However, some consensus on a global scale is being reached:

[15] http://wind.mit.edu/~emanuel/anthro2.htm

"The scientific debate concerning the Webster et al. and Emanuel papers is not as to whether global warming can cause a trend in tropical cyclone intensities. The more relevant question is how large a change: a relatively small one several decades into the future or large changes occurring today?"
IWTC-6, San José, Costa Rica, November 2006

Furthermore, there are indications that cyclones in the south Indian Ocean are likely to intensify[16] and shift southwards, though there may be a reduction in the frequency of especially weaker events[17]. These assessments are still based on very different methodologies and assumptions and should be treated with caution as there is, as yet, no consistent and widely recognised methodology for making these assessments. It is also likely that the different factors influencing tropical cyclones will change non-linearly in the future and therefore lead to different changes with time i.e. there will not be a linear change in these characteristics as the climate evolves.

5 Reconciling observed and expected future change

The projected changes in rainfall and temperature for the middle and end of the 21st century that have been presented here are linked to physical changes in the regional climate system, which offers a way to reconcile observed trends and future projected change where they are different. Consistently projected future change is a consequence of the following physical changes:

1. Increase in temperature, which promotes convective activity, especially during mid-late summer
2. Increase in humidity, which increases the amount of moisture available for rainfall once it is triggered.
3. Retreat of the mid-latitude storm systems and increases in the continental high pressure system during winter (and potentially autumn and spring)

However, these changes in the physical system will interact and couple in a non-linear manner and individually manifest themselves at different periods in the future. The regional expression of change is therefore dependent on which mechanisms, which may compete with each other (e.g. increases in rainfall may offset decreases in rain days), are dominant at any particular time. Unlike the temperature signal due to climate change, which is currently observable, the rainfall signal (as estimated from low variability GCM data and therefore likely a conservative estimate) is not expected to be observable for several decades.

Reconciling these past and future changes is a difficult, yet necessary challenge. Where current trends are in line with projected change, and the physical mechanism related to both is understood, planning and adaptation related to such changes have firm grounds for moving ahead. However, where observed trends disagree with future projections, then further investigation is required as observed changes may be due to natural variability. In the case when there are no consistently observed trends, but projections suggest a change that is physically plausible, further monitoring is necessary to detect any such changes if and when they happen in the future. Such an analysis

[16] Yip, J. (2008) Potential change in tropical cyclones of Southwest Indian Ocean under climate change. Hons thesis. University of Cape Town
[17] Mavume. A and Brundrit G. (2009) Sea level rise and cyclone analysis. In INGC. 2009. Main report: INGC Climate Change Report: Study on the impact of climate change on disaster risk in Mozambique. [Asante, K., Brito, R., Brundrit, G., Epstein, P., Fernandes, A., Marques, M.R., Mavume, A , Metzger, M., Patt, A., Queface, A., Sanchez del Valle, R., Tadross, M., Brito, R. (eds.)]. INGC, Mozambique

requires focusing on smaller regions to understand local changes and relating them to larger-scale atmospheric change, which in turn requires a more in-depth analysis and the use of downscaling methodologies.

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