Floods, Droughts, Tropical Cyclones and Heatwaves: Present and Future - A Contribution for Early Warning Systems for Southern Africa

Work presented to the MAP-Fis PhD Programme to fulfil the requirements for obtaining the ESSAY Module Assessment

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FCT

Work Structure

Introduction

- Climate Extreme
- EWS
- RCMs

State of Art

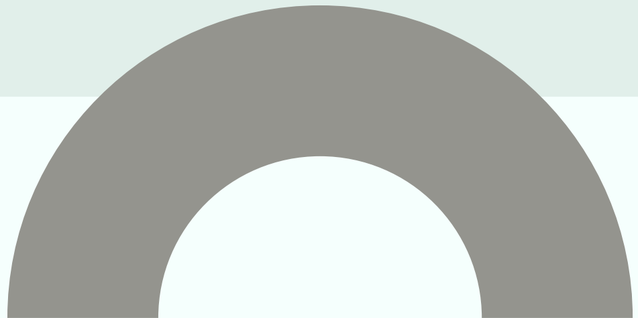
Southern Africa

Southern Africa (SA)

- Study Limitations
- Drivers

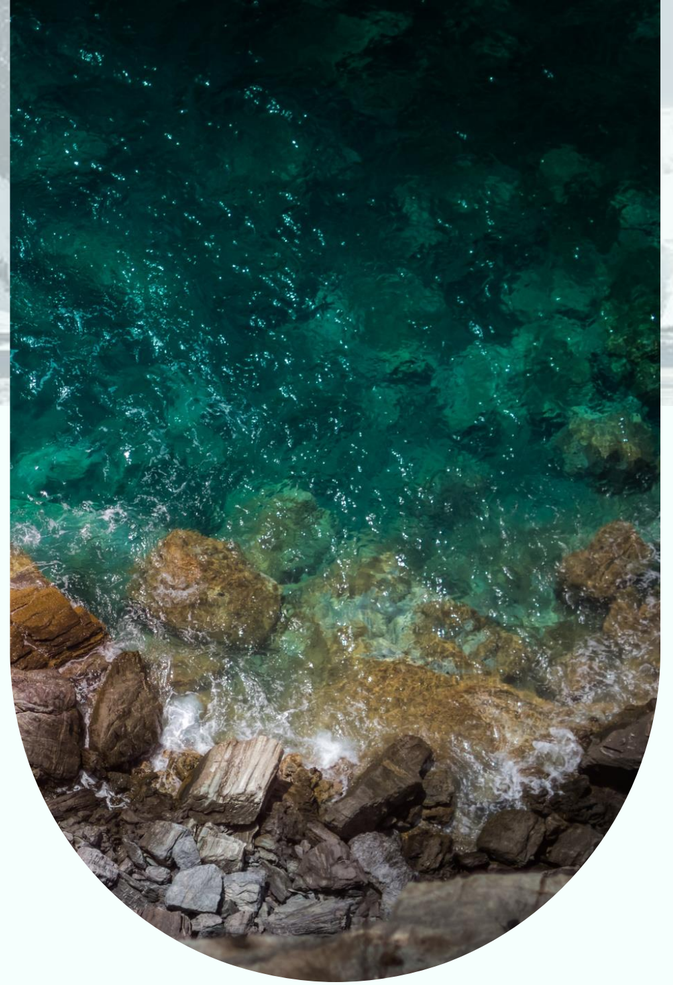
Research Proposal

The scientific research design is presented in general terms.



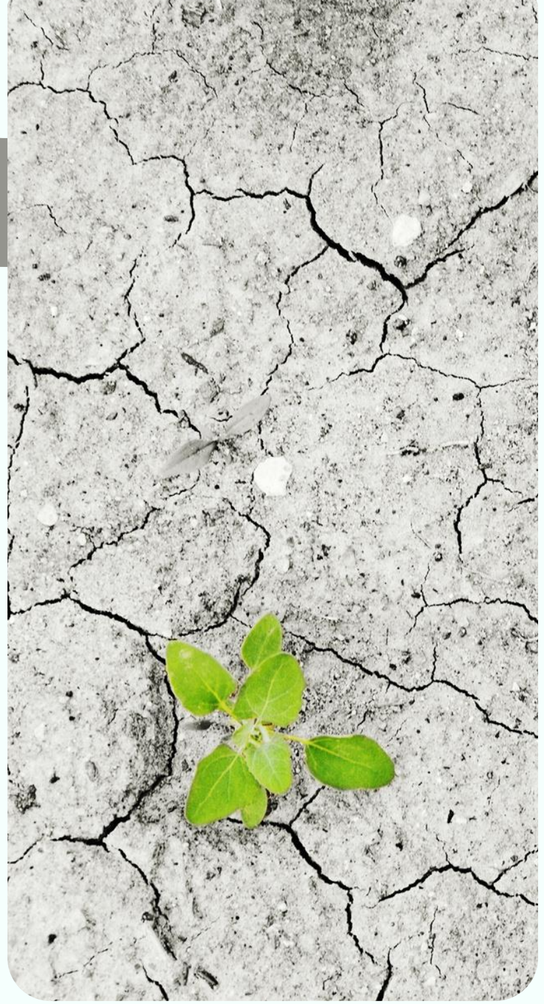
Introduction

CLIMATE EXTREMES



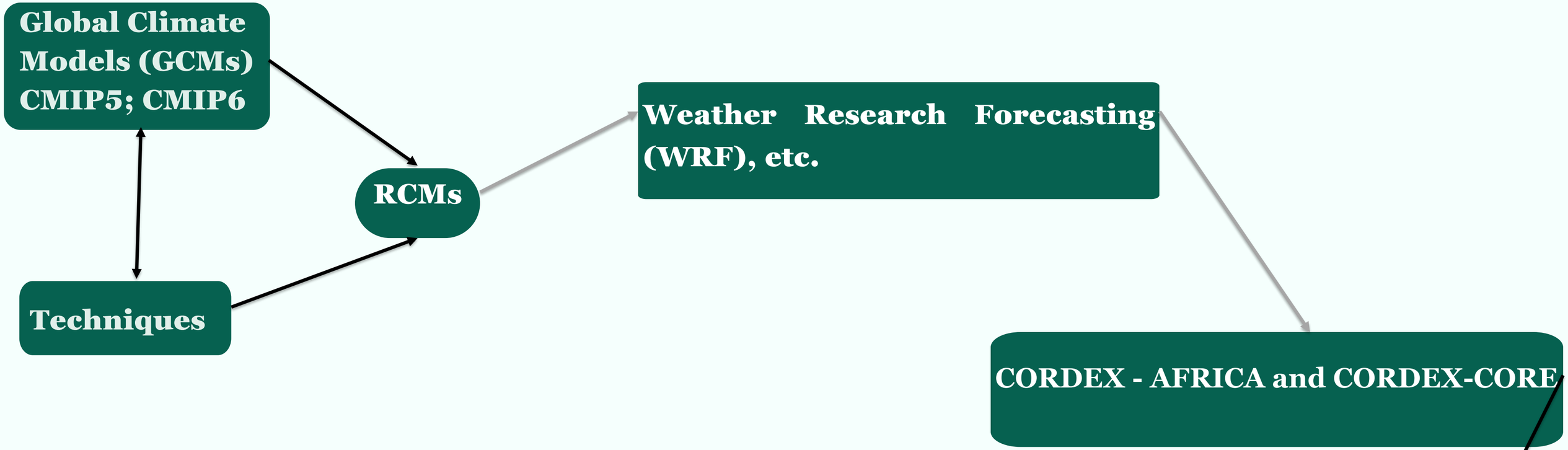
Definition of Extreme Climate

- Floods
- Tropical Cyclones
- Heat Waves
- Droughts



The presentation we will mainly address the climate extremes related with droughts and tropical cyclones.

Regional Climate Models (RCMs)



Africa was the first continent selected for the Coordinated Regional Climate Downscaling Experiment - CORDEX (Dosio, 2017) leading many climatologists to study the performance of RCMs in SA. In recent years, the seasonal characteristics of rainfall have become a topic of interest for SA making the data produced by CORDEX a valuable resource for enabling future projections of high-frequency rainfall in the region (Shongwe et al., 2015).

Early Warning Systems

In the countries of the SA region, many National Meteorological and Hydrological Services (NMHSs) have serious difficulties in providing EWS for extreme hydro-meteorological events, including flash floods, severe weather alerts and warnings. It makes investing in EWS in the Southern African Development Community (SADC) region more urgent (Braimoh et al., 2018).

Projects

Southern Africa

Severe Weather Forecast Demonstration Project (SWFDP)

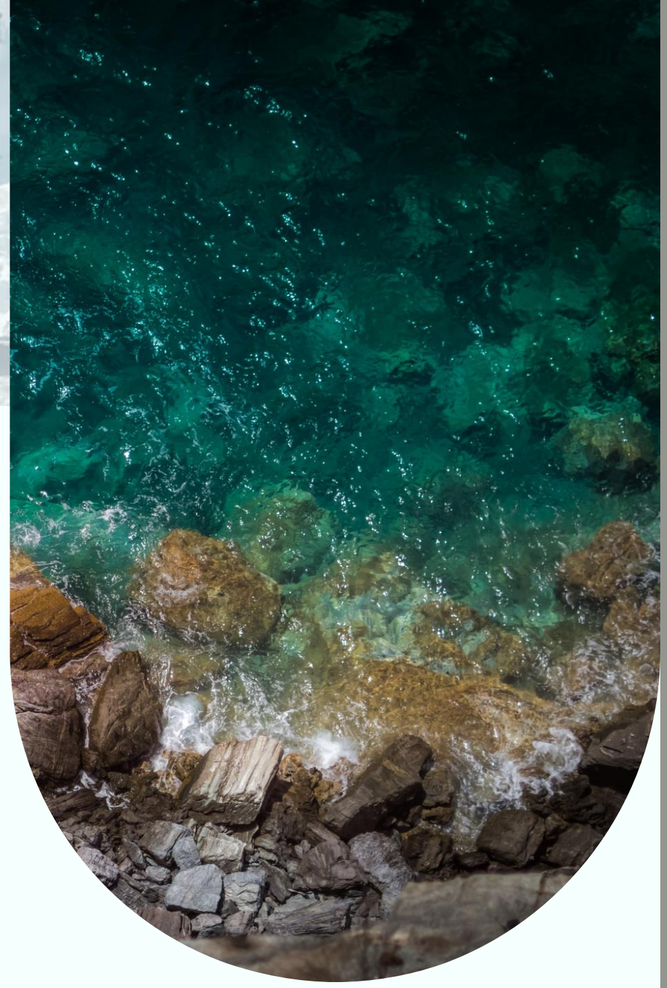
Southern Africa Region Flash Flood Guidance (SARFFG)

EW4ALL

Technologies:

- Artificial Intelligence (AI)
- robotics
- sensor networks
- remote sensing
- Monitoring devices to effectively capture weather phenomena
- blockchain
- 3D printing
- Machine learning and fourth industrial revolution (4IR)
- Alarms
- Earth observation
- big data

State of Art



Assessing the regime of droughts, tropical cyclones, regional climate models and early warning systems in southern Africa

LOCATION OF THE STUDY AREA AND FACTORS INFLUENCING THE CLIMATE

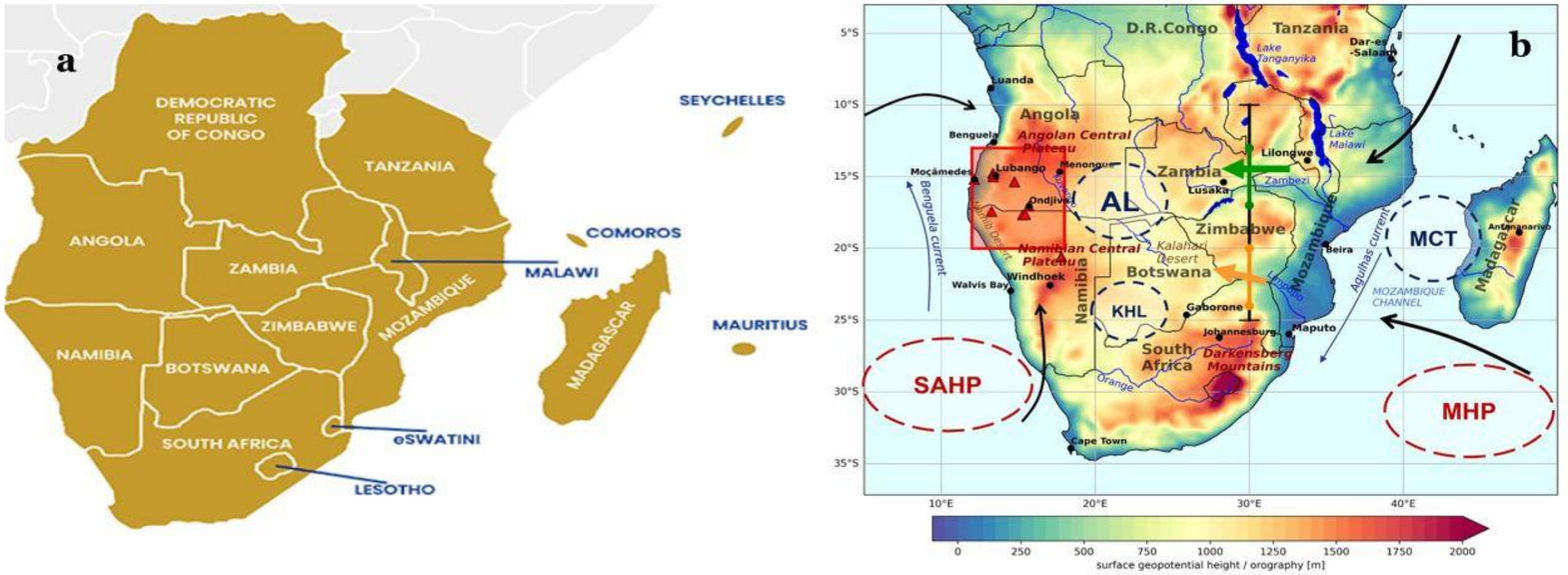


Figure 1 – (a) The Southern African Development Community (SADC) member states (SADC, 2022). (b) Surface geopotential height over SA subcontinent (colour scale), acquired from ERA5 (Pereira et al., 2024).

- Inter-Tropical Convergence Zone (ITCZ)
- El Niño-Southern Oscillation (ENSO)
- Benguela Niño/Niña events
- Indian Ocean Dipole (IOD)
- South Indian Ocean Dipole (SIOD)
- Southern Annual Mode (SAM)
- Madden-Julian Oscillation (MJO)
- Sea Surface Temperature (SST)
- Marine Heatwaves
- Quasi-Biennial Oscillation (QBO)
- Anthropogenic influences

THE DROUGHT REGIME IN THE SOUTHERN AFRICA

Drivers → **ENSO** — **IOD** — **SST** — **Benguela Niño/Niña events** — **Anthropogenic**

THE TROPICAL CYCLONES IN THE SOUTHERN AFRICA

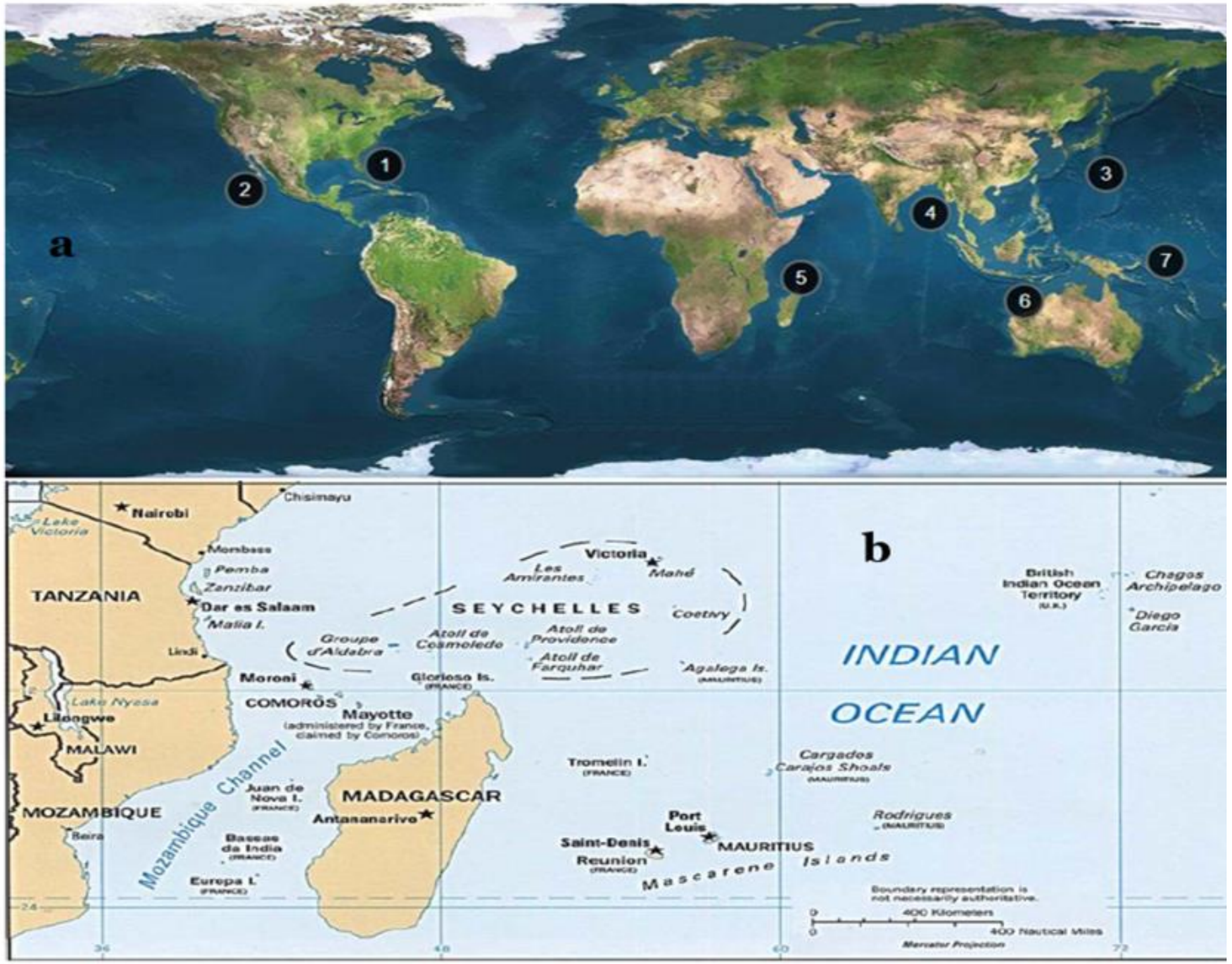


Figure 2 – (a) Distribution of TCs basins in the world (NOAA, 2023). (b) Location map of the region of interest in the present study (Chang-Seng & Jury, 2010).

CLIMATOLOGY

- **The cyclones occur within the season from November to April, with a peak of occurrence between January and March;**
- **One system per year makes landfall in Mozambique and/or Madagascar;**
- **Annual average of 11 cyclones per season.**

DRIVERS

- **Tropical Cyclone Heat Potential (TCHP)**
- **Subtropical high pressure (i.e. the Mascarene high)**
- **SIOD**
- **ENSO**
- **MJO**
- **SST**
- **VWS**
- **IOD**
- **QBO**
- **ITZC**
- **SAM**
- **Marine heatwaves**
- **Anthropogenic influences**

MONITORING, PREDICTING AND FUTURE WEATHER OF EXTREME CLIMATE IN THE SOUTHERN AFRICA

Drought Monitoring

Remote sensing technics

Anomaly Hot Spots of Agricultural Production (ASAP)

The emerging technologies like Global Navigation Satellite System - Reflectometry (GNSS-R)

Drought Predicting

Remote sensing data

RCMs: (WRF)

The SA Regional Climate Outlook Forum (SARCOF): Seasonal weather forecast

Recent research into future projections continues to show the dominant effect of anthropogenic drivers as the crucial driver of drought change in the SA region (Ayugi et al., 2024).

Future Weather

Tropical Cyclones Monitoring/Track

Remote sensing technics

International Best Track Archive for Climate Stewardship (IBTrACS)

CyTRACK

Power dissipation index (PDI)

Tropical Cyclones Predicting

RSMC-Pretoria guidance forecast

Climate Forecast System (CFS)

GCMs

WRF

United Kingdom Met Office (UM)

Anthropogenic factor is an influence in shift positions of TC genesis, which is linked to an increase or decrease frequency (Cao et al., 2024).

LIMITATIONS OF EXISTING STUDIES

Discussing the drought regime's characteristics in SA is challenging because of the limited number of publications on the topic. South Africa has the most publications on the drought regime, whereas Angola and Namibia have the fewest publications/studies (Chivangulula et al., 2023).

According to the study, only one paper describes the characterisation of the drought regime in SA with all the descriptors (frequence, duration, severity, intensity and spatial distribution) of spatial-temporal analysis that includes inter- and intra-annual distribution (Chivangulula et al., 2024). However, no document describes the complete characterisation of the drought regime in SA in the same way using different drought categories on all time scales.

Lastly, the recent 2023/2024 drought persisted until December 2024 (JRC, 2025). According to the WMO (2024), it exceeded historical levels. A comparative study with the other droughts that have occurred would be crucial. We would be able to see the evolution of the different types of droughts and have an idea of their descriptors.

LIMITATIONS OF EXISTING STUDIES

Regarding Tropical cyclones (TCs) in SA, all the bibliographical surveys used in the work discuss annual and /or inter-annual analyses of TCs. Most of the studies are centred on Mozambique, some on South Africa.

For the bibliographical survey of the future climate of the TCs in SWIO, we didn't find a study that analysed the projections simultaneously with the Representative Concentration Pathways (RCPs) (2.5, 4.5, and 8.5). The most up-to-date climatology used for comparison was 1965-2014.

The changes in rainfall characteristics are rarely investigated in NMHS observations or regional-scale climate simulations in Africa (Reason et al., 2005). Meque et al. (2021) list different reasons why the SA region presents limited research into rainfall characteristics and changes, which comprises: (i) Lack of appropriate computing, poor internet and telecommunications infrastructure; (ii) Inadequate observation network and lack of operational climate data management systems.

LIMITATIONS OF EXISTING STUDIES

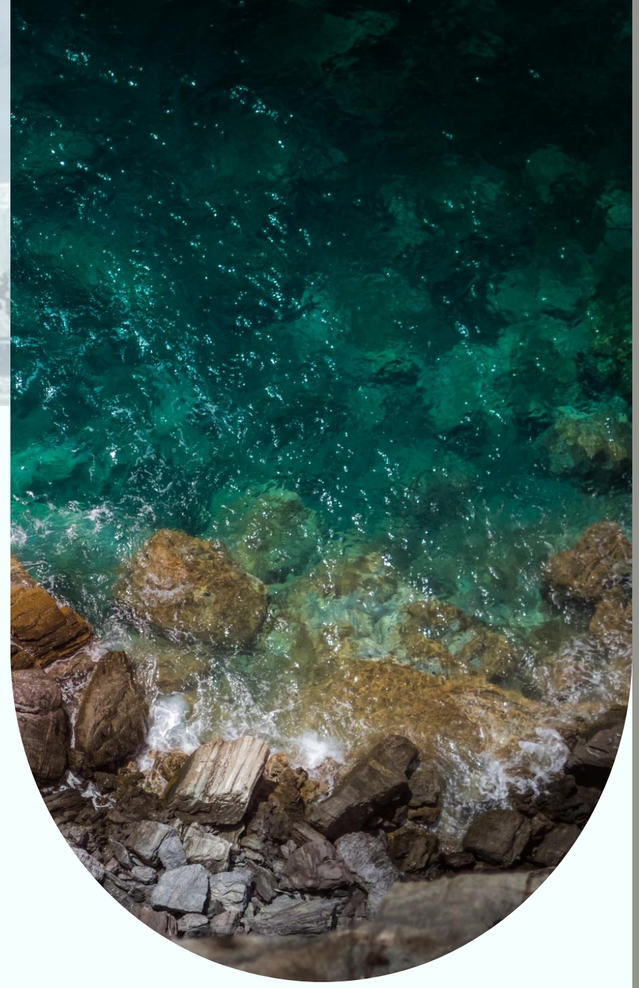
Moreover, the challenge is to assess the ability of RCMs to simulate the entire probability distribution of rainfall at regional scales (Perkins et al., 2007). However, verifying that our modelling tools are suitable for evaluating these changes is crucial (Samuel et al., 2023).

Therefore, the CORDEX Africa program has enabled verification of the performance of RCMs over the SA region (Kalognomou et al., 2013; Meque & Abiodun, 2015). The current RCMs can provide meaningful information on climate precipitation projections over the SA region (Kalognomou et al., 2013; Meque et al., 2021). Moreover, the WRF model is the most widely used.

The lack of scientific knowledge of climate risks in the EWS in SADC influences SADC's vulnerability to climate-induced shocks. Therefore, a serious effort to develop themes that further link resilience to climate risks in the region is crucial. Moreover, the lack of human capacity to use monitoring systems to identify the areas most affected by disasters, adoption and limited use of modern technologies such as television, sirens, megaphones, online services disseminate warning information, and 4IR, thus reducing human casualties and saving property (Agbehadji et al., 2024).

Research Proposal

- Description of the Scientific Research Problem
- Study Subject
- Main Objective
- Specific Objectives
- Hypotheses
- Methodology



• Description of the Scientific Research Problem

- This thesis concerns the challenges faced by the meteorological service in implementing an Early Warning System (EWS) for extreme phenomena. In recent years, Southern Africa (SA) has experienced changes in meteorological parameters such as temperature and rainfall. There has also been an increase in the occurrence of extreme events such as floods, droughts, heat waves, and tropical cyclones.

- Against this backdrop, scientific knowledge of these extreme phenomena, such as analyses of extreme phenomena at various spatial-temporal scales, the factors that produce them, monitoring techniques, and global and regional climate models to support simulation and/or modelling of extreme events, such as forecasting scales and future projections. It could be useful for the authorities to implement an EWS for these extreme phenomena.

• Study Subject

- **Extreme events in the current and future climate.**

• Main Objective

- **Investigating the influence of extreme events and contributing to early warning systems in southern Africa.**

• Specific Objectives

- **To analyse the meteorological drivers that influence the occurrence of extreme events in southern Africa;**
- **Assessing the regime of floods, droughts, heat waves, tropical cyclones, regional climate models and early warning systems in southern Africa;**
- **Carry out a spatial-temporal analysis on various scales of the extreme events discussed in southern Africa using the historical series from 1981 to the present date (the current data available);**
- **Simulating and predict the occurrence of extreme events on various spatial and temporal scales;**
- **Correlate meteorological drivers with extreme events;**
- **Identify the influences of the mechanisms that produce extreme events;**
- **Elaborate climate change projections on various scales of the extreme events.**

• Hypotheses

- **If we analyse the meteorological and/or climatic factors in SA, we can determine their influence on extreme phenomena.**
- **If extreme phenomena over southern Africa are monitored, simulated, forecasted and projected on various spatial-temporal scales, this will contribute to the design of a very effective EWS for extreme phenomena.**

- **Methodology**

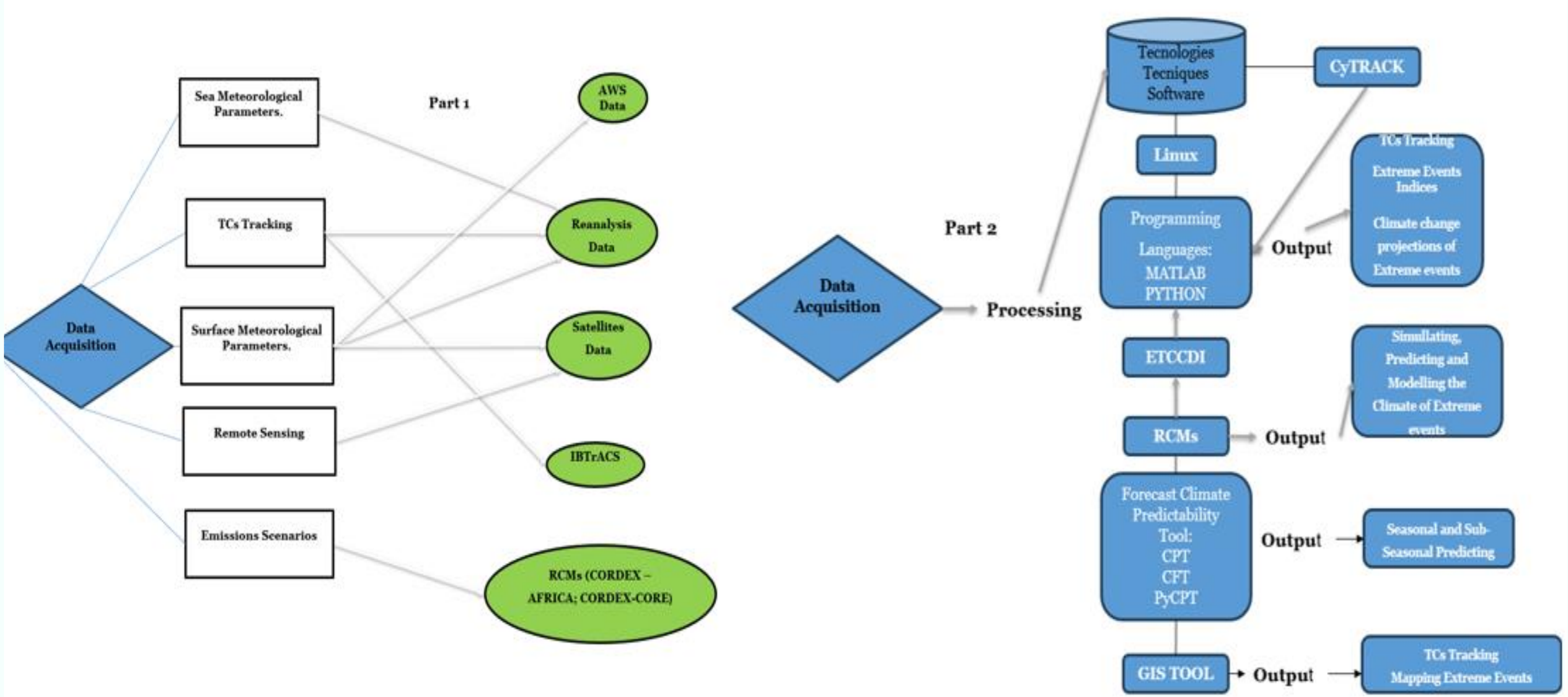


Figure 3 – Flowchart illustrating the proposed research methodology.

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