



# FUTURE CLIMATE FOR AFRICA

## Collection of FCFA Research Consortium and Country Summaries



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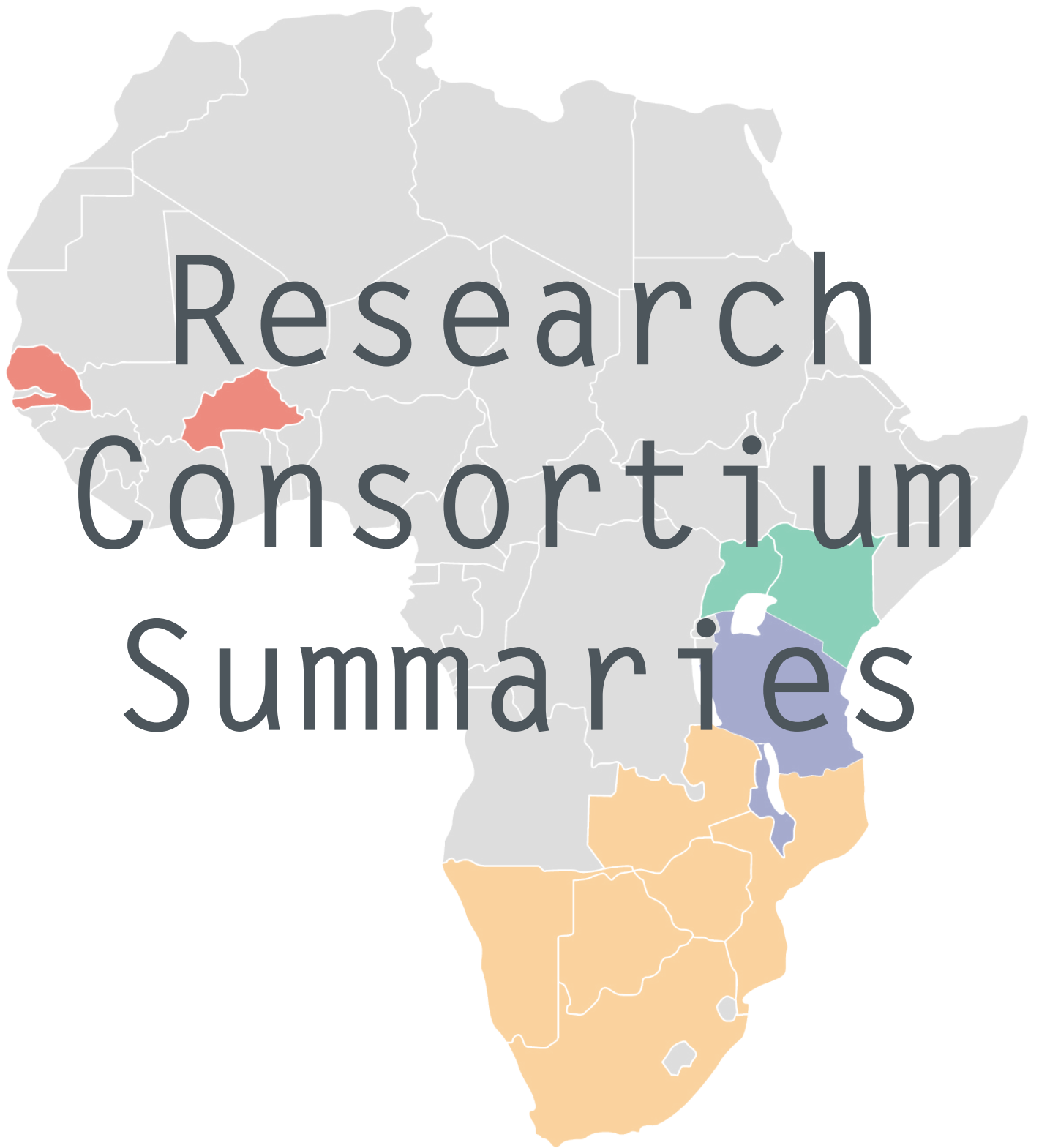
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\* This summary only covers FRACTAL's work in Malawi and there is a separate brief that details UMFULA's research in Malawi on page 93

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Research  
Consortium  
Summaries

# IMPALA: Improving Model Processes For African Climate

## About IMPALA

[IMPALA: Improving Model Processes For African Climate](#) aimed to improve the understanding of Africa's climate and the mechanisms of future change, and thereby helped provide high-quality information that is crucial for effective decision-making across the continent. IMPALA led to a step-change in climate model prediction capability, and delivered information on scales that was not previously available across many parts of sub-Saharan Africa.

With its team of climate scientists from UK and African institutions, IMPALA implemented model developments and evaluated the performance benefits on model prediction capability over the African continent. In turn, this improved model performance underpins reduced uncertainty in climate predictions over the next 5-40 years.

The IMPALA project tackled a major scientific hurdle that limits decision-makers from using climate information; current climate models only have a modest ability to capture African climate systems. Because of this and the limited knowledge of the drivers and dynamics of the African climate, there is large uncertainty and low scientific confidence in important aspects of the projections for Africa's climate in the next 5-40 years - the lifespan of many development projects being designed today.

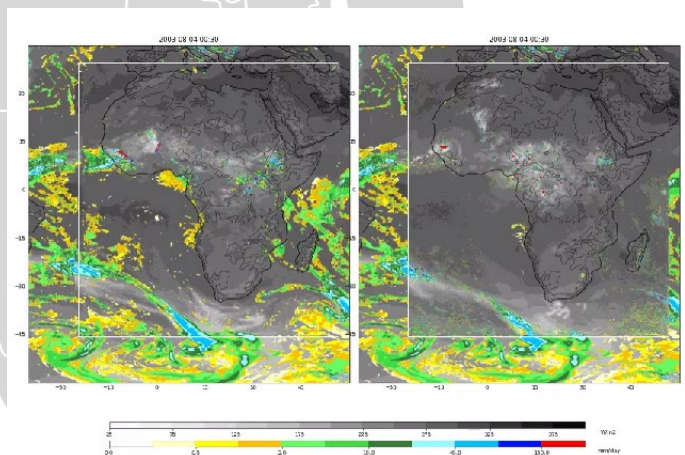
## IMPALA's approach to improving model predictions

IMPALA focused model improvement on a single multi-temporal, multi-spatial resolution model, the Met Office Unified Model (MetUM), to allow rapid pull through of improvements made in the project into improved African climate modelling capability. This focus aids rapid progress which may then be exploited by the wider modelling community as the methodology, new understanding, and process-based evaluation can be applied to all climate models.

## About FCFA

Future Climate for Africa (FCFA) is generating fundamentally new climate science focused on Africa, and ensuring that this science has an impact on human development across the continent.

FCFA consists of five research consortia who are undertaking research to significantly improve the understanding of climate variability and change across Africa and contributing to improved medium to long-term (5-40 year) decision-making, policies, planning and investment by African stakeholders and donors.



Simulations of global R25 (left) and CP4-A (right) models over Africa.  
Credit: Ségolène Berthou

IMPALA has developed the first very high-resolution pan-African regional climate model (grid-spacing of around 4km) that better captures key processes such as convective storms and local-scale weather phenomena including extremes, and it provides new understanding of the roles played by these processes in African climate variability and change. The model is called [CP4-Africa](#). The improved knowledge and new simulations are being used by scientists in the four regional research projects (AMMA-2050, FRACTAL, HyCRISTAL and UMFULA). This will deliver more reliable information for decision-makers and scientists in a range of sectors including agriculture, urban and rural water resources, health and infrastructure management and renewable energy.

## The development of a Model Evaluation Hub for Africa

LaunchPAD (Priority on African Diagnostics) is a 15-month research programme that aims to improve the availability and use of climate information on 5 – 40-year timescales through climate model evaluation with an African lens, designed to improve the understanding of how models represent climate over African regions. LaunchPAD is a key part of the FCFA IMPALA legacy in improving, sustaining and progressing the African climate model work and maintaining and extending the collaboration and network between British and African research institutions.

The LaunchPAD team includes 5 Co-Investigators (Co-Is) and 10 early career fellows in 4 African universities (several of whom were IMPALA early career researchers), as well as a full-time software engineer, research associate, and 3 Co-Is in the UK. The main objective of LaunchPAD is to develop evaluation tools that can be automated across climate models. Climate model evaluation research can be very time consuming – by automating the analysis, the team hopes to make it much easier and quicker for other scientists and model developers to find out how new models represent Africa.

## How IMPALA went about improving climate information for Africa

IMPALA's work on model improvement over Africa was carried out through the following activities:

1. Improving the understanding and evaluating the representation of **large scale modes of variability** which influence the African climate through teleconnection pathways.
  - Improvements in [model imbalances in hemispheric albedo](#) to improve simulation of rainfall within the [Inter Tropical Convergence Zone \(ITCZ\)](#).
  - Addressed modeling errors of remote processes and pathways which control Africa's climate, including variability of the [East Africa Short Rains](#), [East Africa Long Rains](#), [West Africa Monsoons](#), and diagnosing remotely forced systematic errors over Africa.
2. Improving the understanding and representation of **local processes**.
  - Improved representation of [tropical convection](#), both through improved parameterisation schemes in global models and in particular through the use of the convection-permitting CP4-Africa model to improve [rainfall extremes](#) and heatwave modelling on a 4.5km scale.
  - Improved representation of land-atmosphere interactions including [soil moisture recovery](#), surface water budget and grassland phenology.
3. Identifying, reviewing and prioritising **pan-African metrics** focused on process-based analysis and indices with impact relevance. Partnerships with African-based experts played a crucial part in [evaluating model performance](#) and defining regions.
  - Analysis of cloud bands or Tropical Temperate Troughs over Southern Africa.
  - Evaluation of drivers of the main rainfall season over Central Africa.
  - Evaluation of West African precipitation and temperature on annual, seasonal and monthly timescales.
  - Evaluation of the representation of low-level moisture for seasonal rainfall extremes over East Africa.
4. Integrate advances in model development and improvements for other work packages to improve climate change prediction capabilities. Characterise the impacts of model improvement on trustworthiness of processes driving climate change signals over 5 - 40 year timescale, including role of convection-permitting resolution on main processes.
  - Assessment of model changes incorporated into version GA7 of the MetUM - including an in-depth study of the representation of African Easterly Waves.
  - New methodology using Perturbed Physics Ensemble to identify the sensitivity of specific climate parameters.
  - Implications of model improvements on assessment of climate change signals.

# Taking IMPALA's legacy forward

- Maintaining key networks between UK and African scientists, IMPALA scientists will continue working on model improvements with an Africa focus particularly incorporating new developments in modelling convection.
- Inform future model development and interpretation through new analysis and understanding CP4-Africa simulation.
- Deliver user-relevant information through linking to FCFA pilot projects and improve access to CP4-Africa data for African Partners.
- Promote CP4-Africa science and data availability to scientific and user communities through the development of a CP4-Africa Guidance Document.
- Produce a 'high level' scientific paper to be published in BAMS to detail progress made through CP4-Africa.

## Partner Organisations

[Met Office](#) (United Kingdom)

[African Centre of Meteorological Applications for Development](#) (pan-Africa)

[CEH: Centre for Ecology and Hydrology](#) (United Kingdom)

[University of Cape Town](#) (South Africa)

[University of Exeter](#) (United Kingdom)

[University of Leeds](#) (United Kingdom)

[University of Nairobi](#) (Kenya)


[University of Oxford](#) (United Kingdom)

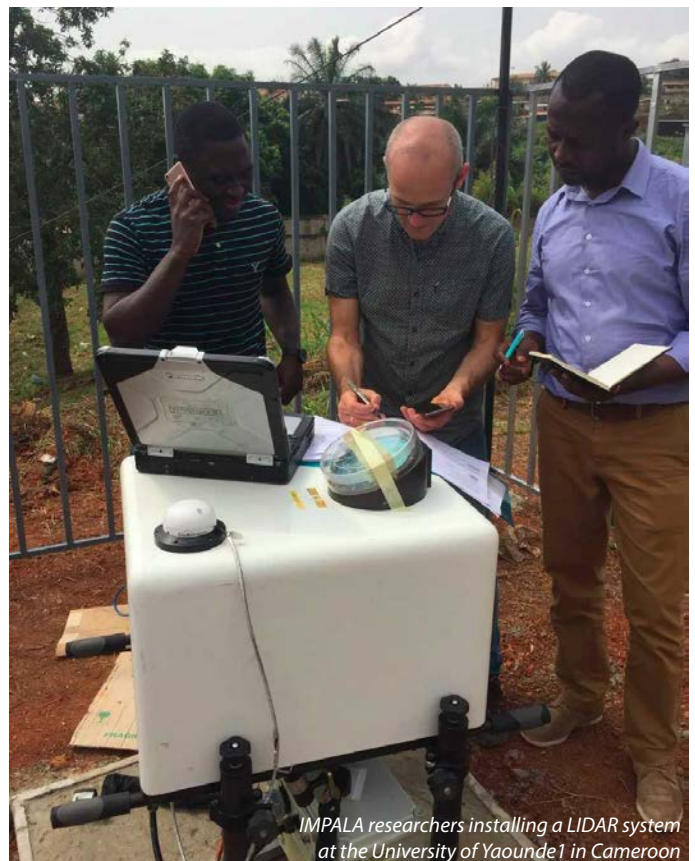
[University of Reading](#) (United Kingdom)

[University of Yaoundé](#) (Cameroon)

For more information on IMPALA visit: <https://futureclimateafrica.org/project/impala/>, or contact [richard.graham@metoffice.gov.uk](mailto:richard.graham@metoffice.gov.uk), or [info@futureclimateafrica.org](mailto:info@futureclimateafrica.org)

 [www.futureclimateafrica.org](http://www.futureclimateafrica.org)

 Twitter: [future\\_climate](https://twitter.com/future_climate)

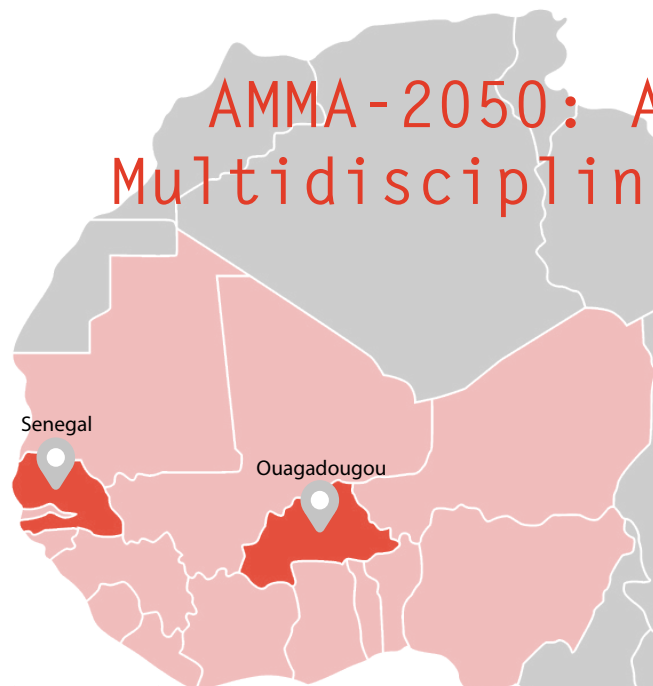


*IMPALA researchers installing a LIDAR system at the University of Yaounde1 in Cameroon*

## Disclaimer

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## AMMA-2050: African Monsoon Multidisciplinary Analysis-2050



### About AMMA-2050

[AMMA-2050: African Monsoon Multidisciplinary Analysis-2050](#) aimed to increase understanding of the regional climate of West Africa and how it will change, applying this knowledge to practical development questions. AMMA-2050 has improved understanding of how the West African monsoon will be affected by climate change in the coming decades (focused on the period up to 2050) and helped West African societies prepare and adapt. Bringing together expertise from across institutions in West Africa and Europe, the project has been working with policymakers in West Africa to identify effective adaptation options, particularly focusing on agriculture and water resource management across the region.

AMMA-2050 conducted pilot studies focused on urban flooding in [Ouagadougou](#) (Burkina Faso) and climate-resilient agriculture in [Senegal](#), both issues of significant [societal concern](#). AMMA-2050 has also sought to tailor and share key messages with different groups of decision-makers across the region, as well as sharing the participatory approaches employed within the project amongst partnering research institutions.

### About FCFA

[Future Climate for Africa](#) (FCFA) is generating fundamentally new climate science focused on Africa, and ensuring that this science has an impact on human development across the continent.

FCFA consists of five research consortia who are undertaking research to significantly improve the understanding of climate variability and change across Africa and contributing to improved medium to long-term (5-40 year) decision-making, policies, planning and investment by African stakeholders and donors.



AMMA-2050 Annual General Meeting 2019. Credit CCKE

## Why it's important to understand climate variability and change over West Africa

Lives and livelihoods in West Africa face significant climate-related risks. West Africa, in recent decades, has experienced extreme rainfall variability leading to devastating droughts and floods. The impact climate change will have on climate variability and livelihoods across West Africa remains uncertain. This uncertainty, combined with constrained resources and capacities to invest in planning on decadal timescales, results in development decision-making not being appropriately informed by emerging understanding of climate-related risks.

The impacts of climate change in the coming decades are thus expected to have significant implications for the lives and livelihoods of people in West Africa, and most particularly across marginalised groups. AMMA-2050 has sought to further understanding of future climate variability and change, focusing on areas vital to inform future planning.

## AMMA-2050's approach to integrating climate information into decision-making

- Assess how the climate over West Africa is likely to change in future decades through employing cutting-edge convection-permitting models alongside traditional climate change models supported with observations.
- Combine scientific advances with co-production processes using an 'assess-risk-of-policy' approach to integrate decision-makers from outset, framing uncertainty descriptions to stimulate user ownership of research.
- Improve both the [scientific](#) and [stakeholder engagement](#) capacities of African researchers to produce locally relevant climate science.
- Employing [Participatory Impact Pathways Analysis](#) (PIPA) to bring stakeholders and decision-makers together to co-explore solutions, employing network mapping to identify existing and additional links required to achieve agreed outcomes.
- Co-exploring Adaptive pathways through interactive modelling of [flooding in Ouagadougou](#), and combining the Plateau Game and participatory and [bio-economic modelling](#) of farming systems in

the Peanut Basin of Senegal.

- Employing a range of [participatory approaches](#), including PIPA, participatory modelling and Theatre Forum, to highlight the need for climate adaptation to be developed through inclusive dialogue amongst all key actors.

## How AMMA-2050 went about strengthening adaptation in West Africa

AMMA-2050's work on supporting adaptation in West Africa was carried out through the following activities:

### 1. Enhancing scientific knowledge and prediction of West African climate and the impacts of future climate scenarios

- Examining recent changes in frequency and intensity of [rainfall extremes and dry spells](#), and the [drivers of these extreme events](#).
- Using [historical observations](#) to understand how climate change influences storm intensity in the Sahel.
- Predicting changes in temperature and precipitation [extremes under 1.5°C and 2°C global warming](#).
- Examining the influence of [land-use changes](#) in combination with changes in precipitation.
- Assessing the impacts of climate and other drivers on flooding in [Ouagadougou](#) and [ecosystems and crops in Senegal](#).
- Investigating the coastal consequences of projected regional-scale, long-term changes for the Southern Canary Upwelling System (SCUS) as part of the SCUS-2050 Innovation Fund project lead by Université Cheikh Anta DIOP de Dakar - Ecole Supérieure Polytechnique (UCAD.)

### 2. Enhancing understanding of current and future flood risks in Ouagadougou to inform infrastructural investments and urban planning

- Developing a database and analysing [historical trends of climate and flooding](#).
- Using socio-economic surveys to understand and identify the [climate-related risks](#) faced by people living in flood-prone areas.
- Developing **unique modelling chain methodologies** to meet decision-maker needs by combining regional climate projections capable of representing intense storms, with land-use change projections, to inform detailed flood modelling.



- Developing [Intensity-Duration-Frequency \(IDF\) Curves](#) to inform infrastructural planning in the city.
  - Actively **engaging with [key national and city decision-makers](#)**, seeking to inform infrastructural investments and future planning, sharing and building capacities to appropriately use AMMA-2050 outputs and decision support tools.
  - Undertaking research on the **impacts of climate change on urban water, sanitation and hygiene (WASH)**.
3. **Co-producing climate information for climate-resilient agriculture in Senegal**
- A series of interactions with the Fatick Comité Régionale du Changement Climatique (COMRECC), mayors, members of the national assembly and national decision-makers from across a range of ministries.
  - Engaging farmers and farmer networks through **the [Plateau Game](#)** to; share emerging understanding about climate-related risks, identify ongoing and potential adaptation options, debate policy, and inform and validate modelling results.
  - Supporting **Participatory Modelling** to allow decision-makers and agricultural professionals to review and input knowledge into the project's [bio-economic modelling](#).
- Developing a **[Theatre Forum](#)** play to support dialogue between researchers, national and sub-state policymakers, and farmers and farmer networks, taking this on a '[road show](#)' in Dakar and two other regions.
  - Developing an online climate adaptation portal ([Geo-Portal](#)) to support decision makers in the agricultural sector of Senegal.
4. **Improving the capacities of partnering African scientists to develop climate information that can effectively support development decision-making**
- Producing high quality climate science to inform agricultural development in Senegal and urban planning in Ouagadougou.
  - **Strengthening the technical capacities of West African researchers to deliver [climate metrics](#)** essential to climate-resilient development,
  - Improving the [stakeholder engagement capacities](#) of partnering researchers to co-produce decision-relevant climate information.
  - **Conducted [joint forums](#)** with the [BRACED Zaman Lebidi](#) project and [WASCAL](#) (West African Science Service Centre on Climate Change and Adapted Land Use).

## Taking AMMA-2050's legacy forward:

The activities below were identified as key to the success and legacy of AMMA-2050 and received further funding until March 2021 to extend sharing of project learning and tools and strengthen understanding of how climate change can better support climate-resilient planning in West Africa:

- 1. Develop training to strengthen decision-makers' understanding of AMMA-2050 key findings and tools and how these can support development-planning**
  - Continue training non-technical decision-makers and technical advisors in various sectors on key project learning and tools.
  - In Senegal, training for sub-state and national decision-makers and advisors on use of the GeoPortal, that houses key AMMA-2050 findings.
  - In Burkina Faso, training for City-level and national decision-makers and advisors on the project's key findings related to future climate change and how flood maps and IDF curves can inform urban planning.
- 2. Undertake training for researchers to produce outputs according to the methodologies that AMMA-2050 has developed**
  - Provide additional training for AMMA-2050 researchers and cross-regional training for national met agencies across 4 countries in West Africa to meet decision-makers' climate information needs.
  - Embedding gender and inclusion awareness by working with ISRA to develop a training module on gender and inclusivity integrated alongside training on the Geo-portal.
- 3. Co-develop tools quantifying future projections of extreme rainfall which encapsulate new understanding of Sahelian storms**
  - Development of future IDF curves to describe changing rainfall patterns for engineers.
- 4. Further develop and provide latest climate and impacts data for inclusion on the GeoPortal**
  - Building on the success of this tool by incorporating the new CMIP6 data into the portal.
  - Increase use of the portal through training and communication.

## Partner Organisations

[Institut International d'Ingénierie de l'Eau et de l'Environnement](#)  
(Burkina Faso)

[l'Agence Nationale de l'Aviation Civile et de la Météorologie](#)  
(Senegal)

[UK Centre for Ecology and Hydrology](#) (UK)

[Centre de coopération internationale en recherche agronomique pour le développement](#) (France)

[National Centre for Meteorological Research - the Meteorological Atmosphere Study Group](#) (France)

[Institut Pierre Simon Laplace - Oceanic and Climate Laboratory](#)  
(France)

[Institute for Development Research - Hydrology and Environment](#)  
(France)

[IRD-DIADE: Institute de recherche pour le developpement- Diversité - Adaptation - Developpement des plantes](#) (France)

[Senegalese Institute for Agricultural Research](#) (Senegal)

[VNG Consulting Ltd](#) (UK)

[Met Office](#) (UK)

[National Agency for Civil Aviation and Meteorology](#) (Senegal)

[University of Cape Coast](#) (Ghana)

[University of Leeds](#) (UK)

[University of Sussex](#) (UK)

[Université Cheikh Anta DIOP de Dakar - Ecole Supérieure Polytechnique](#) (Senegal)

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AMMA-2050 team photo at the AMMA-2050 Annual General Meeting 2019. Credit CCKE

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# HyCRISTAL: Integrating Hydro-Climate Science into Policy Decisions for Climate-Resilient Infrastructure and Livelihoods in Africa

## About FCFA

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## About HyCRISTAL

[HyCRISTAL \(Integrating Hydro-Climate Science into Policy Decisions for Climate-Resilient Infrastructure and Livelihoods in Africa\)](#) aimed to develop new understanding of East African climate change and variability and work with regional decision-makers to support effective long-term (5 to 40 year) decision-making in the face of a changing climate.

Uganda

Kenya



Participants discuss posters at the HyCRISTAL Annual Meeting 2018 in Kampala. Credit: CCKE

In collaboration with a range of stakeholders, and formally supported by the East African Community, HyCRISTAL is co-developing climate change adaptation options that meet the region's societal needs in both urban and rural areas. This is through a series of pilot projects covering: urban Water, Sanitation and Hygiene (WASH), rural livelihoods, water management and tea production. It is also contributing to the HyTPP project on transport and Lake Victoria water levels.

By developing climate science and helping users assess their vulnerabilities, HyCRISTAL aimed to increase the resilience of communities in East Africa. HyCRISTAL is working with policy makers to quantify risks and is providing new, accessible, and easy-to-use climate information tools that can be applied to the decision-making process.

## Why it's important to understand climate change and variability over East Africa

East Africa's rapidly growing population faces large natural climate variability. The availability of water is fundamental for development in the region, but this vital resource is already under stress from the growing population through: increased extraction for water supply, land degradation, pollution, and overfishing.

Climate change adds to these problems, greatly increasing the vulnerability of the poorest people in the region. Climate change is expected to increase both temperatures and rainfall intensities, and change rainfall patterns. Recent devastating floods and droughts have demonstrated how East Africa is vulnerable to climate variability and extreme weather. Increasing resilience to weather extremes as the population grows is therefore vital for the future of millions of people in East Africa.



*Kenyans wade through floodwaters from Lake Victoria.  
Credit: Mathew Okello, Practical Action*

## HyCRISTAL's approach to improving climate-resilient infrastructure and livelihoods in East Africa

HyCRISTAL's interdisciplinary approach brought together fundamental climate science with climate-impacts scientists, engineers, hydrologists, hydrogeologists and social scientists. The approach involved:

- Working with decision-makers to understand aspects of climate change and **identifying on-the-ground partners for project uptake** to ensure successful future impacts.
- Engaging with key stakeholders in linking weather and infrastructure/services to **identify critical 'hot**



*Testing observation equipment before installation on the Lake Victoria observation station. Credit: Prof. Kamazima LWiza, Stony Brook University*

**spots'** where impacts of adverse weather events could be clearly demonstrated.

- Using approaches that support **co-production of decision-relevant climate information** and enable channels for on-going dialogue between the providers and users of climate information across various sectors.
- **Improving understanding of [climate change over East Africa](#)** particularly focusing on furthering understanding of changes in rainfall (past and future), quantifying and narrowing uncertainty of projections, and incorporating processes not well represented in global climate models (e.g. moist convection, land-use change, aerosol changes).
- Taking a **risk-based approach**, with all climate model projections treated as plausible, unless proved otherwise.
- **Communicating possible future scenarios** for [urban](#) and [rural](#) areas through [Climate Risk Narratives](#).
- Building and maintaining **hydroclimate monitoring infrastructure** that provides data to underpin long-term decision-making.

## How HyCRISTAL went about improving climate-resilient infrastructure and livelihoods in East Africa

**Generating a [step-change in the scientific understanding of East African climate change](#)** HyCRISTAL's unique methodology brought together information on possible change from global model ensembles, such as CMIP, with both bespoke modelling and observations to quantify climate change risks. This involved:

- **Quantifying [future user-relevant metrics](#):** these were defined in a co-production approach from a wide range of global climate models.

- **Narrowing the range of possible future rainfall changes:** it is still unclear if total rainfall will increase or decrease, but the [largest modelled increase in the East African long rains has been found to be implausible](#).
- **Demonstrating the role of non-greenhouse gas drivers of climate change:** future global patterns of [aerosol emissions](#) are expected to affect future East African climate, especially for the short rains, and the next-generation projections and analysis should account for this.
- **Understanding future increases in extremes:** using high-resolution “CP4A” climate simulations (from [IMPALA](#)) to show that [extreme rainfall](#) is expected to intensify more than is projected by global climate models, and that increases in extremes may be more widespread than in those models.



Participants discuss posters at the HyCRISTAL Annual Meeting 2018 in Kampala. Credit: CCKE.

- **Using global models and CP4A to show that significant changes in seasonality may occur:** many models show later and longer short rains and an earlier end to the long rains, with a larger rainfall increase in the short rains than the long rains (this is linked to [deepening of the Saharan Heat Low](#)). Although it must be noted that changes to both onset and cessation are still uncertain in both seasons.
- **Exploring the “East African climate change paradox”:** showing that past rainfall trends resulted from shorter not drier long rains, linked to some regional drivers, and rainfall has increased again in recent years.
- **Understanding of rainfall variability:** including [how remote tropical cyclones can increase or decrease East African rainfall](#) depending on their location.

More details are provided in HyCRISTAL’s [climate change summary](#)

## Use of climate change information to support rural livelihoods in Homa Bay (Kenya) and Mukono (Uganda)

- **Developing new pathways for climate research** that supports [resilience of rural communities](#) vulnerable to climate change to help decision-makers with informed short-term and long-term decisions on rural adaptation.
- Building an **evidence-based pathway to rural adaptation** at the county and national levels, using the [Household Economic Approach](#) (HEA) and [Individual Household Method](#) (IHM).
- **Training local farmers in visual storytelling**, using [filmmaking](#) as a way to communicate directly with the Mukono district government.
- **Training of the Trainers approach** employed for **Household Economy Assessment** to build capacity in local HEIs to collect data going forward.
- **Providing users with access to an integrated resource** for climate, crop, fisheries, hydrology, and livelihoods information, by developing the [Integrated Database for African Policymakers](#) (IDAPS) platform.
- **Engaging with governments** on the National, sub-national and local level to influence policy, budget and implementation. Including; delivering a [briefing paper on rural adaptation](#) to the Ugandan Parliament, providing **input to the Ugandan National Environmental Bill**, engaging with Ministry of Agriculture to **support the implementation of the Koronovia Joint Work Programme on Agriculture** in Uganda, **enabling increased funding** for agriculture extension services in Mukono, providing **advice to the Ministry of Health** thereby influencing the Uganda Climate Change Act, and **providing information on the Kenyan livelihoods analysis and future climate scenarios** to the Lake Region Economic Bloc (LREB) to support adaptation and mitigation activities.



Fishermen working on their nets on the shores of Lake Victoria. Credit: Linda de Volde.

## Use of climate change information in planning of urban Water, Sanitation and Hygiene (WASH) in Kisumu (Kenya) and Kampala (Uganda)

- **Introducing local stakeholders to emerging climate research**, while supporting climate scientists to identify information that is locally relevant
- Created **simulations of surface water flooding** under various plausible climate scenarios.
- **Engaging with local community groups** about their [lived experience of flooding](#) to assess the local relevance of the flood model and producing an **informational video** to share these flood stories.



*Drainage channel in informal settlements of Kamwookya, Kampala pose health hazards to residents particularly when flooding occurs.  
Credit: Enno Schröder, SuSanA Secretariat / CC BY (<https://creativecommons.org/licenses/by/2.0>)*

- **Making new observations** of urban hydrometeorology to characterise spatial variability, test flood models and inform decisions.
- Producing **enhanced spatial coverage of rainfall and flow measurements** in Kampala together with the Ugandan Ministry of Water and Environment (MWE) and Uganda National Meteorological Authority (UNMA) to inform hazard mapping.
- **Developing a geo-spatial health hazard model** to examine the health impacts of flooding.

## Use of climate change information in water resource planning in Uganda

- **Improving use of climate information** in [Integrated Water Resource Management \(IWRM\) in the Lake Victoria Basin \(LVB\)](#) by partnering with the Ugandan Ministry of Water and Environment (MWE)

- **Assessing future changes in river flow** in the LVB by comparing data from the CP4-Africa climate model and global climate models. An automated system has been built to enable river models to be developed from historic river flow datasets and used with climate model outputs to assess future flows and their uncertainty. This system will be embedded in an existing water resource management information system in Uganda, operated by MWE.
- **Co-production and embedded learning from the impact modelling** in the LVB for both long-term strategic planning and for operational purposes. Uganda has in recent years adopted a decentralised Integrated Water Resource Management approach. The modelling tools developed within HyCRISTAL and the understanding gained from their application, will be used in decision-making undertaken within IWRM stakeholder fora.

## Use of climate information in planning for Lake Victoria level changes (with HyTPP project)

- **Analysing possible future lake levels and outflow** under climate change with modelling showing that both increases and decreases are possible.
- **Enabling approaches that incorporate risks into decisions** based on plausible ranges in future lake levels by sharing results with the World Bank (Corridors for Growth Trust Fund administrators) and other stakeholders.

## Use of climate change information in long-term decisions in tea production (CI4Tea) in Kenya (collaboration with UMFULA)

- **Developing a novel approach** to combine regional and global model uncertainty and observations and communicating locally relevant climate information for more resilient tea production.
- **Iteratively engaging tea sector stakeholders** to help tailor climate information to their needs and incorporate their feedback to develop usable climate information.
- **Producing a video** on the impacts of climate change on tea in Malawi and Kenya, which showcases the CI4Tea research.

## Introducing climate change into the Greater Horn of Africa Climate Outlook Forum (GHACOF)

- [Starting dialogues with climate information users](#) on the timeline of actions needed in response to climate risks, with particular focus on the actions needed now, and providing tools to enable stakeholders to continue these dialogues to lead towards more effective decisions.
- Using recent high-impact events, such as the [2019 floods, locust outbreaks and 2020's record breaking Lake Victoria water levels](#), to engage decision-makers in planning for long-term change.

- Sharing climate lessons from HyCRISTAL to build on GHACOF's past experience of seasonal prediction (working with ICPAC, the UK Met Office and WISER).



Prof. Fred. Semazzi facilitating a group discussion during the Future Climate Current Policy (FCCP) Framework session at GHACOF 54. Credit: CCKE

## Taking HyCRISTAL's Research Forward

- HyCRISTAL is taking its science and pilot projects forward through 2020 and 2021;
- **Maximising uptake of urban WASH planning tools** by deepening the policy engagement in Kampala and Kisumu and widening the policy engagement both regionally and between the infrastructure and climate science communities.
- **Local capacity building for ongoing climate resilient livelihoods research.**
- **Extending the Integrated Database for African Policymakers (IDAPS)** platform through working with identified government partners to explore change scenarios that are relevant to their decision 'use cases' and developing a Training of Trainers (ToT) curriculum with local partners to support on-going quantitative climate-livelihoods impact monitoring.
- **Application of HyCRISTAL's climate change analysis and hydrological modelling** to water allocation planning in Uganda, building capacity and developing hydrological models used for operational decision-making in Uganda.
- Continued **two-way engagement with a wide range of users and user-sectors at GHACOF** by building on the successful HyCRISTAL/WISER collaboration to bring climate change into the forum, alongside its existing and primary focus on seasonal prediction.

## Broader lessons from HyCRISTAL

- HyCRISTAL shows that research can deliver improved and usable predictions, and that the following are all valuable components of a useful and robust methodology:
  - relevant **evaluation of models**
  - understanding the processes that control **user-relevant weather** and **past climate change**
  - understanding **uncertainty in climate change** from ensembles of global models and narrowing this through **future-centric evaluation**
  - quantifying and understanding the roles of **processes or forcings not well-captured in CMIP** (e.g. aerosols or convection)
  - **quantitatively synthesising CMIP and non-CMIP uncertainties** with observations for co-production of projections for key metrics used for decisions.
- HyCRISTAL's climate science methodology could be replicated/built on for other regions. In East Africa much work remains to be done to both continue development of process understanding of recent and projected climate and weather, and to bring this through to improved predictive information. It is noted that:
  - future CP4A-like simulations would benefit from a

coupled lake model, and an ensemble approach that includes models with less wetting for East Africa,

- although **quantitative synthesis of CMIP & CP4A information for decisions has been achieved, this is still a new research area**, but could clearly be achieved 'at scale',
- **links between weather and climate physics** means that much science is applicable to predictions on all time-scales
- Many users make decisions across a range of time-scales and there is opportunity for scientists to engage across all of these too, with success on short time-scales in building trust to enable science to inform long-term planning.
- **Embedded researchers and/or trusted (and funded) on-the-ground partners** is often critical to the success of the project.
- **Projects acting as "an impartial 3rd party"** to facilitate multi-stakeholder workshops can be hugely beneficial. **Climate change is a great way to bring together individuals from diverse backgrounds and disciplines** and can be invaluable in complex multi-sectoral, multi-stakeholder decisions.
- **Recognising, leveraging and making agreements about the use of existing data or previous projects can help build relationships** and is essential for reducing duplication and to build on past work.
- HyCRISTAL's hydrogeology methodology could be built on and applied to understand longer term

changes in groundwater resources in this region and elsewhere. **Understanding the resilience of this large, dispersed water resource to changes in climate is critical** to planning secure water futures in Africa.

- **Introducing climate science has provided context and added urgency to urban WASH decision making.** Incorporating climate change in planning of water and sanitation infrastructure reveals a lack of experience in incorporating even current weather related shocks. It has also provided the opportunity to highlight that sanitation is not a stand-alone 'problem'. Responding to climate impacts requires a **joint effort across a range of sectors**, which requires either decentralised planning and delivery or strong leadership in sector ministries.
- **Including experiences from households and practitioners** is important to understanding how climate changes are affecting peoples' lives and understanding the constraints and opportunities that practitioners have. This ensures outputs can be better tailored to stakeholder needs and thus have greater long-term impact.
- **Projects often uncover the 'real' problem through doing the research** – flexible project funding is invaluable for researchers being able to solve those problems within the project
- **The additional cost of building resilience into regular infrastructure delivery is often marginal when compared with the absolute investment costs required to make up existing shortfalls in infrastructure and services provision.**



Participants participate in group activities during the HyCRISTAL Annual Meeting 2019 in Kampala. Credit: CCKE



## Partner Organisations:

[Lead: University of Leeds \(UK\)](#)

[African Centre for Technology Studies \(pan-Africa\)](#)

[Africa Climate Exchange at the University of Reading \(UK\)](#)

[British Geological Survey \(UK\)](#)

[CEH: Centre for Ecology and Hydrology \(UK\)](#)

[Evidence for Development \(UK\)](#)

[IGAD Climate Predictions and Applications Centre \(ICPAC\), \(Kenya\)](#)

[Jomo Kenyatta University \(Kenya\)](#)

[Loughborough University \(UK\)](#)

[Makerere University \(Uganda\)](#)

[Maseno University \(Kenya\)](#)

[Met Office \(UK\)](#)

[National Centre for Atmospheric Science \(UK\)](#)

[North Carolina State University \(USA\)](#)

[Practical Action \(UK\)](#)

[Stony Brook University \(USA\)](#)

[Tanzanian Meteorological Agency \(Tanzania\)](#)

[Tea Research Institute \(Kenya\)](#)

[Ugandan National Meteorological Authority \(Uganda\)](#)

[Ugandan Ministry of Water and Environment \(Uganda\)](#)

[University of Connecticut \(USA\)](#)

[Victoria Institute for Research on Environment and Development \(Kenya\)](#)

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*HyCRISTAL Team Photo at Annual General Meeting 2019 in Kampala. Credit CCKE*

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### UMFULA: Uncertainty Reduction In Models For Understanding Development Applications

#### About FCFA

[Future Climate for Africa](#) (FCFA) is generating fundamentally new climate science focused on Africa, and ensuring that this science has an impact on human development across the continent.

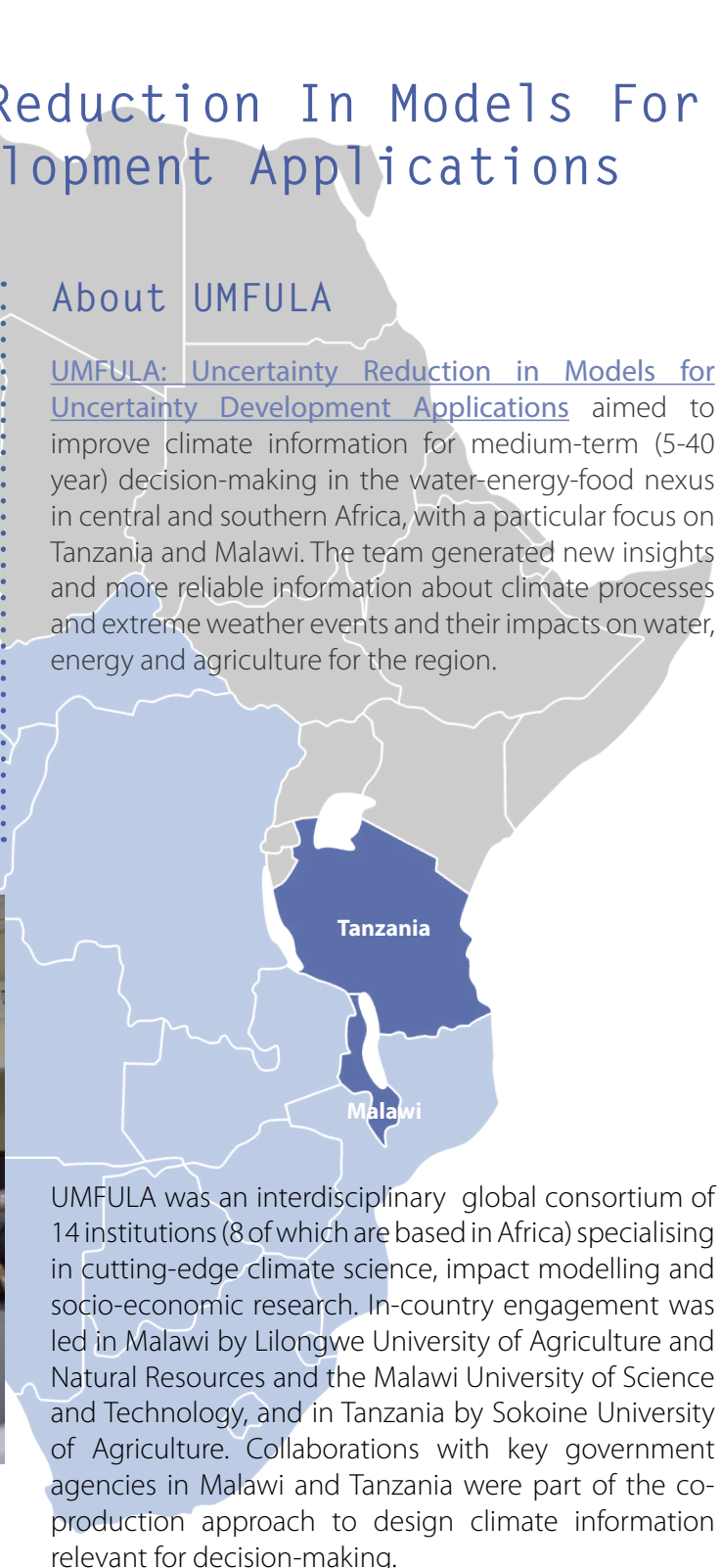
FCFA consists of five research consortia who are undertaking research to significantly improve the understanding of climate variability and change across Africa and contributing to improved medium to long-term (5-40 year) decision-making, policies, planning and investment by African stakeholders and donors.

#### About UMFULA

[UMFULA: Uncertainty Reduction in Models for Uncertainty Development Applications](#) aimed to improve climate information for medium-term (5-40 year) decision-making in the water-energy-food nexus in central and southern Africa, with a particular focus on Tanzania and Malawi. The team generated new insights and more reliable information about climate processes and extreme weather events and their impacts on water, energy and agriculture for the region.



Panel discussion on "how can climate information build a resilient Malawi" co-hosted in 2017 with MUST and the Civil Society Network on Climate Change, with speakers from the Environmental Affairs Department, Department of Climate Change and Meteorological Services and UNDP. Credit: CCKE



UMFULA was an interdisciplinary global consortium of 14 institutions (8 of which are based in Africa) specialising in cutting-edge climate science, impact modelling and socio-economic research. In-country engagement was led in Malawi by Lilongwe University of Agriculture and Natural Resources and the Malawi University of Science and Technology, and in Tanzania by Sokoine University of Agriculture. Collaborations with key government agencies in Malawi and Tanzania were part of the co-production approach to design climate information relevant for decision-making.

## Improving the understanding of central and southern Africa's climate

Malawi and Tanzania's locations in between two major climate systems means it is difficult to predict rainfall over the countries. Knowledge gaps around the functioning of central and southern Africa's climate impedes the ability to project future climate in the region.

UMFULA's climate science team improved the understanding of several features of central and southern African climate through the following:

- Improved understanding of interaction between El Nino Southern Oscillation (ENSO) and [cloud bands](#) which influence widespread rainfall and extreme rainfall events over southern Africa.
- Examined the representation of the [Angola Low](#) regional circulation feature in climate models, and how the Angola Low pressure system and South Indian Ocean high pressure system is affected by ENSO.
- Assessed key moisture transport pathways from the [Congo Basin](#) into central Africa.
- Assessed confidence in model simulations of rainfall including; annual cycles of [cloud bands](#), simulations of [rainfall over southern Africa](#), [projected rainfall](#) in central Africa, the [influence of ENSO](#), and [future projections over southern Africa](#).
- Installed the first LIDAR automatic weather system in Cameroon to provide new insights into climate dynamics over central Africa.

## Applying a Decision-Making Under Uncertainty (DMUU) approach to planning decisions

While advances in climate research can further the understanding of the drivers of variability and inform assessment of confidence in models, waiting for better model projections is not viable when decisions are being made now on major infrastructure investments with long lifespans.

UMFULA applied a Decision-Making under Uncertainty approach in two pilot studies:

- **Robust decision-making for the Shire River Basin, Malawi**

The Shire River Basin is a major outflow of Lake Malawi and is a vital source of hydropower, irrigation, and biodiversity. UMFULA, with government stakeholders, co-produced a [Water Evaluation and Planning \(WEAP\) Model](#) to project the [range of future lake levels between 2021-2050](#). Variability in projections underlines the need for robust decision-making in light of uncertainty to make choices that will perform well regardless of future conditions.

- **Understanding trade-offs in the Rufiji River Basin, Tanzania**

The Rufiji River Basin accounts for half of Tanzania's river flow, providing water for domestic use, irrigation, livestock, and ecosystems. Additional socio-economic development and hydropower generation are planned through the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) and Rufiji Hydropower Project. UMFULA [regionalised a global hydrological crop model](#) to project future scenarios for river flow between 2021-2050 and then used coupled hydrological systems and water resource models to provide the [evidence base for identifying trade-offs in decision-making on water allocation](#).

## Understanding the context of decision-making around climate change

UMFULA produced key insights into whether and how climate information can be used to inform cross-sectoral decision-making. This included:

- **Analysis of the political economy in Malawi and Tanzania** to understand how ideas, power and resources converge to create an institutional environment that supports or constrains climate action
- **Identifying [climate information needs](#) for Southern Africa**
- Identifying how **carefully designed [capacity building](#)** in the ministries is an essential condition for effective climate adaptation
- How producers and users of weather and climate information **can co-produce seasonal weather information and advisories through [participatory scenario planning](#)**

## What are the impacts of climate change on tea and sugarcane sectors in Malawi and Tanzania?

The tea and sugarcane sectors are vital for the economy and livelihoods in Malawi and Tanzania. Both crops are extremely sensitive to different climate conditions, and could be adversely affected by climate change. UMFULA aimed to improving the understanding of the impacts of climate change on tea and sugarcane sectors through:

- Examining the impacts of future climate changes on crops and livelihoods.
- Investigating relevant climate metrics and identifying viable adaptation options for tea production in Malawi as part of the joint UMFULA and HyCRISTAL [Cl4Tea project](#).
- Considering equity issues of large scale adaptation decisions for smallholder farmers.

## Significant impacts of UMFULA's work

### ● Working with local partners to identify adaptation options

- Close collaborations with partners in the Shire River Basin and Rufiji River Basin allowed co-exploration of adaptation options for robust decision making.

### ● Contributing to national policy processes in Malawi

- Made presentations to the National Technical and Steering Committees on Climate Change in Malawi.
- Provided input to the draft National Resilience Strategy and its implementation plan in Malawi.
- Provided key findings to members of the National Planning Commission of Malawi
- Provided inputs to Malawi's Third National Communication of Malawi

### ● Sharing research through public engagement activities

- Findings presented through various platforms including; Malawi's first National Adaptation Symposium in 2018, lectures and clinic sessions with students at Sokoine University of Agriculture and the University of Dar es Salaam in Tanzania, participation in Africa Water Week and Adaptation Futures, as well as through various webinars.

### ● Partnership with National Meteorological and Hydrological Services

- Partnership with Malawi's Department of Climate Change and Meteorological Services

(DCCMS) throughout the project, including during project planning processes, which led to the [co-production of country climate projections](#).

- Early Career Researchers presented their key findings and impacts to the Tanzania Meteorological Agency and DCCMS.

### ● Capacity building of Early Career Researchers

- Postgraduate degrees awarded to 10 African (with 3 in progress) and 4 UK Early Career Researchers.

## Taking UMFULA's legacy forward

During the extension phase of UMFULA to March 2021, three main strands of work will be prioritised:

1. Co-producing narratives of plausible future climates, future water availability and possible adaptation options in the Shire River Basin, Malawi.
2. Migrating the model from Rufiji River Basin to a fast open-sourced model on an online platform and hosting a workshop with Tanzania stakeholders to evaluate climate change and potential trade-offs in the basin.
3. Determining the future characteristics of extreme rainfall events over Malawi and Tanzania resulting from deep convection and tropical cyclones.

These three strands of work will be complemented with two cross-consortia activities which include:

1. Double and triple-loop learning approach to co-production for applied research.
2. Production of a book "Climate risk in Africa: Adaptation and resilience" (to be published by Palgrave Macmillan in 2020).

## Key resources:

[The current and future climate of central and southern Africa. What we have learnt and what it means for decision-making in Malawi and Tanzania](#)

[How can we improve the use of information for a climate-resilient Malawi?](#)

[Projecting future water availability in Lake Malawi and the Shire River basin](#)

[Future climate projections for Malawi](#)

[Designing a process for assessing climate resilience in Tanzania's Rufiji river basin](#)

[Future climate projections for Tanzania](#)


For more information visit <https://futureclimateafrica.org/project/umfula/> or contact [info@futureclimateafrica.org](mailto:info@futureclimateafrica.org) or

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## Partner organisations:

[Grantham Research Institute on Climate Change and the Environment](#) (United Kingdom)

[Kulima Integrated Development Solutions](#) (South Africa)

[University of Oxford](#) (United Kingdom)

[University of Cape Town](#) (South Africa)

[Sokoine University of Agriculture](#) (Tanzania)

[Lilongwe University of Agriculture and Natural Resources](#) (Malawi)

[Malawi University of Science and Technology](#) (Malawi)

[University of Leeds](#) (United Kingdom)

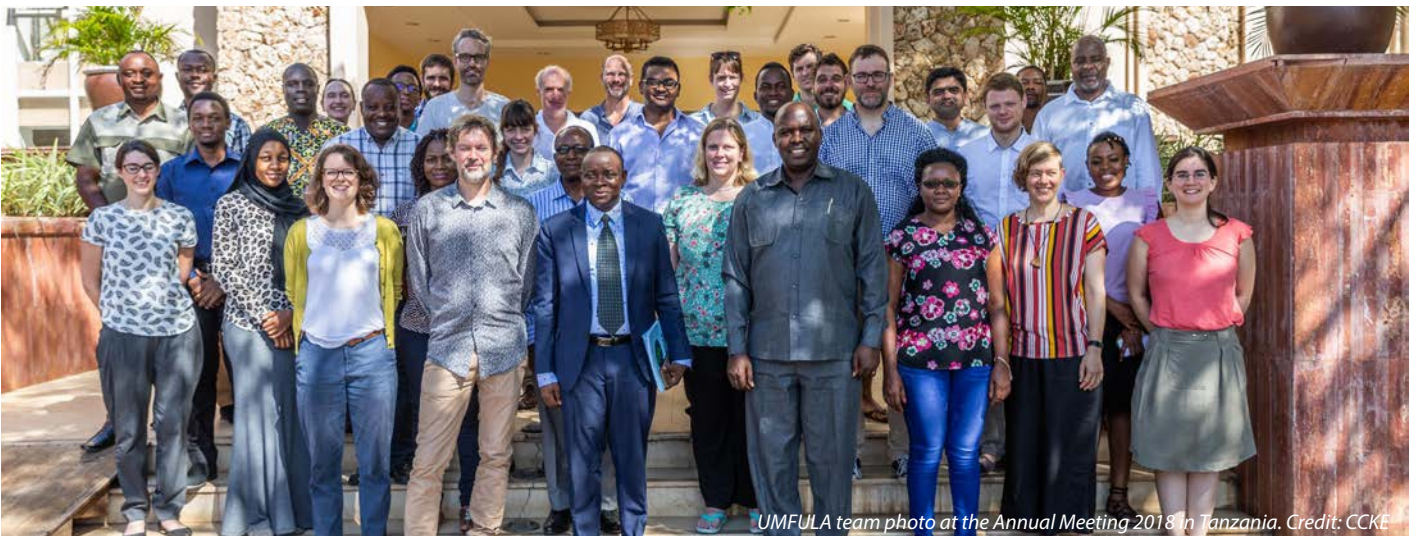
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UMFULA team photo at the Annual Meeting 2018 in Tanzania. Credit: CCKE

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## FRACTAL: Future Resilience for African Cities and Lands

### About FRACTAL

The [FRACTAL](#) (Future Resilience for Africa Cities and Lands) team aimed to advance understanding of southern Africa's climate, notably processes, as well as regional and local trends, and to work with decision-makers to integrate scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years). FRACTAL worked to varying degrees with team members in nine southern African cities: [Blantyre](#), [Durban](#), [Cape Town](#), [Gaborone](#), [Harare](#), [Johannesburg](#), [Lusaka](#), [Maputo](#), [Windhoek](#).

The project included researchers, engineers, government representatives, NGOs and other stakeholders in learning processes to better understand risks that will likely be exacerbated by climate change in southern African cities, particularly related to resource management and urban development. These learning processes also resulted in the co-production of relevant climate knowledge to support resilient development pathways.

### About FCFA

[Future Climate for Africa](#) (FCFA) is generating fundamentally new climate science focused on Africa, and ensuring that this science has an impact on human development across the continent.

FCFA consists of five research consortia who are undertaking research to significantly improve the understanding of climate variability and change across Africa and contributing to improved medium to long-term (5-40 year) decision-making, policies, planning and investment by African stakeholders and donors.



Participants share their reflections on the final day of the FRACTAL Annual General Meeting 2019. Credit CCKE



## Why the need for a different approach?

FRACTAL was borne of the frustration that even though much of the climate change information being produced is useful, very little is actually informing decisions, especially in southern African cities. Traditionally, climate change information is produced and packaged for 'users' with the idea that it will fit neatly into a decision-making process. Decision-makers and planners sometimes feel overwhelmed by the availability of climate change information that is shared through reports, portals, platforms, hubs, etc. usually in a format that requires specialised skills for interpretation.

Not all information that is being produced is relevant to the scale at which decisions are made and, more importantly, not all information is significant for local priorities, plans and decision stages. Those making decisions in southern African cities have also generally not had opportunities to engage with concepts of uncertainty associated with climate change information. In many cases, the request for more 'precise' information results in scientists making decisions about 'trading' uncertainty for risk of being wrong about the future. (i.e. not considering a broader range of plausible future scenarios). Scientists traditionally make these choices under pressure, while the potential consequences of these choices are borne by decision-makers and those who might experience the impacts of climate change in the future. The complexity of the climate change challenge is exacerbated in cities, which are dense hotspots of rapid, social, economic, and environmental change.

FRACTAL aimed to support deeper engagement and learning for scientists to understand decision contexts of southern African cities, and for those making decisions to gain literacy in climate change science and information (including assumptions and challenges) so that these groups might interrogate, (co)produce and apply climate information to support resilient development of southern African cities into the future.



City of Windhoek's Climate Change Strategy Stakeholder Workshop in 2018. Credit: FRACTAL team member

## How did FRACTAL do things differently?

- Challenging the information and communication deficit framings (i.e. the idea that scientific information is not yet adequate to inform decisions); focusing instead on connecting city actors to existing science through in-depth transdisciplinary research.
- Embedding researchers in city councils and regular in-city learning labs to support social learning involving all partners and city actors
- Strong focus on understanding governance of southern African cities and looking for opportunities to support climate-related decision-making.
- Involving city actors in interrogating how climate change information is constructed, including decisions on underlying assumptions, trading certainty against risk of error, communication etc.
- Using co-produced climate risk narratives or stories of the future for city-regions to support dialogue around climate change and engagement with uncertainty.
- A climate information distillation framework to support transparent and collaborative climate information construction.



Participants co-explore burning issues in their city during learning labs in Lusaka. Credit: Bettina Koelle

## The novel approaches FRACTAL used in Southern African cities

FRACTAL supported several novel approaches to bridge divides between different stakeholder groups including researchers, decision-makers and civil society. These approaches built common knowledge among city stakeholders; related to the intersection of climate variability and change with developing cities and risks. Each stakeholder group offered their unique and

important perspectives to understand problems as well as potential responses. Some of these approaches are described below:

- **Embedded Researchers (ERs)** were funded by FRACTAL and occupied positions within the local city council offices as well as at the local partner university. The ERs proved instrumental in linking research to existing city processes and navigating the complexities involved in this. Along with the local academic Principal Investigators, the ERs drove the in-city research and organised regular in-city focussed dialogues and broader learning labs.



*Embedded Researchers at the FRACTAL Annual General Meeting 2019. Credit: CCKE*

- **Learning labs** are engagements strongly focussed on mutual and integrated learning about identified development issues in cities. Drawing strongly on serious gaming, mess mapping and even improvised drama to encourage building trust, openness, and transparency, the labs had significant impacts and outputs in many of the cities. A strong principle of learning labs is a 'level playing field' where no single discipline or group dominated learning, and participants were encouraged and supported to be open to new perspectives and understanding.
- **Small Opportunity Grants (SOGs)** were made available through several calls and proposal processes. Teams within FRACTAL cities designed and undertook research relevant to the broader objectives of FRACTAL as the needs arose. This allowed for a strong element of emergence in the project.
- **Inter-city exchanges** allowed researchers and city representatives to visit other cities to share experiences and knowledge, as well as explore different approaches to dealing with climate risk.
- **Climate risk narratives** were originally brought into the project to "short circuit" the process of interpreting complex climate information in the

local context as well as facilitating engagement with uncertainty. Climate risk narratives involve multiple stories of the cities set in the future with each story capturing a particular climate possibility and the set of stories spanning the uncertain range of futures. While originally envisaged as a communications device for climate change information, the narratives rapidly transformed into a deliberation and co-production device supporting discussions related to current and future risks. Importantly, narratives were iterated several times, integrating knowledge from the broad groups of learning lab participants.



*Stakeholders co-explore burning issues within their city during the first Learning Lab in Windhoek. Credit: FRACTAL team member*

- **Disciplinary research** was also undertaken to provide a foundation for trans-disciplinary research in cities. Climate science research focussed on better describing and resolving contradictions between observations and model outputs, exploring linkages between climate processes at different scales, as well as understanding the added value of particular climate science methods (e.g. downscaling and high-resolution modeling) and outputs. This research provides a stronger basis for information distillation. Research on urban governance, decision-making and urban water modeling have provided further foundations for information distillation in the cities. An example is the development of a water resource model (WEAP), implemented for the Lusaka and Kafue catchment, which was developed through bottom-up processes with city stakeholders.



## Significant Impacts:

- Deep and ongoing involvement in [Windhoek Integrated Climate Change Strategy and Action Plan \(CCSAP\)](#). Collaborative development of policy briefs on [groundwater](#), [water supply](#), [water quality](#), and [flooding](#) in Lusaka.
- Ongoing engagement with Lusaka City Council Councillors on climate risk and ward development planning (through the [Lusaka Water Security Action and Investment Plan](#)).
- Coproduction of an [online tool to map vector and waterborne disease](#) risks in Maputo,
- Support for initiating the Urban Resilience Hub in Maputo
- Development of [climate risk narratives](#) in Blantyre, Gaborone, Harare, Lusaka, Maputo and Windhoek.
- Input to the [eThekweni biodiversity and climate change monitoring framework](#).
- Training of councillors in climate science in Maputo, [Lusaka](#) and [Windhoek](#).
- Training of executives and other senior managers on [Transformational climate change leadership](#).
- [Talanoa dialogues](#) in [Lusaka](#) and [Windhoek](#).
- Sensitisation and support for the initiation of the Climate Change Desk under the Town Clerk in the [City of Harare](#).
- In-depth capacity analysis through a Climate Capacity Diagnosis & Development (CaDD) tool in Lusaka and Windhoek.
- [A strong network of city and academic partners](#) enthusiastic about pushing the process forward in each city.

## Taking FRACTAL's Lessons Forward:

The impacts of the productive relationships that have been formed through FRACTAL are notable. Equally as important, many lessons have been learned through 'dead ends'. Building on these lessons, ideas for scaling and/or deepening FRACTAL work have been developed, including those listed below:

- Implementing a novel and inclusive approach to 'mainstreaming' climate change into planning by honing in on risks and opportunities (e.g. by integrating climate risk narratives) that intersect with spatial development plans of all governance types (state, customary etc.). This would happen through social learning processes similar to those of FRACTAL and would acknowledge the complex planning arrangements that are present in many parts of Africa.
- Establishing an online distillation platform to easily and rapidly access climate data, publications, reports, etc., as well as increasing ability to analyse and interrogate this data (i.e. synthesising instead of producing more outputs).
- Formalising the urban climate resilience inspiration and knowledge network and supporting city exchanges for peer-to-peer learning, especially for those stakeholders who have been involved in FRACTAL traveling to other, new cities involved in the learning.

- Developing approaches to produce climate risk information on seasonal to decadal timescales that aligns with operation through to medium-term planning activities and mechanisms within cities.
- Testing mechanisms to streamline and sustain climate resilience learning processes to ensure the legacy of FRACTAL extends beyond the FCFA programme.



*A field trip to an informal settlement supports the experiential learning of participants during the second learning lab in Lusaka. Credit Bettina Koelle*

# Partner Organisations

[University of Cape Town](#) (South Africa)

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[START](#) (International)

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*FRACTAL team photo at the Annual General Meeting in Cape Town, 2019.  
Credit: Izidine Pinto*

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# Country Summaries

## Summary of FCFA's work in Burkina Faso

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Burkina Faso focused on [AMMA-2050's](#) pilot study to support flood-resilient planning in the country's capital, Ouagadougou. AMMA-2050 combined future climate and land use change projections to inform hydrological models and the mapping of flood risks to inform national and city-level decision-makers.



### Highlights from Ouagadougou

- [Key climate science messages](#) from AMMA-2050 indicate that the Sahel region will continue to become hotter while more intense rainfall will become more frequent.
- The [increasing frequency of extreme rainfall](#) and rapidly expanding urbanisation in Burkina Faso has resulted in rising severity of floods in recent decades.
- AMMA-2050 has introduced and [co-developed with decision-makers](#), a range of tools designed to support flood-resilient planning. These include; a flooding database, a flood-risk map of Ouagadougou, [Intensity-Duration-Frequency](#) (IDF) curves (important tools for informing infrastructural investment), and a policy brief synthesising emerging scientific understanding regarding future climate-related risks tailored for Burkinabé decision-makers.
- AMMA-2050 also collaborated with those involved in complementary climate initiatives, including the Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) Zaman Lebidi project and the West African Science Service Centre on Climate Change and Adapted Land-Use (WASCAL), working with the institution's Competency Centre in Ouagadougou to [support development of decision-relevant climate services](#).

### About AMMA-2050

**The African Monsoon Multidisciplinary Analysis - 2050 (AMMA-2050)** consortia aimed to increase understanding of the regional climate of West Africa and how it will change, applying this knowledge to practical development questions.

AMMA-2050 aimed to improve understanding of how the West African monsoon will be affected by climate change in the coming decades and help West African societies prepare and adapt. AMMA-2050 conducted pilot studies that are focused on the issues of urban flooding in Ouagadougou, Burkina Faso and climate-smart agriculture in Senegal, both issues of significant **societal concern**.

## Enhanced understanding of current and future flood risks in Ouagadougou

The increasing severity of recent floods in Ouagadougou, particularly in 2009, has become a growing concern for stakeholders in the City. Stakeholders have been interested in understanding how storms and flooding are being impacted by climate change and rapid unplanned urbanisation, and the future flood risks expected for the City.

AMMA-2050 brought together an international multi-disciplinary team of researchers to analyse historical trends of climate and flooding. The work developed fundamental new understanding of how global warming is [already driving more frequent intense Sahelian storms](#), and highlighted linkages to increasing [occurrence of floods in Ouagadougou](#). Socio-economic surveys also furthered understanding of the climate-related risks facing people living in flood-prone areas, as well as their responses to floods. A [detailed case-study on the 2009 flood event](#) provided a cross-disciplinary platform for considering climate change impacts at the city scale and communicating science for decision-makers' needs.



AMMA-2050 Mayoral Meeting in 2018. Credit: AMMA-2050

To further the understanding of future flood risks, AMMA-2050 developed unique modelling chain methodologies to meet decision-maker needs that combined state-of-the-art regional climate projections capable of representing intense storms, with land-use change projections, to inform detailed flood modelling. In collaboration with the [RainCell project](#), AMMA-2050 was able to use rainfall and flow data as inputs to hydrological framework modelling to simulate flooding in Ouagadougou. To represent the return period for intense rainfall events, AMMA-2050 also developed [Intensity-Duration-Frequency \(IDF\) Curves](#) to inform infrastructural planning in the city. AMMA-2050 convened a [meeting in 2018](#) with national and city decision-makers to discuss and further develop the range of products being developed within the project and explore the most accessible formats and approaches to communicate this information to guide planning. AMMA-2050 has also undertaken research on the impacts of

climate change on urban water, sanitation and hygiene (WASH), with surveys across flood-prone areas to understand how people respond to and are impacted by flooding and investigate the evidence that the combination of poor drainage and sanitation has on the health of affected populations. This complementary research has shown that people living in flood-prone areas develop forms of resilience that range from backfilling the yard, to diking areas around gates that create a barrier against flooding of dwellings, to digging trenches for the evacuation of rainwater.

## Improving scientists' capacity to produce relevant climate information for Ouagadougou

Along with producing high quality climate science, AMMA-2050 engagement was also aimed at improving the [technical and engagement capacities](#) of researchers to produce decision-relevant climate information. This included [strengthening the ability of African researchers](#) to deliver climate metrics using tools that can directly support flood planning in Ouagadougou.

The approach to research taken by AMMA-2050 resulted in researchers having strengthened capacity; engage with decision-makers, co-produce relevant climate information, work across institutions and disciplines, undertake and manage research projects, and to communicate and evaluate scientific results. Over the course of the project, AMMA-2050 researchers have facilitated a series of workshops and discussions with mayors and national decision-makers from across a range of ministries. Stakeholder engagements have encompassed a [joint forum](#) with the BRACED Zaman Lebidi project on how climate information can support local government decision-making, a meeting with mayors, city and national technical advisors, and a [joint workshop](#) with WASCAL on operationalising the links between researchers and policymakers in West Africa. Continued training to support co-production and uptake of co-developed outputs is proposed in 2020- 2021, over the course of the AMMA-2050 project extension.

## Climate Metrics

Bringing together respective expertise from across disciplines and institutions, AMMA-2050 researchers identified [climate metrics](#) important in enabling decision-making to be informed by climate-related risks. Across project partners and together with decision-makers, researchers reviewed important metrics for the region including; annual rainfall, change in extreme precipitation days, change in frequency of dry spells and monthly temperature trends. Two researchers from each AMMA-2050 partner university in West Africa were invited to a week-long training on python coding. This equipped African researchers with key skills to produce in-country climate information that can support specific decision-making processes (see [Climate Atlas](#)). Those trained have already [contributed to informing national infrastructural and adaptation planning](#), and have sought to share the technical expertise acquired through the project more widely within their respective institutions.

## Selected Additional Resources

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## Summary of FCFA's work in Senegal



[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Senegal focused primarily on [AMMA-2050](#)'s pilot study to support climate-resilient agriculture. Alongside improving the quality of scientific climate information, AMMA-2050 sought to support the use of this climate information within (sub-state) regional and national decision-making contexts.

### About AMMA-2050

The [African Monsoon Multidisciplinary Analysis - 2050](#) (AMMA-2050) team aimed to increase understanding of the regional climate of West Africa and how it will change, applying this knowledge to practical development questions.

AMMA-2050 aimed to improve understanding of how the West African monsoon will be affected by climate change in the coming decades – and help West African societies prepare and adapt. AMMA-2050 conducted pilot studies that were focused on the issues of urban flooding in Ouagadougou (Burkina Faso) and climate-smart agriculture in Senegal, both issues being of significant [societal concern](#).

### Highlights from Senegal

- [Key climate science messages](#) from AMMA-2050 indicate that the Sahel region will continue to become hotter while more intense rainfall will become more frequent.
- In Senegal, the most likely scenario is a [reduction in seasonal rainfall by 2050](#), though an increase cannot be ruled out.
- The impacts of climate change in this region are likely to result in [reduced yields](#) of key crops, including sorghum and millet, placing pressure on rural livelihoods in Senegal and across West Africa.
- Utilising [participatory approaches](#) seeking to support co-production, AMMA-2050's work in Senegal focused on bridging climate science and decision-making processes in the agricultural sector.
- AMMA-2050 used a variety of innovative methods to foster co-production of knowledge and support inclusive dialogue between stakeholders, including [Theatre Forum](#), the [Plateau Game](#) and [participatory modelling](#).

## Improving scientists' capacity to produce relevant climate information for Senegal

Along with producing high quality climate science for the agricultural sector (see [Climate Portal](#)), AMMA-2050 project engagement was aimed at improving the [technical and engagement capacities](#) of researchers to produce decision-relevant climate information. This included strengthening the ability of African researchers to deliver climate metrics using tools that can directly support Senegal's agricultural and infrastructural planning and policies.

The approach to research taken by AMMA-2050 resulted in [researchers having strengthened capacity](#) to; engage with decision-makers, co-produce relevant climate information, work across institutions and disciplines, undertake and manage research projects, and to communicate and evaluate scientific results. Over the course of the project, AMMA-2050 researchers engaged with the Fatick Comité Régionale du Changement Climatique (Regional Committee on Climate Change) and through the Projet d'Appui Scientifique aux processus de Plans Nationaux d'Adaptation (PAS-PNA) supported the process informing Senegal's National Adaptation Plan.

Engagements throughout AMMA-2050 in Senegal have led to decision-makers at (sub-state) regional and national levels recognising the utility of the climate science outputs from the consortium.

## Co-producing climate information for climate resilient agriculture in Senegal

AMMA-2050 adopted a [Participatory Impact Pathways Analysis](#) (PIPA) as an overarching framework to guide project engagement and support co-production processes. The emphasis on co-production was focused on bringing together various stakeholders from different disciplines, sectors and decision-making levels to support medium-term decision making. This was done through building common ground between stakeholders as a basis for co-exploring the climate information needs of different groups, as well as for co-developing and co-delivering solutions to emerging climate-related risks.

Some of the key approaches AMMA-2050 employed to support co-production include the Plateau Game, participatory modelling, and theatre forum. [The Plateau Game](#) was used by AMMA-2050 partner Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) as an approach to share emerging understanding about climate-related risks, identify adaptation options, debate policy, and inform and validate modelling results. This was followed by Participatory Modelling which allowed decision-makers and agricultural professionals to review and input knowledge into the project's [bio-economic modeling](#). The Plateau Game and Participatory Modelling enabled modelers

## Climate Metrics

Bringing together respective expertise from across disciplines and institutions, AMMA-2050 researchers identified [climate metrics](#) important in enabling decision-making to be informed by climate-related risks. Across project partners and together with decision-makers, researchers reviewed important metrics for the region including; annual rainfall, change in extreme precipitation days, change in frequency of dry spells and monthly temperature trends. Two researchers from each AMMA-2050 partner university in West Africa were invited to a week-long training on python coding. This equipped African researchers with key skills to produce in-country climate information that can support specific decision-making processes (see [Climate Atlas](#)). Those trained have already contributed to [informing national infrastructural and adaptation planning](#), and have sought to share the technical expertise acquired through the project more widely within their respective institutions.

to test the impacts of different policy interventions and gain deeper appreciation of decision-making contexts.

[Theatre Forum](#) was employed by CIRAD, Institut de Recherche pour le Développement (IRD) and Institut Sénégalaise de Recherches Agricoles (ISRA) to support dialogues between research, policy, and practice. A play was developed by a multidisciplinary team together with a national Theatre Forum group, Kaddu Yarax, and informed by research to identify key tensions and important areas for multi-stakeholder dialogue. The approach was able to build common ground between different stakeholders while conveying and exploring complex concepts such as climate uncertainty, and the causality and impacts of decisions. The theatre forum initiated vital conversations on roles and responsibilities in the process of climate adaptation, exploring the capacities of stakeholders to take responsibility for the consequences of their actions. Internally the Theatre Forum also reaffirmed the commitments of AMMA-2050 researchers to strengthen stakeholder engagement in future research, as well as demonstrating a powerful tool to support this process. AMMA-2050 Theatre Forum was captured in the video entitled '[I acclimatise therefore I am / J'acclimatise donc je suis](#)'.

The processes employed in AMMA-2050's work in Senegal enabled decision-makers to identify variables of interest within climate models that were previously overlooked by modellers (e.g. consideration of wind strength). Co-production was also effective in allowing researchers and decision-makers to jointly explore the relevance of different adaptation options and policies, as well as challenging researchers' underlying assumptions and strengthening their understanding of decision-makers' specific climate information needs.



## Selected Additional Resources

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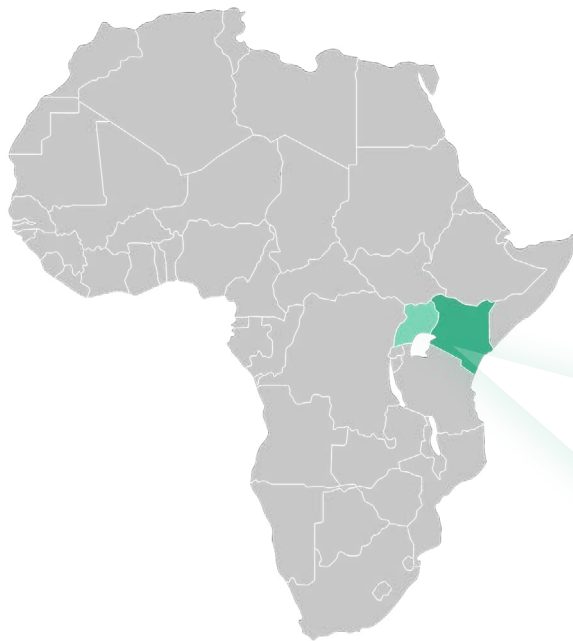
 Twitter: [future\\_climate](https://twitter.com/future_climate)



National Theatre Forum group, Kaddu Yarax

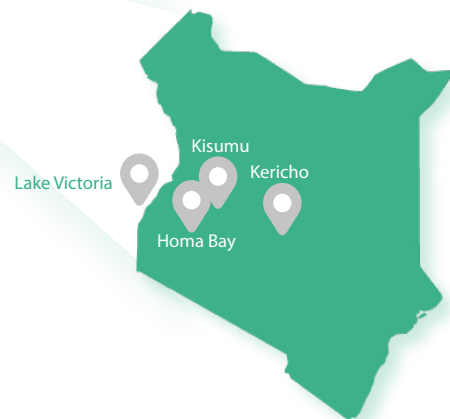
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## Summary of FCFA work in Kenya

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Kenya was carried out by the [HyCRISTAL](#) consortium.



### About HyCRISTAL

**HyCRISTAL** (Integrating Hydro-Climate Science into Policy Decisions for Climate-Resilient Infrastructure and Livelihoods in Africa) aimed to develop a new understanding of East African climate variability and change and to work with regional decision-makers to support effective long-term (5 to 40 year) decision-making in the face of a changing climate. In collaboration with a range of stakeholders, HyCRISTAL co-developed climate change adaptation options that meet the region's societal needs in both urban and rural areas through a series of pilot demonstration projects, covering urban WASH, rural livelihoods, water management, tea production, and transport and lake levels in Kenya and Uganda.

By developing climate science and helping water users assess their vulnerabilities; the HyCRISTAL project aimed to increase the resilience of communities in East Africa. Working together with policy makers, the interdisciplinary research of HyCRISTAL quantified risks and provided the necessary tools to use climate change information for decision-making on a 5 to 40 year timescale. This included the production of new, accessible, understandable, and easy-to-use tools for water resource management in a changing climate.

### Highlights from Kenya

- HyCRISTAL implemented four pilot projects in Kenya focusing on urban Water, Sanitation and Hygiene (WASH) systems, rural livelihoods, tea production, and lake transport infrastructure
- The pilot projects intended to further climate scientists' understanding of local contexts in order to tailor climate information for planning and decision-making processes.
- HyCRISTAL developed a [climate change science summary for East Africa](#), which highlights the key climate science findings of the consortium.
- HyCRISTAL also produced [Climate Risk Narratives](#) for the East Africa region to communicate possible future climate scenarios for [urban](#) and [rural](#) areas and initiate discussions with stakeholders.

## Urban WASH in Kisumu

The [Kisumu](#) pilot project focused on the impacts of climate change on the city's urban WASH systems. HyCRISTAL introduced local stakeholders to new climate research emerging from the consortium, while supporting climate scientists to identify information that is locally relevant. This involved creating simulations of surface water flooding in Kisumu under various plausible climate scenarios, and engaging with local community groups about their [lived experience of flooding](#) to determine the local relevance of the flood model. HyCRISTAL used the discussions to further understanding on the complexity of the issues, and developed an [informational video](#) to share the local communities' stories.



Photo from FCFA AMCOW Africa Water Week 2018 session video presentation

These flood models were combined with sanitation, infrastructure and socio-economic maps and used to develop a health hazard map for the city. HyCRISTAL used this to examine how climate change scenarios may influence flood events and effect health risks in Kisumu. HyCRISTAL is developing this into a model which will examine the likely impacts of sanitation and infrastructure interventions on health outcomes under the context of climate change.

The process of developing the model has created opportunities for discussions between a range of stakeholders including advocates for informal communities. The work has highlighted the fact that local residents have little agency in managing flood risks around their homes, and WASH systems need to be considered in the context of wider city infrastructure systems and within policy and planning spaces in Kisumu. The work has been positively received by local stakeholders with improved understanding of options for risk reduction and clearer dialogue around investment and decision-making.

## Rural Livelihoods in Homa Bay

HyCRISTAL's [rural work](#) in Kenya focuses on developing new pathways for climate research that supports resilience of rural communities vulnerable to climate change. This involved using long-term climate predictions and local context information to help policy and decision-makers with informed short-term (1 to 3 years) and long-term (5 to 40 years) decisions on rural adaptation.

Using the [Household Economic Approach](#) (HEA) and [Individual Household Method](#) (IHM), HyCRISTAL sought to understand livelihood patterns and factors inhibiting adaptive capacities of communities. This was informed by further studies on market systems and value chains, understanding community adaptation potentials, and examining policy implications. The outcomes of these processes support the building of an evidence-based pathway to rural adaptation at the county and national levels.

To provide users with access to an integrated resource for climate, crop, fisheries, hydrology, and livelihoods information, the [Integrated Database for African Policymakers](#) (IDAPS) platform is being developed by HyCRISTAL and country partners. The core of IDAPS is the livelihoods data: this is the point where the resilience of communities, in the face of climate change, can be measured. Livelihoods data in IDAPS is based on the HEA but it also integrates data from other sources to provide policy and decision-makers with actionable insight into the effects that changes in climate may have on specific rural communities. It hopes to enable targeted, longer term policies to be drawn up and actioned by government agencies as well as shorter term, seasonal decisions to be made by farmers such as providing evidence for the best planting time of a particular crop.



Researchers from HyCRISTAL's rural livelihoods pilot at the HYCRISTAL Annual General Meeting in 2018. Credit: CCKE

## Tea Production in Kenya

HyCRISTAL has partnered with the [UMFULA](#) research consortium on the [Climate Information for Resilient Tea Production](#) (CI4Tea) project in Kenya. CI4Tea developed a novel approach to produce and communicate locally relevant climate information for tea production. The climate information is co-produced for tea specific indicators identified by engaging diverse stakeholders from the tea sector including smallholder farmers, large tea estates and the Tea Research Institute. Iterative engagements with tea sector stakeholders helped tailor climate information to their needs and incorporate their feedback to develop usable climate information. This improved understanding of local scale vulnerabilities of current and future climate change will help the stakeholders in identifying relevant adaptation options to sustain tea production in the short and long term. The CI4Tea work was showcased in a [video](#) produced by FCFA.



Farmers harvest their crops near Kisumu, Kenya. Photo: Flickr

## Lake Victoria lake levels and transport

The HyCRISTAL Transport Pilot Project (HyTpp) funded through the [DFID Corridors for Growth](#) Trust Fund (C4G TF) examined changing lake levels in Lake Victoria under possible climate change, as well as the changing lake outflows and the impacts on lake transport infrastructure and management. Climate scenarios were based on changes from an ensemble of climate models (CMIP, CP4A and P25), and two complementary lake-level modelling approaches.

HyCRISTAL's analysis demonstrated how possible future lake levels may be markedly different to levels that have been observed in the recorded past. The results indicate the risks of wetter and drier climate scenarios on the lake which need to be incorporated

into decision-making. The results were shared with the World Bank (C4G TF administrators) via a series of skype calls, a Lake Victoria Workshop in 2018 and the HyCRISTAL annual meetings in 2018 and 2019. Engagement with the World Bank uncovered the apprehension of stakeholders in dealing with uncertainty, however successive calls aided in building a common ground in understanding the needs and possibilities. These engagements help shift consultants away from cost-benefit approaches towards incorporating risks based on plausible ranges.



HyCRISTAL Annual General Meeting 2019 in Kampala

## Selected Additional Resources

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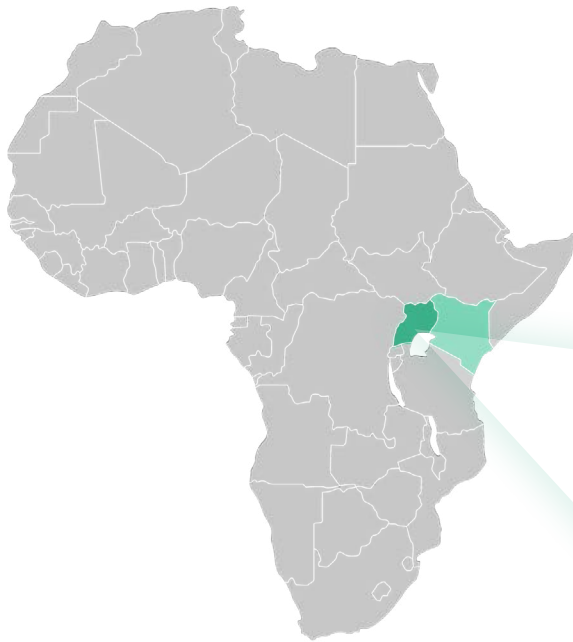
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*HyCRISTAL team at HyCRISTAL Annual General Meeting 2019 in Kampala, Uganda. Credit: CCKE, FCFA*

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## Summary of FCFA work in Uganda

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Uganda was carried out by the [HyCRISTAL](#) consortium.



### About HyCRISTAL

[HyCRISTAL \(Interating Hydro-Climate Science into Policy Decisions for Climate-Resilient Infrastructure and Livelihoods in Africa\)](#) aimed to develop a new understanding of East African climate variability and change including working with regional decision-makers to support effective long-term (5 to 40 year) decision-making in the face of a changing climate. In collaboration with a range of stakeholders, HyCRISTAL co-developed climate change adaptation options that meet the region's societal needs in both urban and rural areas through a series of pilot demonstration projects, covering urban WASH, rural livelihoods, water management, tea production, and transport and lake levels in Kenya and Uganda.

By developing climate science and helping water users assess their vulnerabilities; the HyCRISTAL project aimed to increase the resilience of communities in East Africa. Working with policy makers, the inter-disciplinary research (hydrology, economics, engineering, social science, ecology and decision-making) of HyCRISTAL quantified risks and provided the necessary tools to use climate change information for decision-making on a 5 to 40 year timescale. This included the production of new, accessible, understandable, and easy to use tools for water resource management in a changing climate.

### Highlights from Uganda

- HyCRISTAL implemented pilot projects in Uganda focusing on urban Water, Sanitation and Hygiene (WASH) systems, rural livelihoods, water resource management, and lake transport infrastructure.
- The pilot projects intended to further climate scientists' understanding of local contexts in order to tailor climate information for planning and decision-making processes.
- HyCRISTAL developed a [climate change science summary for East Africa](#), which highlights the key climate science findings of the consortium.
- HyCRISTAL also produced [Climate Risk Narratives](#) for the East Africa region to communicate possible future climate scenarios for [urban](#) and [rural](#) areas and initiate discussions with stakeholders.

## Rural Livelihoods in Mukono

HyCRISTAL's rural work in Mukono, Uganda, focuses on developing new pathways for climate research that supports [resilience of rural communities](#) vulnerable to climate change. This involved using long-term climate predictions and local context information to help policy and decision-makers with informed short-term (1 to 3 years) and long-term (5 to 40 years) decisions on rural adaptation.

Using the [Household Economic Approach](#) (HEA) and [Individual Household Method](#) (IHM), HyCRISTAL aimed to understand livelihood patterns and factors inhibiting adaptive capacities of communities. This was informed by further studies on market systems and value chains, understanding community adaptation potentials, and examining policy implications. The outcomes of these processes support the building of an evidence-based pathway to rural adaptation at the county and national levels.

To provide users with access to an integrated resource for climate, crop, fisheries, hydrology, and livelihoods information, the [Integrated Database for African Policymakers](#) (IDAPS) platform is being developed by HyCRISTAL and country partners. At the core of IDAPS is the livelihoods data: this is the point where the resilience of communities, in the face of climate change, can be measured. Livelihoods data in IDAPS is based on the HEA but it also integrates data from other sources to provide policy and decision-makers with actionable insight into the effects that changes in climate may have on specific rural communities.

It hopes to enable targeted, longer term policies to be drawn up and actioned by government agencies as well as shorter term, seasonal decisions to be made by farmers such as providing evidence for the best planting time of a particular crop. Two IDAPS user forums were hosted in 2017 by the Uganda National Council for Science and Technology and in 2018 by HyCRISTAL. During these meetings key stakeholders were convened to provide valuable input to ensure IDAPS matches the needs and priorities of its stakeholders. The rural work in Uganda led to the delivery of a [briefing paper on rural adaptation](#) being delivered to the Ugandan Parliament, as well as contributions to the [Ugandan National Environmental Bill](#).

## Urban WASH in Kampala

The Kampala pilot study was focused on the impacts of climate change on the Urban Water, Sanitation and Hygiene (WASH) systems of the city. HyCRISTAL introduced local stakeholders to new climate research emerging from the consortium, while supporting climate scientists to

### Filmmaking to support agri-extension in Uganda

Traditionally farmers in Uganda have relied on government or private extension officers for access to climate change information. This means farmers internalise climate messaging from state or private entities and do not get the opportunity to participate in knowledge production processes. Through training local climate change champions in visual storytelling, researchers from HyCRISTAL aimed to use [basic filmmaking](#) as a way to shift traditional one-way knowledge exchange within farming communities in Mukono. The visual storytelling aims to address the mismatch between the information provided to farmers and the information needed by farmers. This allows farmers to produce knowledge in their own language, in a manner which reflects their personal experiences.

identify information that is locally relevant. This involved creating simulations of surface water flooding in Kampala under various plausible climate scenarios, then talking with local community groups about their [lived experience of flooding](#) to check the local relevance of the flood model. HyCRISTAL used the discussions to help understand the complexity of the issues, and developed an [informational video](#) to share their stories.

One of the key aims for HyCRISTAL was to synthesise data of flooding, infrastructure and services into useful tools. Flood modeling efforts have been carried out previously, but little evidence exists of this being translated into useful management tools or design interventions. Combining new flood models with sanitation, infrastructure and socio-economic maps, HyCRISTAL has developed a geo-spatial health hazard model to examine the health impacts of flooding in the city. This model allows various climate scenarios and infrastructure interventions to be explored, showing the impacts they will have on likely flood extents and depths, and health outcomes.

The process of developing the model has created opportunities for discussions between a range of stakeholders including advocates for informal communities. The work has highlighted that people have little agency in managing flood risks around their homes, and that WASH systems need to be considered in the context of wider city infrastructure systems - with implications for policy and planning in Kampala. The work has been positively received by local stakeholders such as the Kampala Capital City Authority (KCCA) and the National Water and Sewerage Company (NWSC) and equipped them with an improved understanding of options for risk reduction and clearer dialogue around investment and decision-making.

## Water resources in the Lake Victoria Basin

HyCRISTAL partnered with the Ugandan Ministry of Water and Environment (MWE) to improve the use of climate information in [Integrated Water Resource Management in the Lake Victoria Basin \(LVB\)](#). As MWE was in the process of developing catchment management plans for the newly established Water Management Zones, there was a clear opportunity for the HyCRISTAL team to develop strong working relationships with MWE to produce climate information. Improving the understanding of the impacts future climate change has on water resources strengthens the case for no-regret interventions in water resource planning and investment through building resilience to existing and future risks.

Comparing data from the Pan-African Convection-Permitting Regional Climate model (CP4-Africa) and global climate models (CMIP), HyCRISTAL was able to assess future changes in river flow in the LVB. For example model results for the Katonga River indicate increased rainfall in the catchment exceeds the increase in evaporation, leading to higher river flows overall. This improved understanding of the implications of climate change, plays a large role in defining socio-economic measures within catchment management plans, particularly in terms of balancing water supply and demand to address any deficits.

Assuming the model adoption by MWE, the co-production and embedded learning from the impact modeling in the LVB can be used in the future for both long-term strategic planning (assessment of climate change impacts and scenario analysis) and for operational purposes (eg. seasonal forecasting of river flows). A stakeholder workshop is planned for early 2020 to disseminate results from this work.

## Lake Victoria lake levels and transport

The HyCRISTAL Transport Pilot Projects (HyTpp) funded through the [DFID Corridors for Growth](#) Trust Fund (C4G TF) examined changing lake levels in Lake Victoria under possible climate change, as well as the changing lake outflows and the impacts on lake transport infrastructure and management. Climate scenarios were based on changes from an ensemble of climate models (CMIP, CP4-A and P25), and two complementary lake-level modelling approaches.

HyCRISTAL's analysis demonstrated how possible future lake levels may be markedly different to levels that have been observed in the recorded past. The results indicate the risks of wetter and drier climate scenarios on the lake which need to be incorporated into decision-making. The results were shared with the World Bank (C4G TF administrators) via a series of skype calls, a Lake Victoria Workshop in 2018 and the HyCRISTAL annual meetings

in 2018 and 2019. Results were shared with stakeholder at a workshop in 2019 with representatives from Uganda and the East African Community. Engagement with the World Bank uncovered the apprehension of stakeholders in dealing with uncertainty, however successive calls aided in building a common ground in understanding the needs and possibilities. These engagements help shift consultants away from cost-benefit approaches towards incorporating risks based on plausible ranges.



HyCRISTAL Annual General Meeting 2018 in Kampala. Credit CCKE

### Selected Additional Resources

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Finney, D et al. 2019. [Scientific Understanding of East African climate change from the HyCRISTAL project](#). Report. University of Leeds, United Kingdom.



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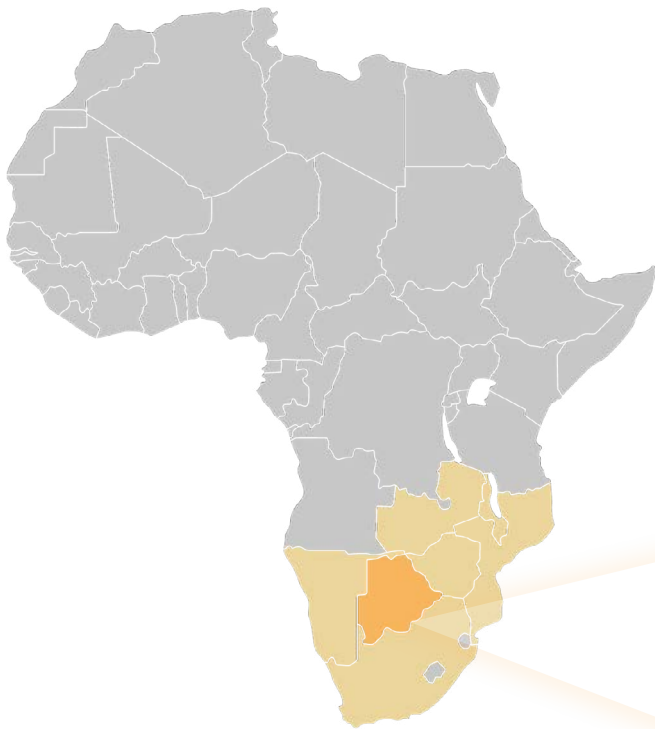
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## Summary of FCFA work in Botswana

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Botswana took place in the capital city, Gaborone. It was carried out by [FRACTAL](#) and was led by the University of Botswana.



### Highlights from Gaborone

- Less engagement occurred in Gaborone than other FRACTAL cities. Research was primarily focused on the transferability of relevant climate knowledge.
- Local researchers developed [Climate Risk Narratives](#) in a 2017 workshop where climate information from the FRACTAL team informed the researchers vision for the future of the city.
- Surveys allowed the local team to present the Climate Risk Narratives to various decision-makers and get their feedback and reflections.
- A [second workshop](#) in 2018 shared feedback and designed cross-city outputs for Gaborone, Harare, and Blantyre.
- FRACTAL's work contributed to stimulating the city's awareness of climate change issues. One of the positive outcomes included the city manager brainstorming a city-specific climate change action plan.
- Gaborone's city-specific plan was further developed through learning exchanges with Windhoek, where city planners were given the opportunity to gain insight into the development of Windhoek's Integrated Climate Change Strategy Action Plan during [Windhoek's third Learning Lab](#) in 2018.
- Another key outcome of FRACTAL's work was the creation of links between the City's Planning Department and Meteorological Department during a four day Climate Scenario and Action Plan workshop.
- During FCFA's extension phase, FRACTAL will aim to facilitate [policy forums](#) in Gaborone where stakeholders will examine climate vulnerabilities in the city and consider how planning and budget can contribute to the Gaborone City Council meeting their climate scenario goals. The extension phase will also aim to create mechanisms for relevant information from the Meteorological Department to be accessed by the City.

## About FRACTAL

**FRACTAL** (Future Resilience for African Cities and Lands) aimed to understand the decision context and the climate science required to contribute to climate-resilient development in nine southern African cities (Blantyre, Durban, Cape Town, Gaborone, Harare, Johannesburg, Lusaka, Maputo, Windhoek). The FRACTAL team aimed to contribute to an advanced understanding of scientific knowledge about climate processes, regional and local climate trends to improve understanding of southern Africa's climate and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years).

The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

## Selected Additional Resources

FRACTAL. 2019. [Climate Risk Narratives: Envisioning possible futures for your city](#). FRACTAL Poster. University of Cape Town, South Africa. FRACTAL. 2018.

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## Summary of FCFA work in Malawi: Exploring Decision-Making in Blantyre

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's research in Malawi was carried out by the [FRACTAL](#) and [UMFULA](#) consortia.

*Important note: This brief only covers FRACTAL's work in Malawi and there is a separate brief that details UMFULA's research in Malawi and [how we can improve the use of information for climate-resilient planning](#).*



### Highlights from Blantyre

- FRACTAL's research in Blantyre (led by the Polytechnic University of Malawi) had fewer engagements and activities than other FRACTAL cities, instead it focused on the transferability of relevant climate knowledge and lessons.
- [Climate Risk Narratives](#) were developed through initial socio-economic narratives which were co-produced with stakeholders living and working in Blantyre to describe three possible futures for the city. Climate science was woven into these narratives to surface possible climate risks for the city.
- The process brought together many different stakeholders, sparking conversations about climate change in the city.
- [A think tank workshop](#), supported through the FCFA Innovation Fund, provided useful initial insight into the values guiding decision-making in the city, which are largely driven by the mandates of different government sectors.
- The Blantyre City Council's decision to research turning waste to energy in order to increase energy supply for the city was used as an exemplar to explore the different values that guide decision-making.
- Over a period of two days, the think tank held loosely guided conversations with the various relevant stakeholders, which surfaced several drivers of decisions taken in the city.
- Representatives from Blantyre and Harare also teamed up to [explore decision-making](#) around water and climate change in the city.

## About FRACTAL

**FRACTAL** (Future Resilience for African Cities and Lands) aimed to understand the decision context and the climate science required to contribute to climate-resilient development in nine southern African cities (Blantyre, Durban, Cape Town, Gaborone, Harare, Johannesburg, Lusaka, Maputo, Windhoek). The FRACTAL team aimed to contribute to an advanced understanding of scientific knowledge about climate processes, regional and local climate trends to improve understanding of southern Africa's climate and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years).

The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

## Selected Additional Resources

Bowden, R. 2019. [Balancing inclusivity and progress, the challenge for Blantyre City development](#). FCFA News Article.

FRACTAL. 2019 [Climate Risk Narratives: envisioning possible futures for your city](#). FRACTAL Poster. University of Cape Town, South Africa.

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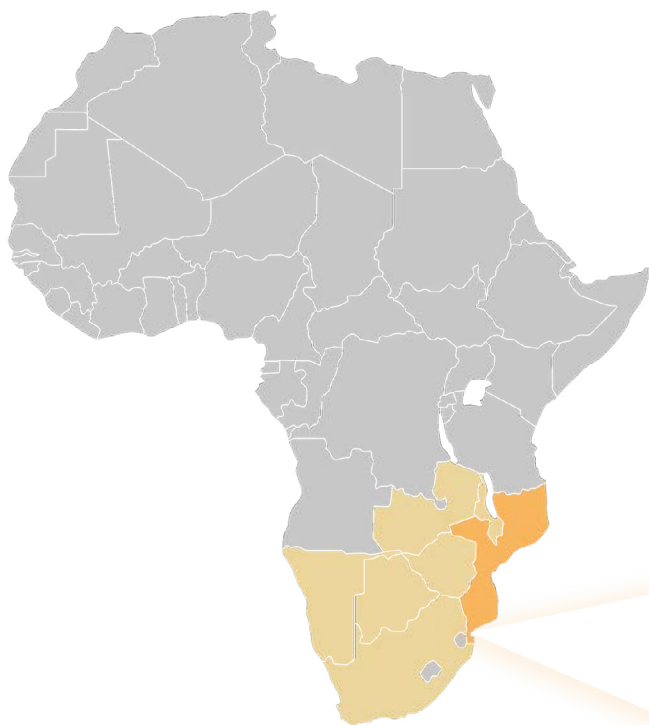
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## Summary of FCFA work in Mozambique

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's research in Mozambique was conducted in the capital city, Maputo, by the [FRACTAL](#) consortium and led by researchers from Eduardo Mondlane University.



### About FRACTAL

[FRACTAL](#) (Future Resilience for African Cities and Lands) aimed to understand the decision context and the climate science required to contribute to climate-resilient development in nine southern African cities (Blantyre, Durban, Cape Town, Gaborone, Harare, Johannesburg, Lusaka, Maputo, Windhoek). The FRACTAL team aimed to; contribute to an advanced understanding of scientific knowledge about climate processes, regional and local climate trends to improve understanding of southern Africa's climate and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years).

The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

### Highlights from Maputo

- [City learning process](#) focused on addressing issues of water supply, and water-related health risks within the city.
- Climate information for future water supply already existed for Maputo, however the up-take and use of this information was not evident in planning or governance.
- [Learning Labs](#) and an [Embedded Researcher](#) helped build a mutual understanding of water issues in Maputo.
- Eduardo Mondlane University, the National Institute of Health, Maputo Municipality, and other partners co-produced a web-based online tool for estimation of the risk of vector and water-borne diseases as a function of climate variables.

## City learning processes in Maputo

In Maputo, the FRACTAL team implemented city learning processes through four FRACTAL learning labs. The learning process proved to be much slower to initiate in Maputo compared to other FRACTAL cities. Several factors contributed to these delays, including bureaucratic procedures and the need for all engagements and products to be translated into Portuguese. During the [first learning lab](#) in March 2017, stakeholders identified challenges facing the city, prioritised research questions, and agreed upon FRACTAL's role in the research process. The City learning revealed that climate change information relevant to water supply was already available but was not being used by the City.

FRACTAL identified some potential reasons why climate information was not being used by Maputo Municipality (and other relevant stakeholders) for planning including; the information existed in institutional silos and there were few processes to coordinate and contextualise information for decision-makers and technicians. Based on feedback from representatives, it was clear that the City of Maputo required more coordination and information sharing across the municipality to put information into use, which the FRACTAL learning processes aimed to facilitate.

Subsequent learning labs in May 2018, October 2018 and May 2019, as well as two city dialogues in February 2018 and September 2018 allowed stakeholders to explore water issues in the city while also establishing [new interpersonal connections and networks](#). The city learning process in Maputo was able to support the development of positive relationships in the city, and was effective in getting a range of stakeholders to engage in solving issues around water. It led to the co-production of an online tool for estimating risks of vector and water-borne diseases in the city, through FRACTAL's Small Opportunity Grants.



Maputo Water Dialogue 23 February 2018. (Source: D. Scott)

## The Embedded Researcher in Maputo

The [Embedded Researcher approach](#) was adopted by FRACTAL to bridge the science-policy divide (most notably for climate science). An official from the city government of Maputo was appointed in a research and research coordination role for the duration of the project. The aim of this approach was to co-explore and co-produce knowledge, create and sustain learning opportunities to integrate climate information into cities, strengthen urban governance networks, and sharing lessons between African cities and beyond.

## Information distillation in Maputo

To provide Maputo with three plausible climate futures, FRACTAL developed [Climate Risk Narratives \(CRN\) for Maputo](#). These three futures included: 1) hotter and drier, 2) warmer with no changes in rainfall and 3) warmer with more extreme rainfall. Interestingly, the participants of the labs expressed a dislike for the negative and critical framing of CRNs while this framing had worked well in Lusaka and Windhoek.

At a water-specific dialogue, Water Risk Narratives were developed to explore the issue in more depth and to consider entry points for climate change information, which proved challenging. The three horizons approach was used to unpack water issues in the (1) present day situation, (2) transition phase, and (3) future or goal scenario. Both processes furthered understanding of water supply governance, the environmental and engineering aspects to support a mutual understanding of the water system relevant to Maputo. Development trajectories (such as population growth) were identified as key constraints to water supply, which is similar to lessons learned in all FRACTAL cities.

## Building receptivity in Maputo

The concept of [receptivity](#) was developed by FRACTAL team members through their participation in the learning labs of Maputo. The development and application of the concept was specifically intended as an alternative to seeking entry points for climate information among stakeholders participation in co-production processes.

The city learning process and the appointment of an Embedded Researcher enhanced receptivity in Maputo. The Embedded Researcher played a critical role in deepening understanding and engagement between the research and decision-making communities in Maputo, thereby building the receptivity of the City to climate information.

## Selected Additional Resources

- Jack, C., et al. 2019. [Climate Information Distillation: What is it and why do we need a framework?](#) FRACTAL Briefing Note. Cape Town, South Africa
- Pretorius, L. et al. 2019. [An Embedded Researcher approach to integrate climate information into decision making in southern African cities: lessons from FRACTAL](#). FRACTAL Working Paper. Cape Town, South Africa.
- Renaud, C., et al. 2018. [Preliminary mapping of water and climate change governance in Lusaka, Windhoek and Maputo](#). FRACTAL Briefing Note. Cape Town, South Africa.
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- Scott, D. & Taylor, A. 2019. [Receptivity and judgement: Expanding ways of knowing the climate to strengthen the resilience of cities](#). FRACTAL Working Paper. Cape Town, South Africa.


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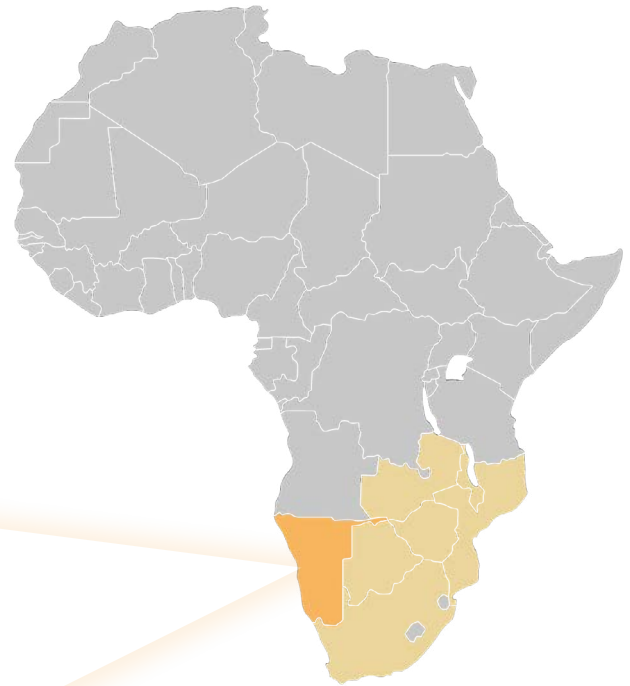
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## Summary of FCFA work in Namibia

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Namibia, was carried out in the capital city, Windhoek, by the [FRACTAL](#) consortium and led by the University of Namibia.



### Highlights from Windhoek

- [City learning process](#) which included providing climate information, contributing to water-related infrastructure planning and building climate change leadership within the City of Windhoek.
- [Learning Labs](#), an [Embedded Researchers](#), and councillor training facilitated engagements between FRACTAL researchers and City council.
- [Climate Risk Narratives](#) were developed to illustrate possible climate futures
- Engagements lead to FRACTAL informing and co-designing sections of [Windhoek Integrated Climate Change Strategy and Action Plan \(ICCSAP\)](#).

### About FRACTAL

[FRACTAL](#) (Future Resilience for African Cities and Lands) aimed to understand the decision context and the climate science required to contribute to climate-resilient development in nine southern African cities. The FRACTAL team aimed to contribute to an advanced understanding of scientific knowledge about climate processes, regional and local climate trends to improve understanding of southern Africa's climate and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years).

The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

## Learning Labs in Windhoek

Learning Labs is a transdisciplinary process involving [co-producing research questions that are relevant for all actors](#), including academics and practitioners, and knowledge that contributes to answering these questions. FRACTAL's Learning Labs approach partly contributed to a shift in how the City viewed climate issues, most notable was the reframing of their climate response plan into a broader response with an *Integrated* Climate Change Strategy and Action Plan (ICCSAP) rather than the sectoral Climate Change Strategy and Action Plan (CCSAP), which was initially envisioned.

The [first Learning Lab](#) in Windhoek in March 2017 played an important role in framing climate change, with a variety of stakeholders co-exploring relevant 'burning issues' in Windhoek. The biggest issues identified by participants were [water insecurity, and the lack of access to energy and services in informal settlements in Windhoek](#). Later in 2017, [the second of these Learning Labs](#) introduced stakeholders to the proposed CCSAP and presented preliminary results of the water security research being conducted by FRACTAL partners. After the second Learning Lab, stakeholders identified key next steps for the ICCSAP being: the need for technical support for climate components of ICCSAP, a vulnerability assessment, focused training with councillors to improve governance and leadership on climate change issues, and for the next Learning Lab to present an opportunity to consult external stakeholders. These steps were supported through FRACTAL, and in order to improve the technical capacity of the City at least two climate science training workshops were implemented.

At the [third Learning Lab](#) in August 2018, FRACTAL facilitated dialogues about water and energy. This allowed stakeholders to co-explore key issues and concepts, while climate information training increased stakeholders' knowledge of climate systems and climate modelling. The lab also reflected on the way forward for the ICCSAP and the sustainability of the "co-learning" work to support the implementation of the response plan. Two FRACTAL representatives from Gaborone (from the University of Botswana and the City of Gaborone) attended this lab to learn from Windhoek stakeholders, as they had initiated discussions in Botswana to develop their own city-specific climate change plan.

This prepared stakeholders for the [final Learning Lab](#) in June 2019, where the progress of FRACTAL in addressing burning climate change issues was reflected on. The Learning Lab provided a platform for stakeholders from Windhoek, Maputo and Durban to share and learn from the experiences of other FRACTAL cities. FRACTAL colleagues presented research on the factors that have influenced the "Windhoek Managed Aquifer Recharge Scheme" and participants considered how lessons from this research could be integrated into the development of the Master Water Plan for Windhoek, initiated at that time of the last lab. Participants also brainstormed ways to integrate

### The Embedded Researcher in Windhoek

The [Embedded Researcher approach](#) was adopted by FRACTAL to bridge the science-policy divide (most notably for climate science). Early career researchers from local universities were appointed as ERs to work within government spaces (e.g. municipalities) in Southern African cities. The aim of this approach was to co-explore and co-produce knowledge, creating and sustaining learning opportunities to integrate climate information into cities, strengthening urban governance networks and sharing lessons between African cities and beyond. In Windhoek, the ER played a vital role in ensuring sustained engagements around climate issues, in particular support for the ICCSAP in the City.

climate information into this plan. While the learning labs aimed to improve the capacity within the City of Windhoek, much of the final event reflected on whether the work had stimulated human agency to ensure the sustainability of FRACTAL's work. The extension phase of FRACTAL will focus on supporting the implementation of the ICCSAP (co-designing Monitoring and Evaluation) and, where possible, informing the Water Masterplan.

### Information distillation in Windhoek

FRACTAL developed the [distillation framework](#) as an attempt to map out some guiding principles, concepts and processes to inform climate information communication. Information distillation in Windhoek, commenced through engagement around the first [Climate Risk Narratives](#). This engagement highlighted key local insights that were missed by the narratives and also raised the issue of framing the challenge as negative storylines that are ineffective in getting stakeholder buy-in, as opposed to positive outcomes of interventions. Strong engagement by local youth representatives, during a [Climate Change Awareness Workshop for City of Windhoek Junior Council](#), provided a forward-looking positive framing of successful implementation of policies and plans.

The emergence of the Integrated Climate Change Strategy and Action Plan (ICCSAP) process provided a valuable path to impact and the revised narratives, using the distillation framework, provide key storylines in the ICCSAP. Targeted climate science training for councillors focussed on the underlying; assumptions, interpretations, limitations, confidence, and uncertainty of the climate information and built understanding and trust between disciplinary experts and decision-makers.

Further detailed exploration of key issues such as extreme rainfall, and the risk of increasing temperature on wastewater reuse processes also fed into the process.

## Selected Additional Resources

Mfune, J. & lipinge, K. 2017. [Windhoek City Learning Lab Report](#). FRACTAL Workshop Report. University of Cape Town, South Africa.

lipinge, K. 2017. [Windhoek Second Learning Lab Report](#). FRACTAL Workshop Report. University of Cape Town, South Africa.

lipinge, K. 2018. [Windhoek Third Learning Lab Report](#). FRACTAL Workshop Report. University of Cape Town, South Africa.

lipinge, K. & Haukelo, S. 2018. [Windhoek Transformational Leadership on Climate Change Training](#). FRACTAL Workshop Report. University of Cape Town, South Africa.

Scott, D., lipinge, K.N., Mfune, J.K., Muchadenyika, D., Makuti, O.V. and Ziervogel, G., 2018. [The story of water in Windhoek: a narrative approach to interpreting a transdisciplinary process](#). *Water*, 10(10), p.1366.

lipinge, K. & Kokanya, E. 2019. [Windhoek Final Learning Lab Report](#). FRACTAL Workshop Report. University of Cape Town, South Africa.

Brandon, K. 2020. [Learning Labs: creating collaborative ways to address climate change in African cities](#). SEI Oxford. 14 January 2020.

Ndebele-Murisa, M.R., Mubaya, C.P., Pretorius, L., Mamombe, R., lipinge, K., Nchito, W., Mfune, J.K., Siame, G. and Mwalukanga, B., 2020. [City to city learning and knowledge exchange for climate resilience in southern Africa](#). *PloS one*, 15(1), p.e0227915.

Walker, N.J., lipinge, K.N., Cullis, J.D.S., Scott, D., Mfune, J., Wolski, P. and Jack, C. 2017. [Integrating climate change information into long term planning and design for critical water related infrastructure in Windhoek and other African cities](#).

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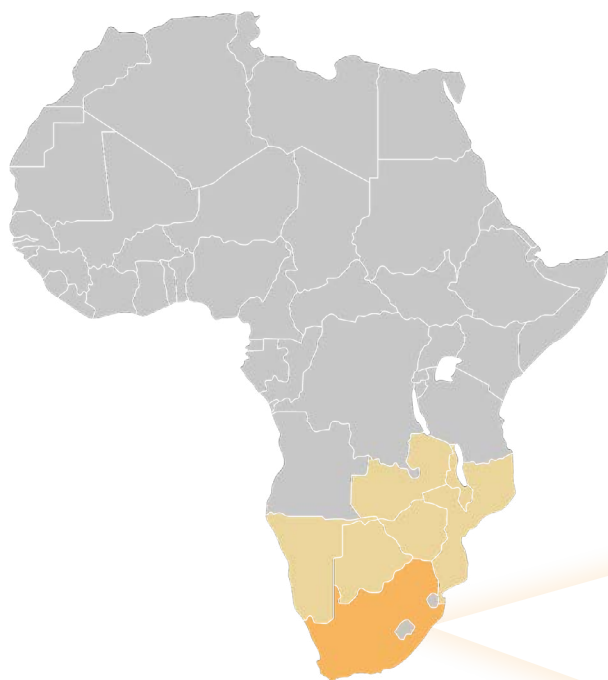


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## Summary of FCFA work in South Africa

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in South Africa was self-funded by the cities of Cape Town, Durban, and Johannesburg as part of the [FRACTAL](#) consortium.



### About FRACTAL

[FRACTAL](#) (Future Resilience for African Cities and Lands) aimed to understand the decision context and the climate science required to contribute to climate-resilient development in nine southern African cities (Blantyre, Durban, Cape Town, Gaborone, Harare, Johannesburg, Lusaka, Maputo, Windhoek). The FRACTAL team aimed to contribute to an advanced understanding of scientific knowledge about climate processes, regional and local climate trends to improve understanding of southern Africa's climate and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of 5 to 40 years).

The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders were co-producing relevant knowledge that aimed to support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

### Highlights from South Africa

- Self-funding meant cities held autonomy regarding work in their city, but were involved in larger project meetings to share lessons with other FRACTAL cities.
- The Embedded Researcher approach in Durban and participation in [city learning exchanges](#), resulted in FRACTAL contributing to [biodiversity planning in the city](#).
- [Climate Risk Narratives](#) were developed for Cape Town to update projects for the city, and FRACTAL lessons informed support to the City during the 2015-2018 drought.
- Lessons learned from Cape Town drought have been shared with other FRACTAL cities.

## Durban

In Durban, FRACTAL, led by the University of KwaZulu-Natal used the [Embedded Researcher](#) (ER) approach to focus particularly on the impacts of climate change on biodiversity. The ER for Durban worked with the Environmental Planning & Climate Protection Department (EPCPD) from the City of eThekweni as well as academics from the University of KwaZulu Natal and FRACTAL. Integrating climate information into biodiversity planning proved to be challenging in Durban due to difficulties in identifying entry points and creating [receptivity](#) for officials to take up climate information. Gaps in climate information and data also resulted in challenges for the city.

### The Embedded Researcher Approach

[The Embedded Researcher \(ER\) approach](#) was adopted by FRACTAL to bridge the science-policy divide (most notably bringing climate science to decision makers). Early career researchers from local universities were appointed as ERs to work within government spaces (e.g. municipalities) in Southern African cities. The aim of this approach was to [co-explore and co-produce knowledge](#), create and sustain learning opportunities to integrate climate information into cities, strengthen urban governance networks and share lessons between African cities and beyond.

The ER undertook a literature review to understand the ways in which climate information is most commonly used to plan for and manage biodiversity conservation. The ER also compared the activities of EPCPD to recommended practices in global literature. The work of the ER culminated in a monitoring framework to establish and implement a co-produced, comprehensive, adaptive biodiversity monitoring framework/programme in the City of eThekweni, which takes into account long term (climate change) and short term (immediate environmental change) impacts, and draws from various specialists and partnerships.

Through further engagements with the planning process in Durban, the ER was able to support partnerships forming between the Development Planning Department and the Durban Botanical Trust education officers, the Strategic Spatial Planning branch, the Land Use Management Branch, the climate protection branch, Cities Fit For Climate Change (GIZ) and the Municipal Institute for Learning to pilot leadership training on climate change. Furthermore, the ER process improved data sharing and management between stakeholders, which contributed to the creation of a new post for a data manager.

## Cape Town

The Climate Systems Analysis Group (CSAG), the lead implementing institution in FRACTAL was actively involved

in supporting the City of Cape Town during the unprecedented three-year drought and subsequent water crisis between 2015-2018. Considering CSAG's role in the consortium, many activities were informed by FRACTAL lessons. Furthermore, [lessons learned from the Cape Town](#) drought were shared in several other FRACTAL cities (e.g. Maputo, Lusaka, and Windhoek). CSAG contributed to researching climate change attribution, testing water supply models, developing Climate Risk Narratives and [improving climate-related terminology](#) to support the response of the City to the water crisis. This included the development of the 'Big Six Monitor' showing water levels in major supply dams in the recent past and immediate future. CSAG is interested in playing a role in developing a climate change think tank within the city, to further develop their information distillation processes.

At the beginning of FRACTAL, [Climate Risk Narratives](#) were produced for the City of Cape Town, as part of a move to update the climate projections for the city. These Climate Risk Narratives were developed by scientists who then engaged with the city. These engagements sparked useful discussions between scientists and decision-makers with regarding the city's future.

### Climate Risk Narratives

[Climate Risk Narratives](#) are stories of various climate futures that have ideally been co-produced using a diversity of knowledge sources and perspectives. The co-production of knowledge uses climate information with stories of plausible futures from a wide range of stakeholders to bring together climate information and local knowledge into Climate Risk Narratives that can broaden conversations across sectors.

The process supports informed decision-making across sectors through learning exchanges and improving understanding of climate change. Climate Risk Narratives should be updated to reflect ongoing interactions between climate, social and environmental aspects.

## Johannesburg

In Johannesburg, FRACTAL partners from the University of Witwatersrand worked with the City of Johannesburg with the intention of [building relationships and gaining insight into the governance](#) and development within the City. The FRACTAL contact point in Johannesburg has played a key role in developing the updated Climate Adaptation Plan for the City and has shared extremely valuable insights with the broader FRACTAL team. The Climate Change Adaptation Framework reports have been presented to government committees in the City. These were well received indicating the possibility for continued engagement between researchers and government officials on climate change issues.

## Selected Additional Resources

- Ndebele-Murisa, M.R., et al. 2020. [City to city learning and knowledge exchange for climate resilience in southern Africa](#). PLOS ONE, 15(1), p.e0227915.
- Pretorius, L. et al. 2019. [An Embedded Researcher approach to integrate climate information into decision making in southern African cities: lessons from FRACTAL](#). FRACTAL Working Paper. University of Cape Town, South Africa.
- Scott, D. and Taylor, A. 2018. [Receptivity and judgement: expanding ways of knowing the climate to strengthen the resilience of cities](#). FRACTAL Working Paper. Cape Town, South Africa
- Steynor, A and Lee, J. 2018. [Towards developing a common language for climate change in the City of Cape Town](#). FRACTAL Working Paper. Cape Town, South Africa.


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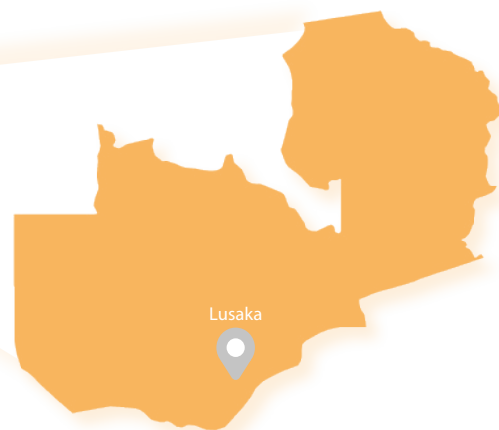
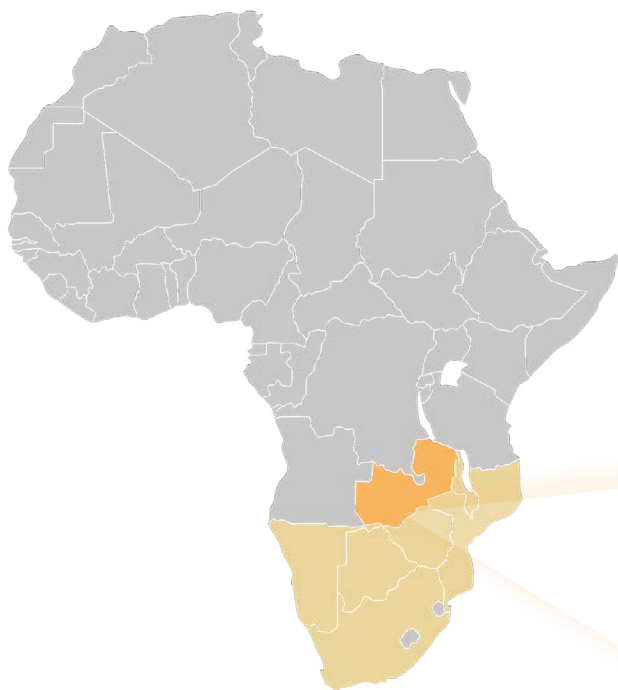
FRACTAL Annual General Meeting 2019 in Cape Town, South Africa. Credit: CCKE, FCFA

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## Summary of FCFA work in Zambia

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's research in Zambia, was carried out in the capital city, Lusaka, by the [FRACTAL](#) consortium and led by the University of Zambia.



### About FRACTAL

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The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

### Highlights from Lusaka

- [City Learning processes](#) focused on water and climate change in the city, specifically the themes of water supply, groundwater pollution, groundwater levels and flooding in peri-urban areas.
- Learning Labs and City Dialogues were used to [co-explore issues](#) around climate and water.
- [Embedded Researcher](#) seconded from city government supported learning processes and co-production of policy briefs.
- [Climate Risk Narratives](#) provided city with three possible future climate scenarios
- [City-to-City learning](#) exchanges provided decision-makers with opportunities to learn from other Southern African cities.

## City Learning processes in Lusaka

In Lusaka, the FRACTAL team utilised [Learning Labs](#) as a mechanism to engage diverse stakeholders and [co-explore climate risks](#) within the City and co-produce knowledge for solutions. The [Embedded Researcher approach](#) was adopted by FRACTAL to bridge the science-policy divide (most notably for climate science). A Lusaka City Council official was appointed in a research and coordination role for the duration of the project. The Embedded Researcher in Lusaka played a vital role in co-production processes through facilitating learning and strengthening links between research and governance. Five Learning Labs were carried out between 2016 and 2018 that focused on issues of water and climate change in the city.

The [first Learning Lab](#) in Lusaka invited stakeholders from the water and energy sectors of the City to explore the burning issues within these cities, alongside NGOs and civil society organisations. The first learning lab sparked interest in learning about climate change and considering climate information in planning. The idea of producing policy briefs to guide decision-making on climate change issues stemmed from an in-country discussion after the first lab. The initial lab was also followed by a water-specific [City Dialogue](#), which revealed the need for better knowledge sharing and improved access to climate data. To support the use of climate change information in decision-making spaces, FRACTAL hosted a [training workshop for city councillors](#) in 2017.

The [second Learning Lab](#) continued engagements related to Lusaka's water issue and stakeholders identified knowledge gaps in city processes associated with planning infrastructure, research, and health. Field trips to an informal settlement (during the second Learning Lab), and the Shaft 5 borehole in Lolayi, and the Lolanda treatment plant in Kafue (during the third Learning Lab) supported experiential learning alongside the Learning Labs; These trips allowed participants to see the reality of water issues in Lusaka, and ask questions to those managing the water sources.

During [the third Learning Lab](#) stakeholders further engaged in the water issues and began to co-explore solutions for water supply, water quality, groundwater extraction, and flooding. Lessons from inter-city learning exchanges between Windhoek and Lusaka were presented to stakeholders to further discussion around how cities can address water issues. The Learning Lab concluded with an update of the [Climate Risk Narratives](#) that had been co-produced to represent three possible futures for Lusaka.

The [fourth Learning Lab](#) aimed to further explore some of the issues which had previously been identified and would

## City-to-city learning

The Windhoek-Lusaka Learning Exchange Programme funded by the Small Opportunity Grants facilitated exchanges between the City of Windhoek and the City of Lusaka.

Discussions took place around each city's burning issues and how current policies and plans could be improved through the inclusion of climate information. Exchanges between Durban, South Africa and Harare, Zimbabwe facilitated further [city-to-city learning](#). The city exchanges allowed for sharing of knowledge and experience on issues of water and climate change.

be developed into co-produced policy briefs. The key issues investigated during this Learning Lab were groundwater abstraction and water quality. This was supplemented with a water story from Cape Town, South Africa. [Two dialogues](#) with the city followed this Learning Lab. The governance dialogue in Lusaka allowed stakeholders to consider decisions that influence the water supply in the city and unpack climate terminology. A [Talanoa Dialogue](#) was hosted alongside the FRACTAL governance dialogue (framed under COP23) as a way to convene all levels of government to explore their National Determined Contributions ahead of COP24.

The whole learning lab process in Lusaka culminated in four policy briefs on [flooding](#), [groundwater](#), [water supply](#) and [water quality](#). These policy briefs were disseminated at the final Learning Lab. Discussions were held around how these briefs could influence policy and decision-making, including through the development and implementation of the Lusaka Water Security Action and Investment Plan (LWSAIP). The information from these briefs has been integrated into community training to support the implementation of the LWSAIP.

## Information distillation in Lusaka

FRACTAL's [climate information distillation framework](#) was developed as a humble science approach allowing for open interrogation of problem framing and assumptions. Climate Risk Narratives were used as entry points for engagements around climate risks in Lusaka. Water Evaluation and Planning (WEAP) systems, were developed with stakeholders in a bottom-up manner to assess future changes in water supply and hydropower generation on the Kafue River. Climate Risk Narratives defined three plausible futures for Lusaka, namely: (1) hotter and drier, (2) warmer and more erratic and extreme rainfall, and (3) warmer and more extreme rainfall.



## Selected Additional Resources

- Mwalukanga, B., et al. 2019. [Exploring perspectives that underpin decisions for southern African urban development - Insights from Lusaka, Zambia](#). FRACTAL Think Piece. University of Cape Town, South Africa.
- Mwamba, D. et al. 2019. [Lusaka Water Supply and Sanitation](#). FRACTAL Brief. University of Cape Town, South Africa.
- Mwamba, D. et al. 2019. [Lusaka City Faced with Severe Consequences of Declining Groundwater Levels](#). FRACTAL Brief. University of Cape Town, South Africa.
- Nchito, W. et al. 2019. [Lusaka Preparing for Increased Flooding](#). FRACTAL Brief. University of Cape Town, South Africa.
- Ndebele-Murisa, M., et al. 2020. [City to city learning and knowledge exchange for climate resilience in southern Africa](#). PloS one, 15(1), p.e0227915
- Nyanga, P. et al., 2019. [Lusaka Groundwater Pollution: Key Threats to Water Security & Health](#). FRACTAL Brief. University of Cape Town, South Africa.
- Pretorius, L. et al. 2019. [An Embedded Researcher approach to integrate climate information into decision making in southern African cities: lessons from FRACTAL](#). FRACTAL Working Paper. University of Cape Town, South Africa.


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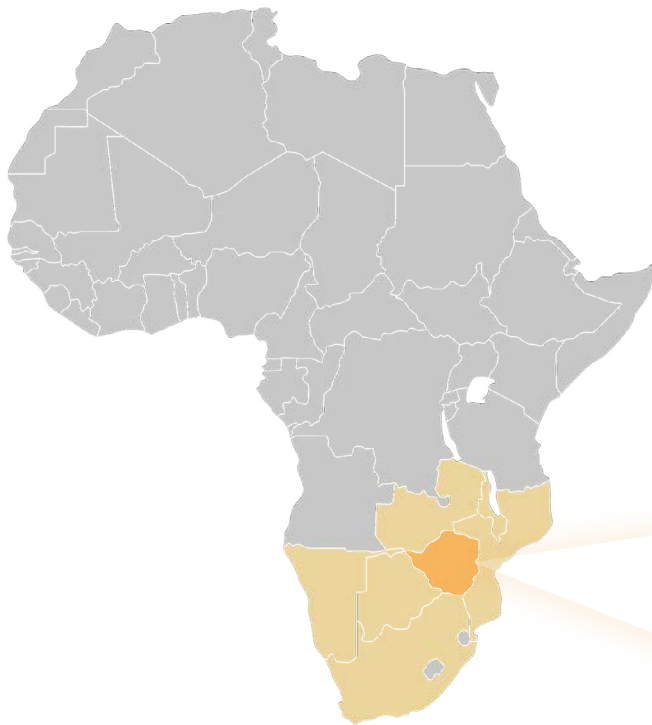


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## Summary of FCFA work in Zimbabwe

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's research in Zimbabwe was conducted in the capital city, Harare and was led by FRACTAL consortium partner Chinhoyi University of Technology.



### Highlights from Harare

- Less engagement than other FRACTAL cities, with research focused on transferability of relevant climate knowledge
- Work included START's Africa Global Environmental Change (GEC) project exploring the City's climate-water-energy nexus to understand climate vulnerability and inform policy and practice in Harare City Council
- Embedded Researchers helped bridge divide between science and practice
- Climate Risk Narratives, Learning Labs and a Think Tank helped explore decision pathways, particularly related to the upgrades to the Morton Jaffray Water Treatment Plant.
- FRACTAL partly responsible for engagements on improving planning and mainstreaming climate adaptation plans at the city level.

### About FRACTAL

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The project engaged with scientists, engineers, government representatives and other stakeholders. Working together, the researchers and stakeholders are co-producing relevant knowledge that will support resilient development pathways and enable decision-makers to better integrate pertinent climate knowledge into their resource management decisions and urban development planning.

## Exploring water issues in Harare

Prior to FRACTAL's involvement in Harare, few city-focus climate knowledge projects had been carried out. FRACTAL played a pivotal role initiating stakeholder reflection on decision-making processes involving climate information. The development of [Climate Risk Narratives](#) for Harare initiated this reflection by understanding the [perceptions of climate change](#) among decision-makers. Through the appointment of two [Embedded Researchers](#) (ERs) in Harare City Council, a new approach was implemented to focus on building relationships and [receptivity of stakeholders](#) to issues relating to climate variability and climate change. The ERs were responsible for investigating the city's [climate-energy-water nexus](#), as part of START's GEC project, to further the understanding and engagements around cross-cutting issues of the City's water and energy sectors.



*Water supply is severely restricted by droughts and ageing infrastructure in Harare.*

Through increasing the receptivity of stakeholders, [greater awareness and willingness for engagement](#) and exploration of these cross-cutting issues emerged. Funding from the Small Opportunities Grants supported [learning exchanges](#) with Windhoek and Lusaka, which offered stakeholders from Harare the opportunity to [share and learn from the experiences on best practices](#) in other southern African cities. This fostered new approaches for effective collaboration in the water and energy sectors. The increased engagement and appetite for shared learning within the city led to researchers and the Zimbabwe National Water Authority (ZNWA) proactively seeking additional funding to ensure the continuation of the ERs.

## The Embedded Researcher approach

The [Embedded Researcher \(ER\) approach](#) was adopted by FRACTAL to bridge the science-policy divide (most notably for climate science). Early career researchers from local universities were appointed as ERs to work within government spaces (e.g. municipalities) in Southern African cities. The aim of this approach was to co-explore and co-produce knowledge, create and sustain learning opportunities to integrate climate information into cities, strengthen urban governance networks and share lessons between African cities and beyond.

## Harare Think Tank

A [Think Tank](#) session held under FCFA's Innovation Fund to explore perspectives that underpin decisions in Harare. A small group of decision-makers specifically related to the upgrade of Morton Jaffray waterworks in Harare were engaged through semi-structured discussions. The Think Tank revealed the City operates primarily on a crisis decision-making basis, suffers from political interference, lacks policy guiding decision-making processes in the water sector, and lacks financial resources. FRACTAL's principles of collaboration, co-production, and co-exploration have therefore been noted to be critical for bridging the gap between researchers and decision-makers in Harare.

## The Morton Jaffray Water Treatment Plant

Harare City Council is mandated to provide potable water to the Greater Harare area. However the city infrastructure designed to supply 350 000 people is severely under capacity to provide water for the growing population. The water infrastructure is also affected by climate as water supply is limited during droughts and contamination issues arise for periods of above average rainfall. The Morton Jaffray Treatment Plant, originally built in 1956, was upgraded in 1994 to increase the capacity of the plant, and again in 2010 as a response to a cholera outbreak. Despite these costly upgrades, the plant is still operating at a 58% capacity and is unable to sufficiently provide water to households across the Greater Harare area.

In order for the Morton Jaffray plant to sufficiently supply water to the City and be climate resilient, upgrades need to be proactive rather than reactive in times of crisis. FRACTAL's Embedded Researchers engaged with discussions around future upgrades to the plant to [explore the decision-making processes around water in the City](#) and to provide key climate information into considerations for the upgrade.

## Selected Additional Resources

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Ndebele-Murisa, M. & Mubaya, C. 2019. [Decision-making and climate resilience in the water sector of Harare](#). Policy Brief.

Pretorius, L. et al. 2019. [An Embedded Researcher approach to integrate climate information into decision making in southern African cities: lessons from FRACTAL](#). FRACTAL Working Paper. University of Cape Town, South Africa.

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## Summary of FCFA work in Rwanda

[Future Climate for Africa](#) (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA's work in Rwanda was carried out by the [CCKE](#) unit for the programme. The activities focused on integrating climate information into the design of projects for the [Rwanda Green Fund](#).



### About the CCKE Unit

The [Coordination, Capacity Development and Knowledge Exchange \(CCKE\) unit](#) performs several functions to increase the overall impact of the FCFA programme, including:

- Coordinating activities to promote learning and knowledge exchange between research partners including workshops, conferences, webinars, and meetings.
- Coordinating and compiling reporting to the donors and the annual review of the programme.
- Gap filling research was commissioned as the programme progressed and new research questions emerged.
- Research and travel grants were issued and managed for early career researchers from the FCFA research consortia through the capacity development mechanisms of the FCFA Innovation and Mobility Fund.
- Generating and disseminating content to communicate FCFA work and key research messages to wider audiences through the FCFA website, Twitter account, news stories, press releases, briefs, and other publications.

### Highlights from Rwanda

- [Climate change fact sheet](#) for Rwanda, and subsequently a [risk screening tool](#) for agriculture projects in FONERWA was developed.
- Subsequent engagements during FONERWA proposal development workshops played a key role in facilitating the inclusion of climate change considerations within project proposals.
- Further work in Rwanda supported by FCFA, has examined mainstreaming of climate information in the [tea and coffee sectors](#). This identified challenges related to adaptation in Rwanda and what is needed to address these challenges.
- Engagements in Rwanda are ongoing, with the DFID Rwanda country office requesting support from the DFID Climate Mainstreaming Facility.

## Developing a Climate Risk Screening Tool for FONERWA

The work in Rwanda is centred on developing the capacity of the FONERWA (Rwanda's climate and environment fund) project appraisal team to screen project proposals. This would include a stronger review of applications for climate risks, and provide FONERWA with a reference base for project developers so that climate information is better understood and incorporated into project design and implementation. The first output was a generalized [climate change fact sheet](#), as requested by FONERWA, to start the conversation around climate change and risks amongst the FONERWA team and project developers. The fact sheet was presented to representatives from FONERWA and Rwanda Meteorology Agency during a workshop. Following limited engagement with climate information from the fact sheet and in the workshop, it became apparent that the real need is for climate impact information that can be communicated with the project developers.

This led to the development of a [risk-screening tool](#) (focusing on agriculture) that provides relevant impact information for project developers and a reference base for critiquing proposals for FONERWA staff and reviewers. A second more informal workshop, where the risk screening tool was presented, was more effective in communicating the content as many of the participants were able to use the tool to better understand and relate to climate impacts, as a result, many believed the workshop was more interesting and valuable. The awareness and relevance of incorporating climate information into projects and fund processes were found to be more effective when detailing climate impacts with climate change information as context and not the other way around.



Participants engaging with the climate risk screening tool at a FONERWA workshop. Credit: Julio Araujo

Following the second workshop, direct engagement in the FONERWA Proposal Development Workshop (PD Clinic) proved beneficial in highlighting risks and the relevance of climate information. This resulted in an increase of project proposals which had incorporated climate elements in some form. This was likely attributed to the emergence of local champions within FONERWA who prioritised suggestions to include climate risks in proposals. After the engagement produced tangible outcomes, Meteo Rwanda informally requested to be involved in the following training workshop and PD Clinic.

## Mainstreaming Climate information into tea and coffee sectors of Rwanda

During the [scoping phase](#) of FCFA, the Global Climate Adaptation Partnership (GCAP) was commissioned to carry out a pilot study in Rwanda to examine [the use of climate information to achieve long-term development goals](#). Part of this Rwanda pilot study focused on mainstreaming climate change within the country's [tea and coffee sectors](#). These sectors were chosen as case studies due to their importance in the economy and their vulnerability to climate variability. The study identified three building blocks to address the challenges of adaptation such as uncertainty. These include (1) implementing low-regret options which address current climate sensitivity and improve future resilience (e.g. planting shade trees or intercropping), (2) examining near-term decisions with long lifespans (e.g. the expansion of tea plantations), and (3) considering future risks that may emerge (e.g. through research and monitoring and evaluation). Key findings from the tea and coffee work were outlined in a [video](#) produced by the CCKE.

## DFID Rwanda Call Down support from the DFID Climate Mainstreaming Facility

The DFID Climate Mainstreaming Facility has been established to provide on-demand support to DFID country offices, regional and central departments to help advance DFID's goals on tackling climate change. The Facility is supported through FCFA's Accountable Grant, with the CCKE in partnership with Paul Watkiss Associates forming the Facility Management Team.

In 2020, the DFID Rwanda country office submitted a request for support to review the International Climate Finance portfolio of the country office. The request was particularly seeking guidance for ICF indicators and allocations for their Future of Agriculture in Rwanda (FAIR), Exiting Poverty in Rwanda (EPR) and TradeMark East Africa (TMEA) programmes. Through the Climate Mainstreaming Facility, there will be continued engagement and support for the country office.

## Selected Additional Resources:

Araujo, J.A., Kagabo, D., Kabirigi, M., Zinyengere, N. and Owiti, Z. 2018. [FONERWA climate risk screening tool: Agriculture](#). Future Climate for Africa. Cape Town, South Africa.

Araujo, J.A., Zinyengere, N., Marsham, J. and Rowell, D. 2016. [Rwanda country factsheet: Climate information for an uncertain future](#), in L. Joubert (ed.), Africa's climate: Helping decision-makers make sense of climate information. Climate and Development Knowledge Network. Cape Town, South Africa.

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Watkiss, P. 2015. [Using climate information to achieve long-term development objectives in Rwanda](#). Policy Brief. Future Climate for Africa. Cape Town, South Africa.

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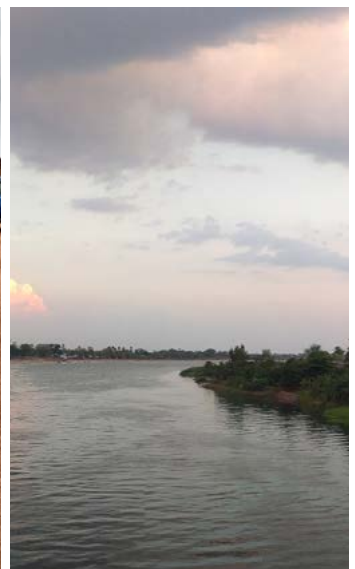
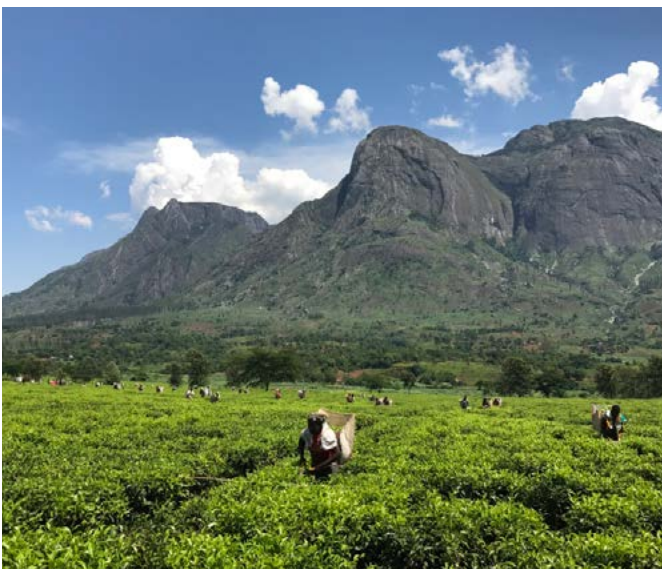
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UMFULA  
Briefs



**The current and future climate of central and southern Africa**  
What we have learnt and what it means for decision-making  
in Malawi and Tanzania

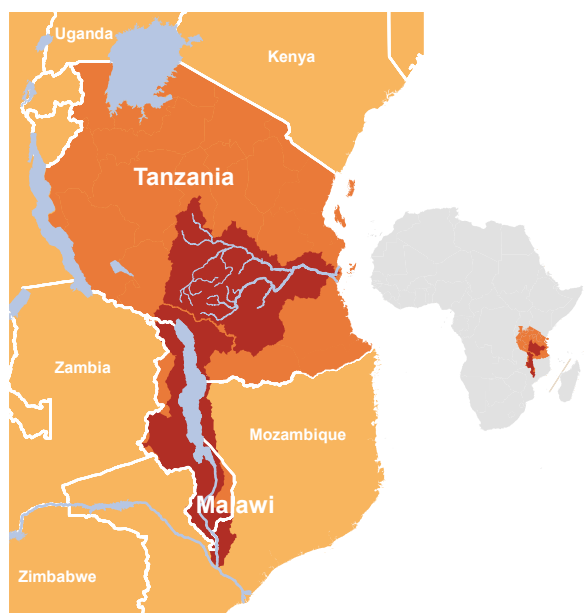


# ABOUT THE FUTURE CLIMATE FOR AFRICA PROGRAMME AND THE UMFULA PROJECT

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science can inform management of future climate risks and has an impact on human development across the continent. The programme is funded by the UK's Department for International Development (DfID) and Natural Environment Research Council (NERC) and is implemented by five consortia and a Coordination, Capacity and Knowledge Exchange Unit (CCKE).

UMFULA (Uncertainty Reduction in Models for Understanding Development Applications) is one of the consortia, looking at central and southern Africa, with case studies in Malawi and Tanzania focusing on managing water with increasing demands for agricultural production and hydropower (the so-called water–energy–food nexus) under a changing climate.

UMFULA has taken an interdisciplinary approach and has collaborated extensively with key government agencies in Malawi and Tanzania to design climate information relevant for decision-making. In Malawi, our engagement has been led by Lilongwe University of Agriculture and Natural Resources and the Malawi University of Science and Technology, and in Tanzania by Sokoine University of Agriculture.



*UMFULA case studies in Malawi and Tanzania, highlighted in dark red*

Among those involved in Malawi are the Department of Climate Change and Meteorological Services (DCCMS), the Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services), the Department of National Parks and Wildlife, the Electricity Supply Corporation of Malawi Ltd. (ESCOM), the Electricity Generation Company Ltd. (EGENCO), the Shire River Basin Management Programme (SRBMP) and operators of the Kamuzu Barrage.

In Tanzania, key stakeholders include the Rufiji Basin Water Board (RBWB), the Tanzania Electricity Supply Company (TANESCO), the Ministry of Water and the Tanzania Meteorological Agency (TMA).

The UMFULA team is immensely grateful to these organisations for engaging with us, and we hope that our research will support their planning for climate change.



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*Ifunda wetland converted into maize fields, Rufiji, Tanzania, 2018*

## SUMMARY

UMFULA has addressed questions of climate science, climate impacts and decision-making processes for adaptation, including:

- How does the climate of central and southern Africa work? And how well do climate models represent the key processes responsible for climate?
- How might the climate of central and southern Africa change in future decades out to ~2050 and how sure are we about the projected changes?
- To what extent can decision-making approaches incorporate climate change uncertainties within investment decisions that cut across the water, energy and food sectors?
- How does the political and institutional environment influence the usefulness and usability of climate information for adaptive decision-making?

Our results show:

- Understanding the likely future characteristics of climate risk is a key component of adaptation and climate-resilient planning, but given future uncertainty it is important to design approaches that are strongly informed by local considerations and are robust to uncertainty, i.e. options that work reasonably well across a range of uncertain future climate (and other) conditions.
- Choosing the right tools and approach for climate risk assessment and adaptation to suit the scale of the decision allows a suitable trade-off between robustness and resources required (time and expertise) for analysis.
- In the medium term, policy decisions require careful cross-sectoral planning, particularly in cases involving large investments, long life-times and irreversibility, where there is a strong argument for assessing resilience to future climate change (for example around water, energy and food in Malawi and Tanzania).
- The process of co-production of knowledge by researchers and wider stakeholders contributes to building societal and institutional capacity to factor climate risks into long-term planning. It also builds the capacity of researchers to better understand real world decision contexts in which climate change is one of many important factors.

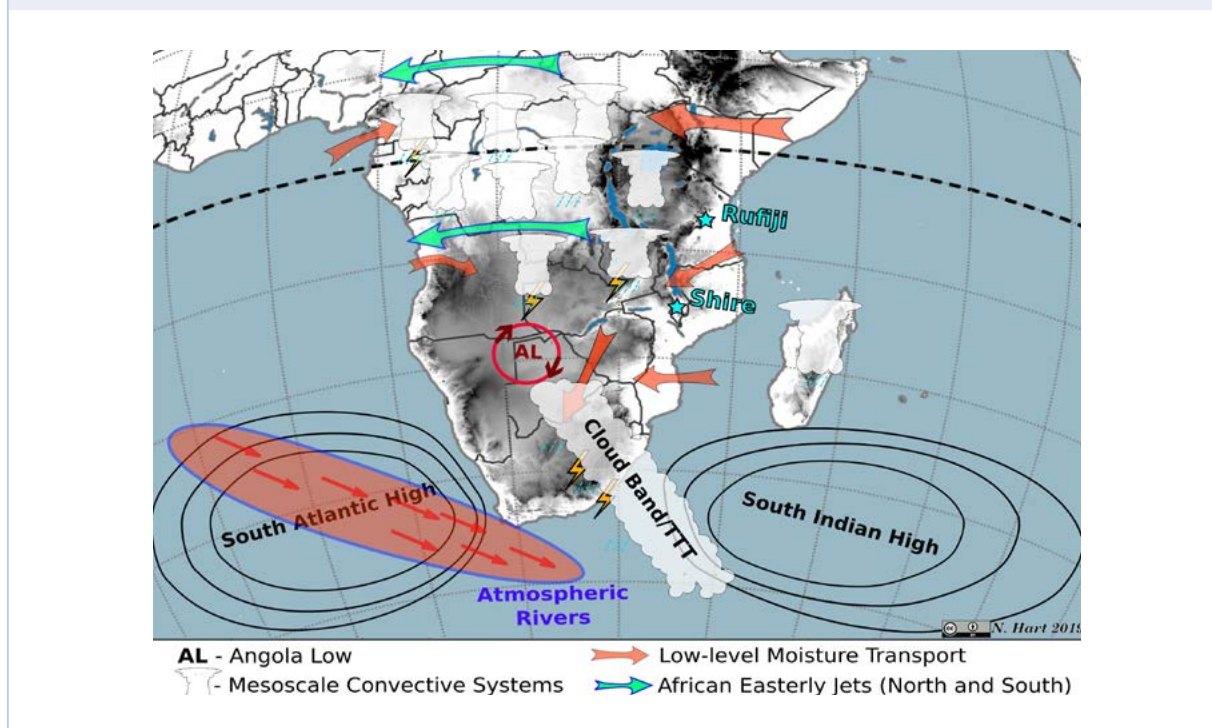


*Lake Malawi showing water levels on the rock, 2017*

# IMPROVEMENTS IN THE UNDERSTANDING OF RAINFALL REGIMES IN CENTRAL AND SOUTHERN AFRICA

UMFULA research has generated key advances in the understanding of the varied processes and features of central and southern Africa’s climate system (Figure 1). With better understanding of the key features of the circulation we can analyse the mechanisms by which climate models simulate the climate system in order to evaluate the credibility of the modelled future climate. This approach is in contrast to more dated approaches whereby model output is simply statistically summarised. We focus on rainfall as the most important challenge for models and the most important variable for the water–energy–food nexus.

Figure 1: Central and southern Africa’s climate is characterised by a range of features and processes that the UMFULA team has studied to advance understanding of the climate system. (Source: Neil Hart)



## Cloud bands

Cloud bands are important because they give rise to widespread rainfall and are responsible for a significant proportion of extreme events. We have improved understanding of the ways in which the El Niño Southern Oscillation (ENSO) circulation system affects rain over southern Africa, in particular the relationship with cloud bands (Hart et al., 2018; see Figure 1). We have found that 150–200% more cloud bands develop during La Niña seasons. During El Niño events fewer cloud bands develop over southern Africa, while they are 150% more likely over the Indian Ocean to the east of Madagascar.

## Extreme events: Cape Town's drought

During the lifetime of the UMFULA project, Cape Town experienced a severe drought which forced the city's industrial sector and residents to implement significant demand management to avoid running out of water in 2018, commonly referred to as "day zero". One key feature of the drought was the competition between urban settlements and agricultural sector water demand – a tradeoff that ultimately featured prominently in both city and provincial response (Archer et al., 2019).

We found a relationship between poleward shifts in the South Atlantic Anticyclone and moisture corridors during 2015–17 and the Cape Town drought (Sousa et al., 2018). Changes in the frontal systems in the South Atlantic that bring the winter rainfall to Cape Town – in terms of how often they occur, where they occur, and how they move over time – can also be linked to the recent dry conditions (Burls et al., 2019). It is likely that such dry conditions will become a more regular occurrence in the future, particularly during the early winter months, but also with a possibility of more frequent dry spells during the winter rainfall season (Mahlalela et al., 2018).

Conditions in the South Atlantic Ocean also play a role in determining when there is high rainfall. In the last three decades, atmospheric rivers (ARs) (long and narrow regions in the atmosphere transporting water vapour) across the South Atlantic were responsible for eight of the top nine rainfall events in the Western Cape region of South Africa (Blamey et al., 2018). The moisture that leads to these ARs contributing to Western Cape rainfall can be traced all the way back to the Amazon region in South America (Ramos et al., 2019).

## Regional circulation features: the Angola Low and South Indian Ocean high pressure systems

We have investigated a previously under-studied regional circulation feature that forms during the summer season – the Angola Low – which is crucial to the southern African region (see Figure 1). We have evaluated how the feature develops through the season (Munday and Washington, 2016; Howard and Washington, 2018) and why it tends to be semi-stationary over southern Africa (Howard and Washington, 2018). Models that are excessively wet tend to simulate an Angola Low that is too intense.

We have also established how features of the regional circulation, such as the Angola Low and the South Indian Ocean High pressure systems, interact with El Niño events to modify rainfall amounts over southern Africa (Howard and Washington, 2019). El Niño events do not all influence southern African climate in the same way. The 2015–16 drought over southern Africa was the most extreme on historical record, and associated with El Niño, while during the equally strong 1997/98 El Niño event normal rainfall levels occurred. The difference between the events has been traced to the intensity of the Angola Low (Blamey et al., 2018).

## The Congo Basin

The Congo Basin in central Africa is a critical driver of the global tropical atmospheric circulation. However, very little is known about the Congo Basin and the viability of its extensive tropical rainforests in a warmer world. Using climate models, we have assessed the key moisture transport pathways into the central Africa region and established how the strength of this moisture transport modulates models that are wetter over the basin compared with those that are drier (Creese and Washington, 2016; 2018).

## ASSESSING CONFIDENCE IN MODEL SIMULATION OF CLIMATE

An understanding of the key features of the climate, and how they work, is critical in order to be able to effectively model climate and have confidence in projected future climates. UMFULA has advanced an existing challenge – the ability of models to capture these key features that drive the climate in central and southern Africa.

### **More accurate simulation of cloud bands with convection-permitting models**

Correctly simulating the seasonal cycle of cloud bands is a challenge for climate models as it requires adequate representation of sub-daily subtropical convection and the subtropical upper level wind stream over southern Africa (Hart et al., 2018). We have identified that the simulated annual cycle of cloud bands in models is generally too flat without the dominant summertime peak that we see in reality, but that the simulation improves markedly in a very high resolution climate model which simulates convection more directly (Hart et al., 2018). Convection-permitting models thus have the potential to more accurately represent African rainfall patterns.

### **Why models simulate too much rainfall in southern Africa**

We have also identified two reasons that models simulate too much rainfall in southern Africa. Models with a stronger Angola Low simulated enhanced northerly moisture transport and an increased rate of moisture convergence over the interior of southern Africa (Munday and Washington, 2016). Another reason is that of an excessive flux of water vapour from the Indian Ocean. This arises because models do not accurately capture the role of topography in limiting the supply of moisture (Munday and Washington, 2018; Barimalala et al., 2018).

### **Projections of rainfall change in central Africa**

Over central Africa, we found that models that historically project more rainfall import more water vapour from surrounding oceans (e.g. Creese and Washington, 2016; 2018). We question the driest rainfall change signals during the rainy season in the east Congo Basin as the models that historically project less rainfall fail to capture the vertical structure of the African Easterly Jet, which is a strong wind around 5km above ground over northern and southern central Africa (Creese et al, 2019). The largest change in rainfall over central Africa occurs in the December to February dry season when models simulate drying. Confidence in this projected drying remains low because the range of average rainfall from the driest to the wettest models is very large compared with the small amount of change. Furthermore, the drying in central Africa is associated with remote connections to the rainfall system over the tropical west Pacific and we have a limited understanding of this connection.



*Sisal plantation, Morogoro, Tanzania, 2018*



### The first Lidar system to study winds in central Africa

Evaluating climate models requires observational data. This is, however, lacking over much of central Africa where there have historically been few weather stations. To address this absence, a Lidar instrument has been deployed in Cameroon as part of the UMFULA project. We believe it is the first Lidar installed in central Africa to study winds. The Lidar, an automatic weather station recording high time resolution parameters, including surface temperature and rainfall and daily measurement of temperature, humidity and pressure through the depth of the atmosphere from weather balloons, will, we hope, provide new insights about the dynamics of the region.

A Lidar is a remote-sensing instrument which is able to retrieve profiles of three-dimensional wind by detecting the back scattering of a laser beam emitted by the instrument. The beam is scattered off small aerosol particles. Movement of the particles by the ambient wind introduces a Doppler shift in the emitted beam frequency. That shift can be traced to the particle movement and hence wind speed and direction recovered by the instrument. Since the time taken for the beam to be returned to the instrument is measured, the height of the wind responsible for causing the Doppler shift can also be calculated. It was configured to record wind profiles every 15 minutes. Up to September 2019, more than 26,000 wind profiles, many to a height of 3 or 4km, have been recorded.



*The Lidar in Cameroon, 2019*

### Effects of the El Niño Southern Oscillation on southern African circulation patterns

The El Niño Southern Oscillation (ENSO) is the single biggest control on rainfall in Southern Africa, but the link is complex. Our improved insights into the ENSO show how a strong Pacific El Niño event affects regional circulation patterns in southern Africa. This linkage of African climate with a phenomenon that takes place on the other side of the globe (known as a teleconnection) highlights one challenge that coupled atmosphere–ocean models face in effectively simulating the effect of ENSO on African climate (Blamey et al., 2018). We also noted that human-caused warming results in increased risk of high intensity drought events – of the intensity experienced over southern Africa in 2015–16 related to the major El Niño event (Kolusu et al., 2019).

### Projections of climate change in southern Africa

Early summer drying over southern Africa is one of two large land-based climate change rainfall signals regarded by the Intergovernmental Panel on Climate Change (IPCC) (2014) as robust. We have confidence that extreme drying is unlikely (e.g. Munday and Washington 2017; 2018; 2019), because the extreme drying occurs in climate models that simulate far too much rainfall in the current period. These models dry out in the future to a climate regime that is very similar to current climate. However, models with a current rainfall regime that is more realistic simulate drying, but not extreme drying.

## Tailored future climate information for the tea sector in Malawi

Tea is a key sector for both the economy and livelihoods of people in Malawi. It is the country's second largest export commodity and largest private sector employer. However, the amount of tea produced and the quality of crop are contingent upon rainfall and temperature. Climate change thus poses a potential risk to the sector.

In particular the tea crop is sensitive to changes in temperature. Heat stress is more prominent across the tea growing regions during the dry season (May to November), leading to increased incidences of leaf sun-scorch, especially for susceptible cultivars. Based on insights from large tea estates and smallholder farmers in Mulanje and Thyolo districts, and the Tea Research Foundation of Central Africa, we have tailored future climate projections using station observations, CMIP-5 models and the new convection-permitting pan-African climate model (CP4 Africa) simulation.

Moving beyond understanding the mean changes in future rainfall and temperature that models typically project, we analysed changes for a set of tea-specific metrics for dry and wet seasons that could affect tea yield or quality such as heat stress and dry spells (Vincent et al., submitted). Co-producing such tailored information enables the tea sector to identify appropriate adaptation options to reduce climate risk.



*Climate change adaptation prioritisation workshop with smallholder farmers, 2018*



*Tea plantation under irrigation, Malawi, 2018*

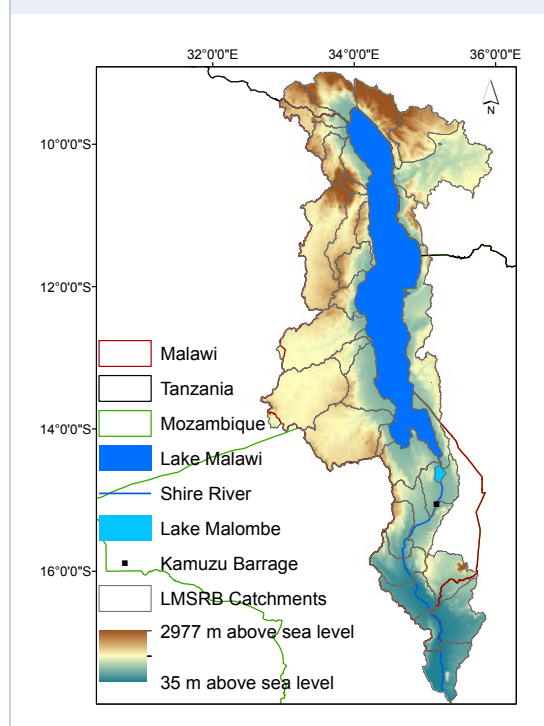
# WHY INCORPORATING UNCERTAINTY INTO DECISION-MAKING APPROACHES IS ESSENTIAL FOR ADAPTATION PLANNING IN MALAWI AND TANZANIA

Malawi and Tanzania were the case study countries adopted by the UMFULA project. While these two countries are representative of the Southern African Development Community (SADC) region in terms of threats posed by climate change to development trajectories, their geographical location, between major climate systems, makes it difficult to confidently project future rainfall conditions. This is because the response in the case study area depends on how the climate of the key regions (southern Africa, eastern Africa and central Africa) changes as well as how broader geographical influences change (e.g. the ENSO) – these all remain highly uncertain.

New scientific insights into the region's climate advance our understanding of drivers of variability and inform how much confidence we can place in the model projections of future climate. However, expecting that climate models will be able to generate projections with much higher confidence, as well as waiting for such outputs, is not the best approach for Malawi or Tanzania, particularly in cases where major decisions are being made now about infrastructure with long lifetimes. Instead, to make adaptive decisions that reduce climate risk, we can investigate the implications of a range of potential outcomes. This allows decision-makers to determine priorities (which could be minimising losses, or maximising potential gains, for example) while factoring in the uncertainties about future climate projections. Development plans being made in both Malawi and Tanzania (but also elsewhere in the SADC region) comprise critical trade-offs between major investment decisions in irrigation, hydropower and agricultural intensification and the impacts on ecosystem services in the affected areas, among other considerations.

## Future water availability in the Lake Malawi Shire River Basin

Figure 2: Location, elevation and catchments of the Lake Malawi Shire River Basin. (Source: Bhave et al., 2019)



In Malawi, we have focused on the Lake Malawi Shire River Basin, which covers most of the country (see Figure 2). Outflows of water from Lake Malawi into the Shire River are critical to support major elements of the country's economy – in the form of hydropower and irrigation, and biodiversity – in the form of environmental flows.

### Co-producing a Water Evaluation and Planning (WEAP) model

We have co-produced a Water Evaluation And Planning (WEAP) model to assess the impact of climate change on water resources, working with in-country stakeholders, including the Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services), the Department of National Parks and Wildlife, the Electricity Supply Corporation of Malawi Ltd. (ESCOM), the Shire River Basin Management Programme (SRBMP) and operators of the Kamuzu Barrage (the structure that regulates lake outflows). This is the first simulation-based water model to represent so many features of this unconventional lake-basin system (Bhave et al., 2019).

### Projecting future water availability in the Lake Malawi Shire River Basin

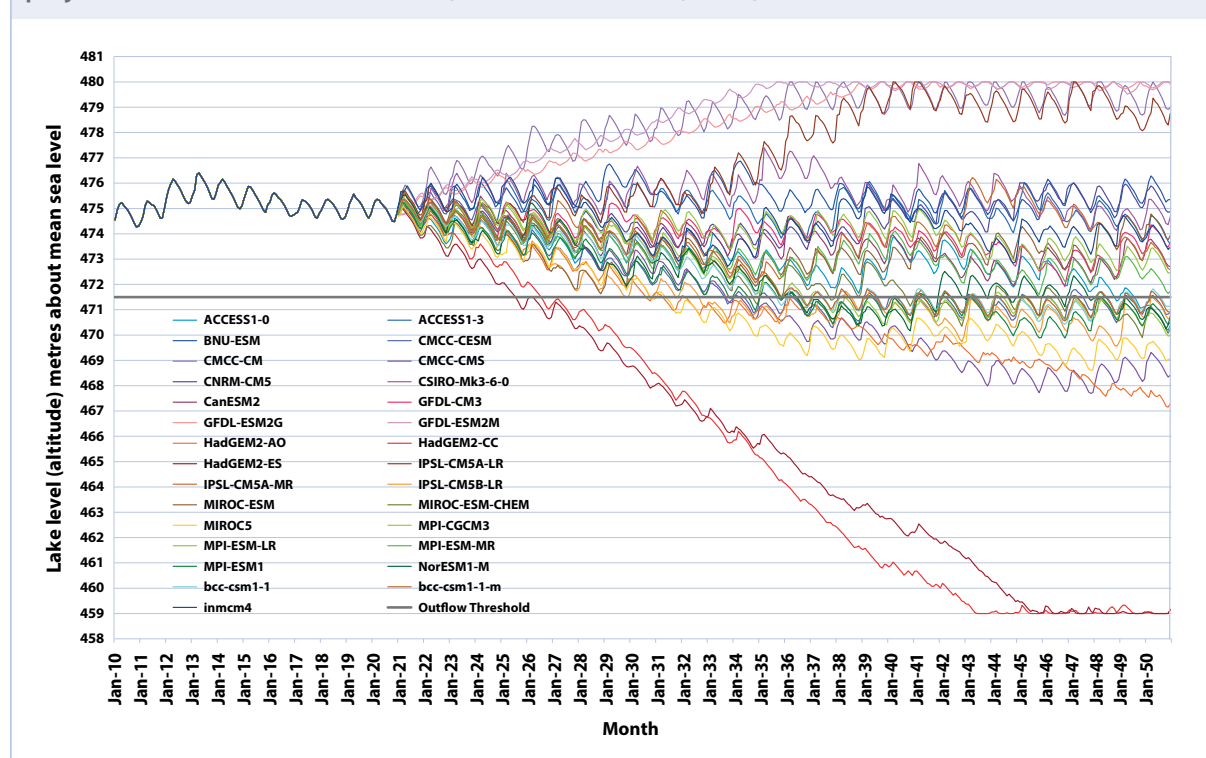
Running the WEAP model under future climate projections from 29 bias-corrected climate models based on the RCP 8.5 scenario (the IPCC scenario with the highest emissions) for the period 2021–2050 shows a range of potential future lake levels (see Figure 3).

Approximately one third of models (9 of 29) show very high lake levels leading to potentially severe downstream floods. Just over one third (11 of 29) of models show substantial decline that will lead to lake levels dropping below the Lake Malawi Outflow Threshold, which would dramatically reduce hydropower generation and irrigation water supply in the Shire River Basin. Finally, approximately one third show lake level fluctuations similar to what has been experienced in the recent past.

### Robust decision-making approaches can minimise climate risk

When making planning decisions relating to water it is important to use robust approaches that will be sustainable, taking into account the full range of projected increases or decreases. We also included a focus on historical variation in lake levels to help provide a stronger resonance with Malawian decision-makers and make more tangible the possibility of extremes to then plan accordingly, for example by considering this range into the upgrading of the Kamuzu barrage.

Figure 3: Climate change impacts on Lake Malawi levels based on 29 Global Climate Model projections in the Shire River Basin. (Source: Bhave et al., 2019)



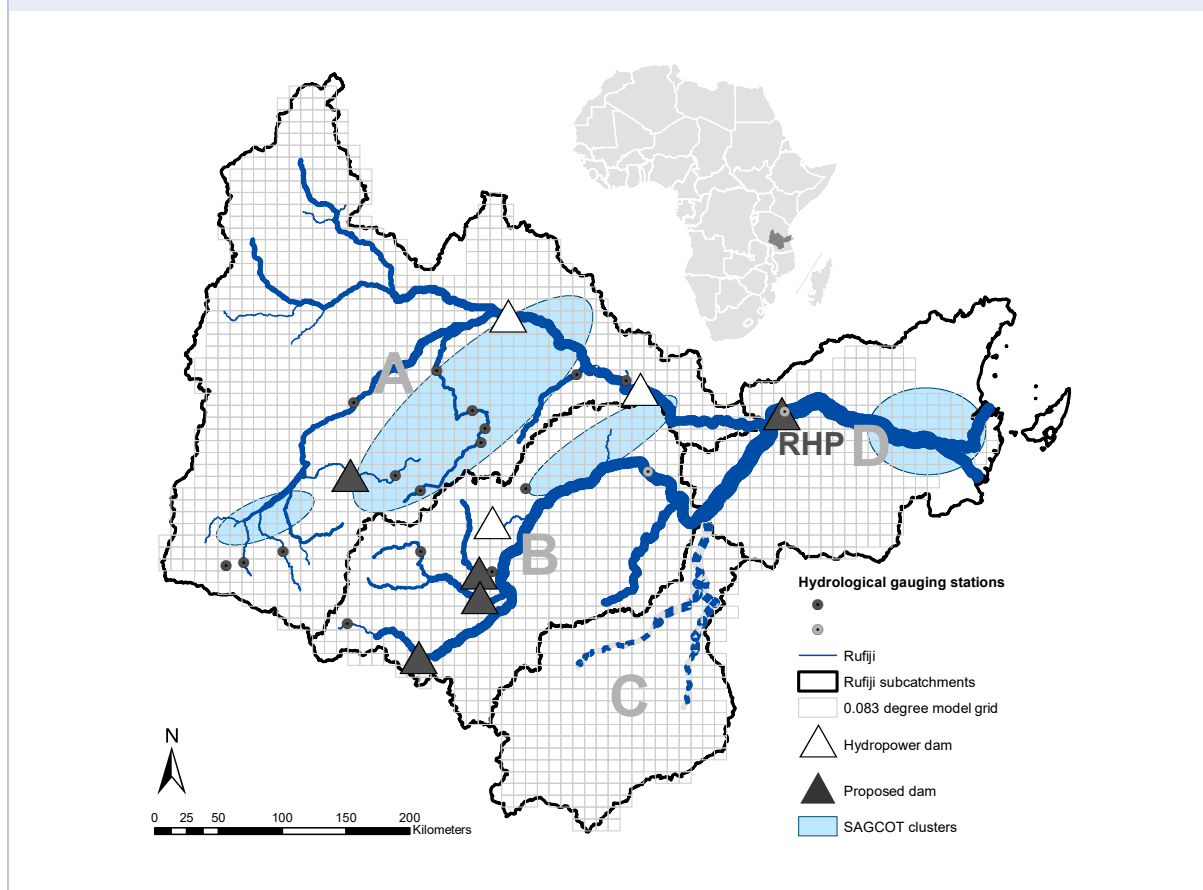
### Trade-offs around water allocation in the Rufiji River Basin

In Tanzania, we focused on the Rufiji River Basin. The Rufiji produces half of Tanzania’s river flow, supplying water for more than 4.5 million people, irrigation and livestock, and generating roughly 80% of the country’s hydropower. The basin also includes several major wetland systems and areas of high conservation value, including formally protected areas, such as National Parks. Major intensified socio-economic development over the next two decades is being planned as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) and the bcc-csm1 has committed to produce more hydropower, in particular via the Rufiji Hydropower Project at Stiegler’s Gorge, near the Rufiji Delta.

## Modelling future water availability in the Rufiji River Basin

We have regionalised a well-known global hydrological crop model, improving input by calibrating the runoff and crop modules and fine-tuning reservoir characteristics to match those of the planned Rufiji Hydropower Project – with a performance good enough to support use for scenario exploration given the very limited observational data in many parts of the basin (Siderius et al., 2018; see Figure 4).

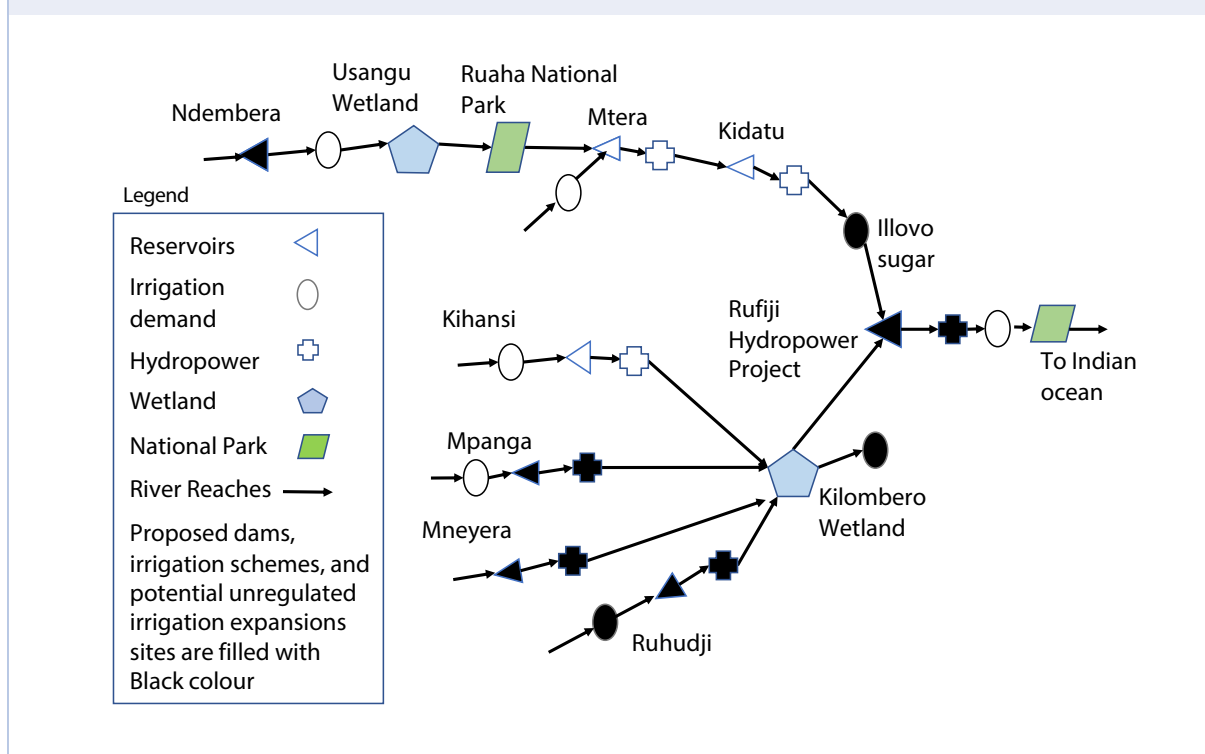
Figure 4: Hydrological model of the Rufiji system overlaid with 0.083 ° (~9 by 9km) grid and areas identified for irrigation expansion (SAGCOT clusters) (Siderius et al., 2018). RHP is Rufiji Hydropower Project. Letters refer to main tributaries: A is Great Ruaha, B is Kilombero, C is Luwegu and D is the Main Rufiji channel. (Source: Conway et al., 2019)



Running the model under future climate projections from the 32 climate models based on the RCP 8.5 scenario (the IPCC scenario with the highest emissions) for the period 2021–2050 shows a range of impacts on river flows in the Rufiji Basin, stretching from much higher flows to substantially lower flows, a situation similar to that found in Malawi.

Considering decisions about plans in the water, energy and food sectors requires coupling the hydrological system with a water resource system model that simulates the operation and effects of dams and irrigation in the basin (Conway et al., 2019; see Figure 5). We are currently doing this to support robust decision-making approaches. The decisions involve many options for combinations of new dams (and their operating rules), and new/expanded irrigation areas. Our aim is to provide an evidence base for making decisions regarding trade-offs in water use. The drier conditions projected by several models would strongly affect the functioning of reservoirs and expectations on firm energy levels.

**Figure 5: Major existing and planned dams and main areas of irrigation simulated in the water resources systems model developed by UMFULA (currently 11 irrigation demand nodes, four existing reservoirs, five new reservoirs and six run-of-the-river hydropower dams).**  
(Source: Conway et al., 2019)



### Identifying trade-offs for water between agriculture, hydropower and environmental flows

Stakeholder consultation across different sectors identified management objectives for the Rufiji basin. These include maximising energy generation and its reliability, maximising irrigation water supply reliability and total irrigation area, and minimising the impact of development on river flows that provide important environmental services (e.g. habitats dependent on seasonal flooding).

An understanding of the consequences of alternative development and management options based on up-to-date evidence is vital – not only in terms of the decision to build infrastructure but also on its design and operational management. Our results show that well managed, adaptive dam operational rules will be needed to deal with variable reservoir inflows – under conditions of climate variability and change at a range of time-scales.

### Socially differentiated effects of different macro-level decisions

There are also socially differentiated implications of such decisions. For example, while irrigation may benefit the large scale and aggregate production levels, it will often affect water availability for small-scale farmers whose scale of operation means developing proper irrigation infrastructure is rarely an option. This was found to be particularly the case for those farmers working in the tea and sugarcane industries, two key sectors important for both the economy and livelihoods in Malawi and Tanzania. Considering equity in adaptation decisions is therefore an important criterion (Pardoe et al., submitted).

# HOW THE POLICY AND INSTITUTIONAL ENVIRONMENT AND AGENCY AFFECT WHETHER OR NOT CLIMATE INFORMATION IS USED IN DECISION-MAKING

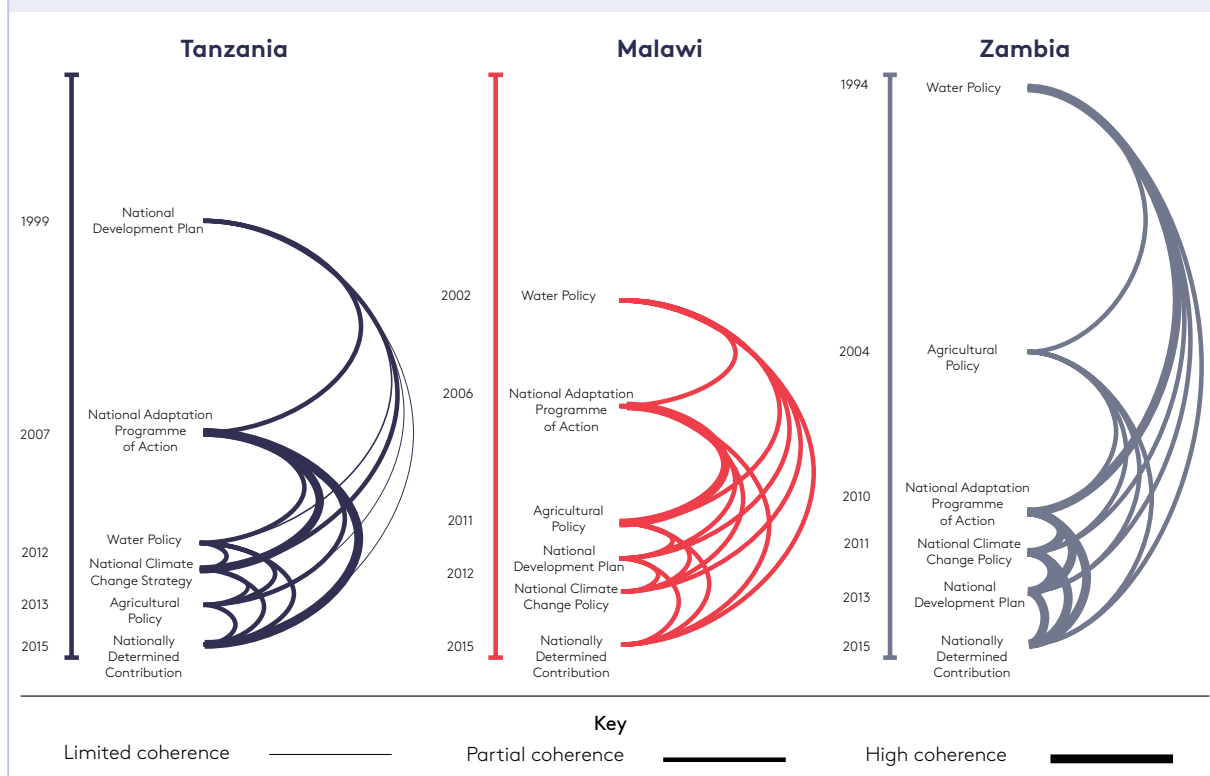
Work across Malawi, Tanzania, Zambia and southern Africa more broadly produced key insights into whether or not and how climate information can be used to inform cross-sectoral decision-making.

Political commitment to addressing climate change and achieving sustainable development in the water, energy and agriculture sectors exists within southern African countries (England et al., 2018). However, optimal efficiency in achieving adaptation is impeded by policy incoherence across sectors (see Figure 6). Ensuring coherence between policies is challenging due to inconsistency in timeframes of policy development and resource constraints that limit the frequency of policy reviews (Curran et al., 2018).

More detailed analysis of the political economy in Malawi, Tanzania and Zambia shows that ideas, power and resources converge in different ways to create institutional environments that either support or constrain the pursuit of climate change policy ambition and targets (England et al., 2018). We found that change in leadership, and the oft-concurrent cabinet reshuffles, changes in ministerial mandates and rotation of high-level civil servants, leads to a focus on short-term planning that links with electoral cycles, rather than the required focus on long-term building of resilience strategies and climate adaptation investments (Pardoe et al., submitted).

Reliance on donor funding can lead to turf wars and competition between ministries for resources (such as in Zambia) and contribute to barriers to coordination for coherent cross-sectoral approaches (such as in Malawi) (England et al., 2018).

**Figure 6: Coherence and sectoral policy linkages around climate, water, energy and agriculture in Tanzania, Malawi and Zambia. (Source: Curran et al., 2018)**



## WHY CAREFULLY DESIGNED CAPACITY-BUILDING IS AN ESSENTIAL CONDITION FOR EFFECTIVE CLIMATE CHANGE ADAPTATION

Surveys and extensive interviews show external reliance also undermines a sense of autonomy and agency to act among staff in the ministries, even when technical capacity and individual motivation exists (Pardoe et al., 2018). They are dependent on donor-determined projects which may be selective in the aspects of climate change adaptation plans and policies they support and even divert focus away from government priorities.

Capacity-building is therefore not necessarily about running more training courses, but providing autonomy and operational budget to government staff so that they can effectively implement adaptation policy across multiple sectors (Mataya et al., submitted). In Malawi, government and development partners have been providing and funding a range of education and training initiatives. Findings indicate that long-term education and short-term training have complementary roles in influencing successful adaptation practices. Short-term training workshops are most useful when they are customised to the particular needs of participants, are participatory in design and implementation, and when they are tailored using context-specific examples. Action planning, on-the-job training and continued mentorship after training are also effective, but remain rarely used. Challenges that impede effective capacity-building relate not only to the training design and structure, but also to the inadequacy of training needs assessments and the organisational structure in which trainees attempt to put their skills and knowledge into practice.

Focusing more broadly on the SADC region, findings mirrored those from Malawi. Capacity gaps were frequently cited as either the most important obstacle, or one of the most important obstacles, to real use of climate information for improved decision-making (Lötter et al., 2018). Capacity-building efforts relying on workshops are frequently used but are not always effective. Instead, sustained engagement with focal points is frequently more productive, even though it can be more resource-intensive – in financial terms and in human capital terms.



*Illovo Sugar plantation in Nchalo, Malawi, 2016*



## Climate information access and use among smallholder farmers

The uptake of climate information among local users relies on the information being useful, usable and used. Through two streams of research in Malawi and one in Tanzania, we have gained insight into smallholder farmers' access and use of climate information.



*Smallholder sugarcane farmer in southern Malawi participating in in-depth interview, 2017*

Participatory Scenario Planning (PSP) has been introduced to several districts in Malawi to bring together producers and users to co-produce interpretations of seasonal weather information. We found that although challenges – including lack of technical capacity, constrained financial resources and aforementioned weak institutional capacity – prevent optimum effectiveness of PSP, the process does have the potential to generate credible, legitimate and salient information that is both usable and being used by the receivers. Its usability is reinforced through demonstration of farmers' effective adoption of the information. Despite nationwide implementation, the numbers of recipients are, however, few and scattered (Tembo-Nhlema et al., 2019).

Smallholder sugarcane farmers in Malawi, despite being part of a large contract-farming organisation comprising nearly 800 farmers in a district where PSP has been implemented, do not benefit from the co-produced climate information. These farmers predominantly rely on the radio or neighbours to receive daily to seasonal forecasts. The research suggests that overcoming the technical, financial and institutional barriers may lead to PSP having significant impact on smallholder farmers' potential to successfully adapt to climate change and climate variability. Ensuring participation of larger co-operatives, contract farming organisations and NGOs in the PSP processes would reach a much larger group of beneficiaries, and would have a potentially significant spill-over effect among villages and communities.

In the Kilombero River catchment of Tanzania, research finds that people make important water-use and farming decisions for the upcoming year, such as season planting, based in particular on the seasonal forecasts they get from the country's national meteorological service. They receive it through the agriculture extension service officers or through broadcasts on local television and radio stations. This shows the importance of keeping regular, accurate forecast information flowing to communities on the ground.

# PUTTING RESEARCH INTO PRACTICE: HOW UMFULA CO-PRODUCED AND COMMUNICATED FINDINGS FOR IMPACT

## Working together with local partners to identify adaptation options

Enshrined within the co-production process to carry out all our activities in Malawi and Tanzania, UMFULA has been committed to ensuring that our research process and findings have impact in our case study countries. Close collaboration with partners in the Rufiji Basin and the Lake Malawi Shire River Basin enabled us to jointly explore adaptation options for robust decision-making in a context of climate and other socio-economic and environmental changes.



Workshop with Rufiji Basin Water Board, Tanzania, 2016



Workshop with energy, agriculture and water stakeholders, Malawi, 2018

## Contributing to national policy processes in Tanzania and Malawi

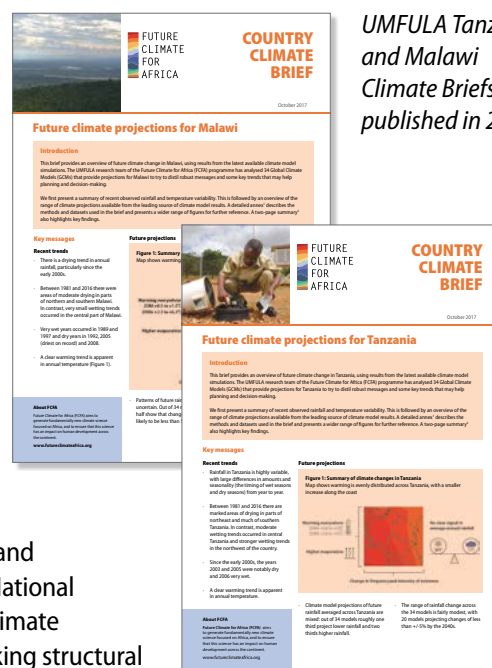
We had several opportunities to provide inputs into national policies and strategies in Malawi. For example, we regularly engaged with the National Technical and Steering Committees on Climate Change in Malawi.

We provided comments on the draft National Resilience Strategy and its Implementation Plan. Among our recommendations was the need to consider longer-term climate change and variability, and to strengthen the details of tangible interventions under the four pillars (agriculture, risk reduction and early warning, livelihoods and social protection, and catchment management), with an emphasis on greater integration.

Key findings are also being provided to members of the National Planning Commission tasked with developing the new long-term development vision for Malawi.

At the invitation of our partner, the Department of Climate Change and Meteorological Services, we also provided inputs to Malawi's Third National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (Chapter 4 on climate projections). As well as making structural recommendations relating to the presentation and explanation of projections, we provided a set of future projections based on country climate briefs we produced in 2017 (Mittal et al., 2017).

UMFULA Tanzania and Malawi Climate Briefs published in 2017



## Sharing UMFULA research through public engagement activities

Highlights of our public engagement activities in Malawi include presentation of a range of UMFULA findings at Malawi's first National Adaptation Symposium in 2018 and co-hosting a panel discussion in November 2017, together with the Civil Society Network on Climate Change (CISONECC), on 'How climate information can build a resilient Malawi'; with speakers from the Environmental Affairs Department, Department of Climate Change and Meteorological Services and the United Nations Development Programme, as well as UMFULA and CISONECC.



*Panel discussion: 'How climate information can build a resilient Malawi?', Malawi, 2017*



*Clinic session with students at the University of Dar es Salaam, Tanzania, 2018*



*UMFULA side event at Africa Water Week, 2016*

In Tanzania, we engaged in universities, through regular lectures and clinic sessions with students, at Sokoine University of Agriculture and the University of Dar es Salaam. We were also one of the facilitators of the Africa Climate Leadership Programme (AfriCLP) held in Dar es Salaam in 2018, addressing challenges in delivering climate services on the continent.

Africa-wide, we participated in Africa Water Week in 2016 and 2018 with, for example, a side event in 2016 on the theme of climate resilience and the connections between the water, energy and food sectors in east and southern Africa, with speakers from the Government of Kenya and the UK's Department for International Development.

We led and participated in several open webinars to present emerging and key findings to a diverse and international audience (for the video recordings, see [www.futureclimateafrica.org/videos](http://www.futureclimateafrica.org/videos)):

- **What you've always wanted to know about central and southern Africa's climate** by Neil Hart
- **How can climate models be improved over Africa?** by Rachel James
- **Policy coherence for sustainable development** by Joanna Pardoe, Andrew Dougill, Katharine Vincent and guest Martin Sishekanu from Zambia
- **Lessons in co-production of climate services from African case studies** by Suzanne Carter, Anna Steynor, Katharine Vincent, Joseph Mutemi, Katinka Lund Waagsaether, Tufa Dinku and Emma Visman
- **Ten principles for good co-production in African weather and climate services** by Katharine Vincent, Emma Visman, Anna Steynor, Katinka Lund Waagsaether and Suzanne Carter

## Partnership with National Meteorological and Hydrological Services

Engaging the national meteorological and hydrological services in Malawi and Tanzania was an essential component of UMFULA's knowledge-sharing and mutual capacity-building efforts.

The UMFULA team partnered with Malawi's Department of Climate Change and Meteorological Services (DCCMS) throughout the project, which included inclusion in project planning processes, a series of visits and information-sharing.

Highlights of our collaboration include briefs that we co-produced to outline future climate in Malawi, based on results of the existing global climate models (Mittal et al., 2017).

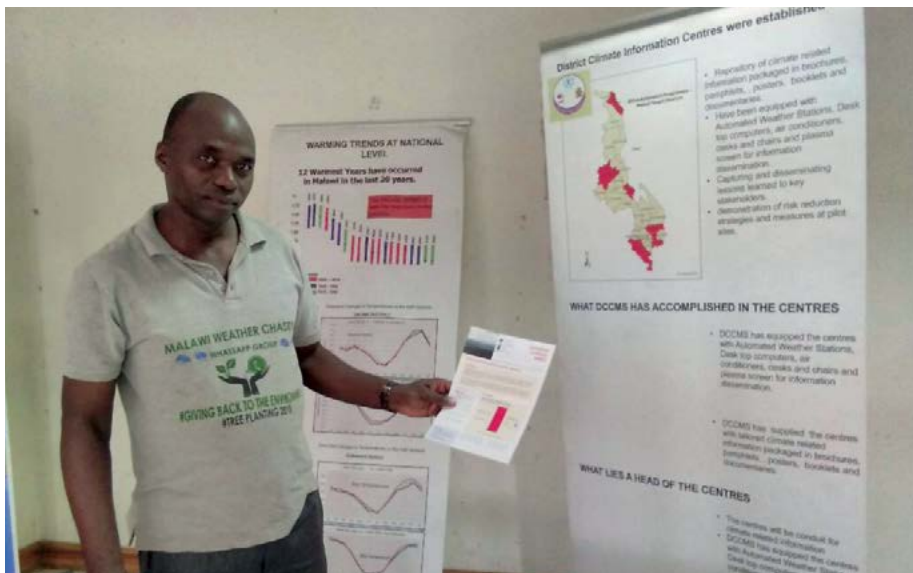
The content and presentation reflected demands of in-country stakeholders as expressed to DCCMS. These briefs were subsequently used by the Department to raise awareness about climate change and its impacts at the World Meteorological Day Celebrations of 2018.

We worked together with DCCMS and provided inputs to Malawi's Third National Communication to the UNFCCC (Chapter 4 on climate projections).

We were also in contact with the Tanzania Met Agency (TMA) and a small group of UMFULA early career researchers visited TMA in 2018 to share findings from our work on climate processes for the region and how they impact Tanzania.



*UMFULA briefs at DCCMS stand, World Meteorological Day, Malawi, 2018*



*UMFULA briefs at DCCMS stand, World Meteorological Day, Malawi, 2018*

## CONCLUSION: IMPROVING THE USE OF CLIMATE INFORMATION FOR ADAPTATION IN CENTRAL AND SOUTHERN AFRICA

Based on UMFULA's research, what combination of model outputs, impact scenarios and decision-support tools improves effective use of climate information for adaptation in an African context?

**Understanding the likely future characteristics of climate risk is a key component of adaptation and climate-resilient planning.** UMFULA has made major advances in understanding rainfall regimes in central and southern Africa, including the role of features such as cloud bands, the Angola Low and South Indian Ocean high pressure systems. These findings have allowed assessment of the ability of climate models to simulate these processes and their influence on current and future climate in the region. However, it remains the case that future climate projections and impacts are highly uncertain, particularly for rainfall conditions which are critical for social and economic activities.

**Given future uncertainty it is important to design approaches that are strongly informed by local considerations and robust to uncertainty,** i.e. options that work reasonably well across a range of uncertain future climate (and other) conditions. This approach exemplifies decision-making under uncertainty. It allows us to inform decisions being made now, without having to wait for possible reductions in uncertainty.

**Choosing the right tools and approach for climate risk assessment and adaptation to suit the scale of the decision allows a suitable trade-off between robustness and resources required (time and expertise) for analysis.** There is a continuum moving from a simple light touch approach suitable for many small and short-lived decisions (for example, small-scale water and sanitation technologies) through to an increasingly detailed approach for major long-lived decisions such as irrigation projects and dams.

**In the medium term, policy decisions require careful cross-sectoral planning.** This is particularly necessary in cases involving large investments, long life-times, critical trade-offs and irreversibility, where there is a strong argument for assessing resilience to future climate change. River basin infrastructure exemplifies this.

In both UMFULA's case studies in Malawi and Tanzania, decisions in the water–energy–food nexus are subject to both climate and other aspects of future uncertainty. Values and trade-offs are inherent to these decisions, and hence consultation with a wide range of stakeholders is important. Co-production provides opportunities to define problems, to communicate complex information about changing climate risks, to prioritise responses, given attitudes to risk and pressures from often critical non-climate factors, and to make and implement decisions.

Consultation with stakeholders highlights the importance of political influences, policy process and local perspectives, and the complex ways in which they affect decision-making processes at all levels.

**The process of partnership embedded within co-production contributes to building societal and institutional capacity to factor climate risks into long-term planning in Malawi, Tanzania and more widely in southern Africa.** It also builds the capacity of researchers to better understand real world decision contexts in which climate change is one of many important factors.

## UMFULA OUTPUTS

For updates, see [www.futureclimateafrica.org](http://www.futureclimateafrica.org)

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## Degrees

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Diana Mataya, MSc Environment and Development, University of Leeds (dissertation title: Role of capacity building for development and implementation of climate change adaptation programmes and policies in Malawi)

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Robel Geressu, DPhil Civil, Environmental and Geomatic Engineering, University College London (dissertation title: Many-objective design of reservoir systems – Applications to the Blue Nile)

Callum Munday, DPhil Geography, University of Oxford (dissertation title: Controls on present-day and future rainfall over southern Africa in coupled climate models)

### Degrees underway

Emma Howard, DPhil Geography, University of Oxford (dissertation title: Synoptic time-scale rain-producing weather systems in tropical southern Africa)

Simphiwe Ngcobo, PhD Hydrology, University of KwaZulu Natal (dissertation title: Hydrological impacts of climate change: implications of water stress on sugarcane yields across southern Africa)

Lizeth Nompumelelo Nkambule, MSc Hydrology, University of KwaZulu Natal (dissertation title: Modelling the impact of climate change on smallholder sugarcane and tea crop yields in the Shire River basin, Malawi)

Xolisile Yende, MSc Hydrology, University of KwaZulu Natal (dissertation title: Investigating the effects of climate change on the productivity in commercial sugar cane farming and milling and effectiveness of response management strategies in Malawi and South Africa)

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*Shire Valley, Malawi, 2016*



Rufiji river, Tanzania, 2017



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## How can we improve the use of information for a climate-resilient Malawi?

### Overview

This brief presents the main research findings from the Future Climate for Africa UMFULA project that are relevant for policy and practice on how to integrate climate information and increase resilience to climate change in Malawi. The research team is grateful to all the stakeholders who informed and helped shape these results and hope that this summary note is of value in planning a more climate resilient future for Malawi.

### Key messages

- Understanding the likely future nature of climate risk is necessary for adaptation and long-term climate-resilient planning via the National Resilience Strategy and essential for the National Planning Commission.
- Malawi's geographical location, between the east and southern African climate systems, means that future climate (particularly rainfall) is challenging to predict accurately – although there are areas of agreement in climate models, notably higher temperatures and higher likelihood of extreme weather events.
- Given future uncertainty, it is important to design robust management options that work across the plausible range of future climate conditions, especially for large investments with long life-times, significant impacts and irreversibility, such as water-related infrastructure (e.g. hydropower or irrigation) & agricultural investments in crop-breeding.
- Decision-making under uncertainty approaches help to understand trade-offs for decisions such as meeting water needs and allocating water for irrigation, energy production and environmental services.
- Careful planning is needed for the agricultural sector that is highly sensitive to temperature changes, including both subsistence and commodity crops (such as tea and sugar).
- Greater efforts should focus on the uptake of climate information by smallholder farmers – Participatory Scenario Planning has the potential to generate credible, legitimate and salient information that is both useable and used by farmers.
- Achieving coherence between sectoral policies requires a more supportive institutional environment for sustainable and resilient decision-making.
- Co-design and use of capacity-building activities, taking into account institutional needs, is essential for effectively responding to climate change.
- Modelling studies show that Tanzanian catchments contribute over half of the water to Lake Malawi in some years. This requires careful trans-boundary management of water resources in coming decades to avoid a situation where there is no outflow from Lake Malawi into the Shire River.

### About FCFA

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent.

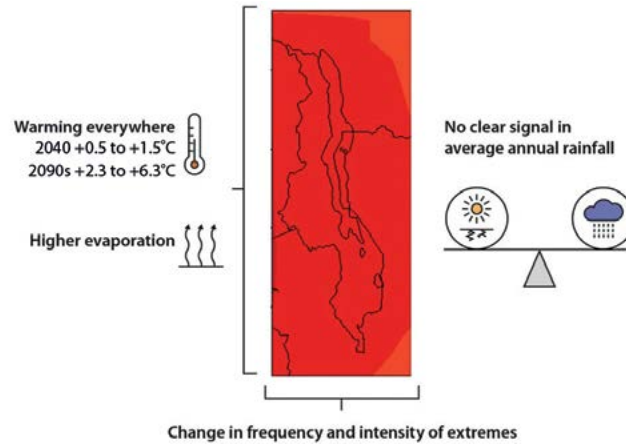
## What will the future climate look like in Malawi?

Changes in climate are already being experienced in Malawi. Temperatures have increased in all seasons and throughout the country. There is an overall drying trend, although there is a lot of variability in rainfall amounts and seasonal patterns.

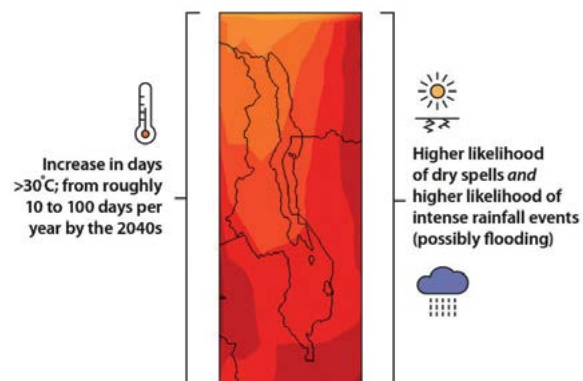
In the future, climate models predict **warming to continue** (Figure 1). We expect higher evaporation with higher temperatures, with significant implications for agriculture and water sectors. We see a **higher likelihood of extreme rainfall events** in the future – both dry spells and drought, but also flooding (Figure 2). This means that extreme conditions that we have seen in recent years, such as flooding in 2015 followed by the 2016 El Niño-related drought and the flood damage associated with Cyclone Idai in 2019, are predicted to become more common.

Patterns of change in rainfall are unclear at a national scale (Figure 3) with initial indications suggesting that rainfall in the north may increase, whilst in the south a decrease is likely in the area where dry spells and droughts are already having a significant impact.

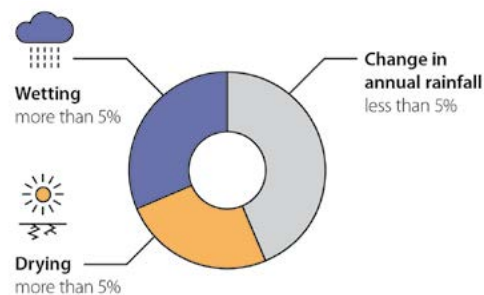
**Figure 1: Future temperature, evaporation and rainfall projections (source: Mittal et al, 2017).**



**Figure 2: Future extreme events (hot days and dry spells) (source: Mittal et al, 2017).**



**Figure 3: Split of future national rainfall projections across 34 CMIP climate models (source: Mittal et al, 2017).**



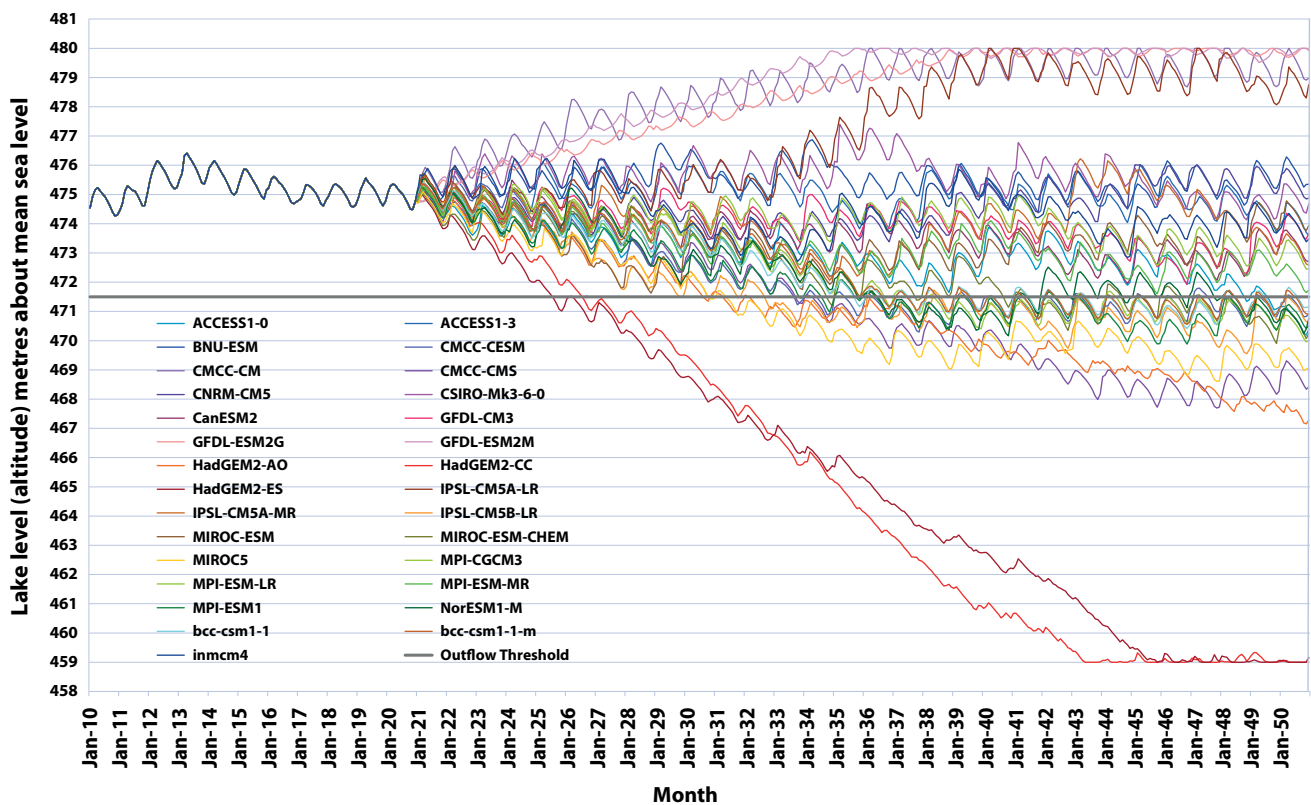
## What will this mean for water availability from Lake Malawi and the Shire River Basin?

Outflows of water from Lake Malawi into the Shire River are critical to support major elements of the economy in the form of hydropower and irrigation, as well as biodiversity and environmental flows, which are essential to human wellbeing.

Running an open access Water Evaluation And Planning (WEAP) model customised for Malawi shows *a range of potential future lake levels for 2021-50* (Figure 4 based on a range of global climate models run under a high emissions scenario). One group of projections shows very high lake levels leading to potentially severe downstream floods. Some projections lead to a substantial decline in lake levels that will lead to

lake levels dropping below the Lake Malawi Outflow Threshold which would dramatically reduce hydropower generation and irrigation water supply in the Shire River Basin. However, some projections show lake level fluctuations similar to what has been experienced in recent decades. These important differences in model results are not apparent when looking only at an ensemble mean.

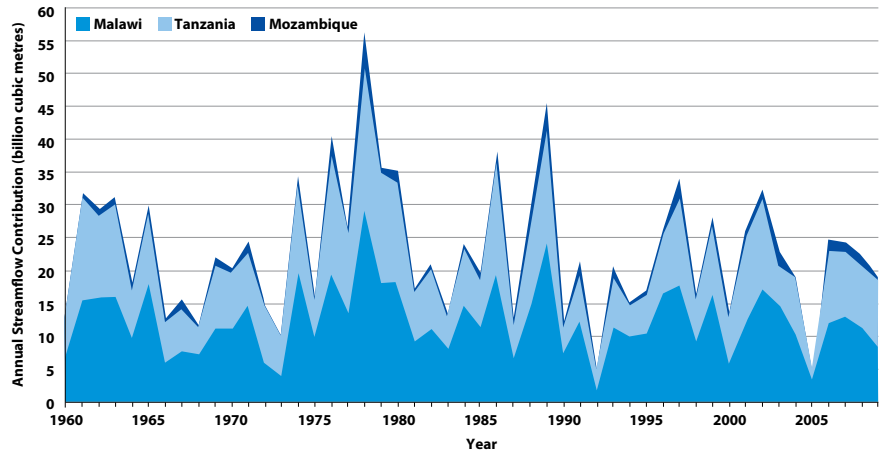
**Figure 4: Climate change impacts on Lake Malawi levels based on 29 Global Climate Model projections**  
(source: Bhawe et al, 2019).



Historical runs of the WEAP model also show that Tanzanian catchments contribute a significant amount of water to Lake Malawi (Figure 5) requiring careful trans-boundary management of water resources.

When making planning decisions relating to water *it is important to identify and apply robust management options that are sustainable* across the full range of projected increases or decreases. Our inclusion of historical variation in lake levels makes such findings more relevant to decision-making, for example by considering this range in the operation and management of the Kamuzu barrage.

**Figure 5: Sources of water to Lake Malawi (Malawi, Tanzania, Mozambique) (source: authors).**





## What will this mean for the tea and sugar sectors?

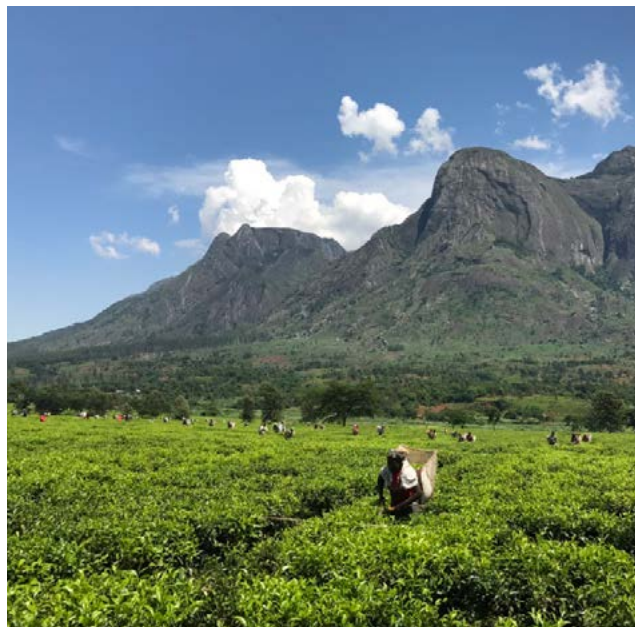
Tea and sugar are key sectors for both the economy and livelihoods of people in Malawi, but the ***crops are sensitive to temperature and at risk of heat stress***. Tea is particularly sensitive during the dry season (May to November) as seen in the 2019 heatwave (Figure 6). Sugarcane requires 30-32°C during the main growing

season and cooler winters to slow down the growth and increase sugar storage.

Future temperature projections show an increase in heat stress conditions and night temperatures for the 2050s compared to observations. The ***nature of adaptation required varies depending on place and the specific projection of future climate***. More warming is projected for tea producing

sites at Mulanje, meaning new tea cultivar varieties will be critical for future adaptation – compared to Thyolo where irrigation will be vital, due to increases in the number of consecutive dry days. Adaptation in sugar producing areas is particularly challenging for outgrower schemes due to lower preparedness for extreme events. Outgrowers would thus benefit from increased support to adapt, including the use of climate information.

Figure 6: Mulanje tea bushes, October 2019 (left), compared to December 2016 (right).



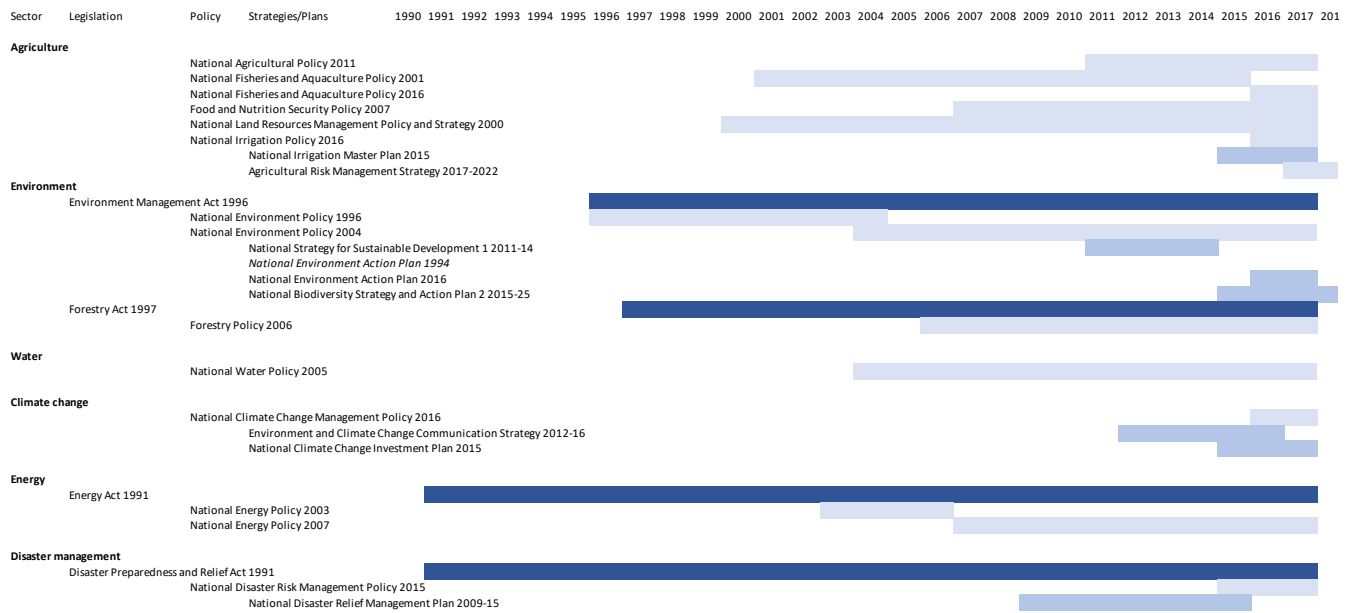
## How can we ensure climate information is used by smallholder farmers to reduce risk?

The uptake of climate information among local users relies on the information being useful and usable. Participatory Scenario Planning (PSP) is a technique to co-produce

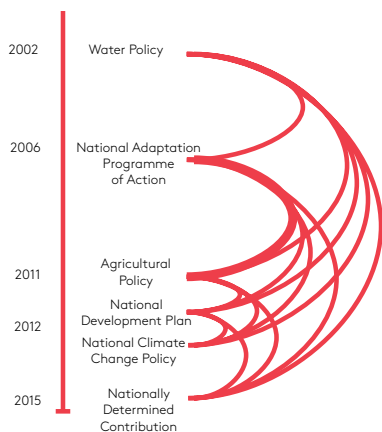
interpretations of seasonal weather information and has been used in several districts. Although there are challenges in co-production, ***PSP has the potential to generate credible, legitimate and salient information*** that is both usable and being used, particularly by farmers. PSP can further assure that the less advantaged (women and elders) get access to, and understand climate information for improved adaptation.

Despite nationwide implementation, the numbers of recipients remain few and implementation is only taking place on a project basis. The recently-approved Meteorological Policy does not include the provision to support PSP. 2019 marked the first National Climate Outlook Forum providing sector-specific advisories based on seasonal forecasts, which is an important practice worth sustaining.

**Figure 7: Timelines of operation of selected approved legislation and policies relating to agriculture, environment, water, climate change, energy and disaster management (source: authors).**



**Figure 8: Coherence and sectoral policy linkages around climate, water, energy and agriculture in Malawi – thick line shows good coherence, thinner line shows partial coherence (source: Curran et al, 2018).**



**How can we create a policy and institutional environment that supports the use of climate information to reduce risk?**

Despite the typical lifespan of policies being five years, the *timeframe of policy development and the limited occurrence of reviews limit the coherence* around climate, water, energy and agriculture (Figures 7 and 8). Figure 7 shows that certain key policies have been in operation for nearly 20 years.

Analysis of political economy shows that ideas, power and resources converge in different ways to create institutional environments that either support or

constrain the pursuit of climate change policy ambition and targets. *Change in leadership, and the oft-concurrent cabinet reshuffles, changes in ministerial mandates and rotation of high-level civil servants, leads to a focus on short-term planning, rather than the required focus on long-term building of resilience strategies and climate adaptation investments.* Reliance on donors can contribute to barriers to coordination for coherent cross-sectoral approaches.

*External reliance also undermines a sense of autonomy and agency to act among staff in the ministries, even when technical capacity and individual motivation exists.*

## How can we design capacity building for effective climate change adaptation?

Significant investments in training have not effectively built capacity to respond to climate change. *Long-term education and short-term training have complementary roles in influencing the design and implementation of successful adaptation practices.* Short-term training workshops are most useful when customised to

the particular needs of participants, are participatory in design and implementation and tailored using context-specific examples. Action planning, on the job training and mentorship after training are effective but rarely used.

In addition to training design, the inadequacy of training needs assessments and the organisational structure in which trainees attempt to put their skills and knowledge into practice impede effectiveness of training.

*More rigorous coordination and monitoring of training efforts and appropriate institutional support for action following training sessions are essential to enhance effectiveness of adaptation planning.*

Capacity-building is not necessarily about running more training courses – but providing autonomy and operational budget to government staff so that they can effectively implement adaptation policy across multiple sectors.

**Figure 9: Collaborative discussion forum between UMFULA researchers and stakeholders, November 2017, Lilongwe, Malawi.**



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## About Future Climate for Africa

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. This brief was written by members of the UMFULA research team: Andy Dougill, David Mkwambisi, Katharine Vincent, Emma Archer, Ajay Bhawe, Rebecka Henriksson Malinga, Diana Chanika Mataya, Neha Mittal and Dorothy Tembo-Nhlema.

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