THE ORGANISATION OF AFRICAN, CARIBBEAN AND PACIFIC STATES

Enhancing Climate Services for Agriculture and Food Security in Africa, the Caribbean and the Pacific

ClimSA

INTRA-ACP CLIMATE SERVICES AND RELATED APPLICATIONS PROGRAMME

An initiative of the Organisation of African, Caribbean and Pacific States funded by the European Union

Funded by the European Union

This compilation of case studies has been produced by **the ClimSA Programme, an initiative of the Organisation of African, Caribbean and Pacific States (OACPS), funded by the European Union through the 11th European Development Fund (EDF),** with the aim to strengthen the climate services value chain in OACPS Member States. The ClimSA Programme has been implemented through a partnership involving eight regional climate centres, three multilateral organisations and the Joint Research Centre of the European Commission.

REGIONAL CLIMATE CENTRES

African Centre of Meteorological Applications for Development (ACMAD)
ACMAD is the continental weather/climate watch and excellence centre designated as World Meteorological Organisation - Regional Climate Centre (WMO-RCC) for the applications of meteorology to development. acmad.org/

AGRHYMET Regional Climate Centre
The AGRHYMET Regional Climate Centre provides tailored climate information, monitoring, and forecasting services to strengthen food security and natural resource management in the West African and Sahelian region. ccr1-agrhymet.cilss.int/

Caribbean Institute for Meteorology and Hydrology (CIMH)
CIMH is a training and research organisation designated as World Meteorological Organisation-Regional Climate Centre (WMO-RCC) assisting in enhancing meteorological and hydrological services across Caribbean nations through education, research and the provision of specialised climate services. cimh.edu.bb/

Climate Applications and Predictions Centre for Central Africa (CAPC-CA)
The CAPC-CA is the specialised institution of the Economic Community of Central African States (ECCAS) in charge of generating climate information and services, and building capacity of users according to specific sector requirements. capc-ac.net/

IGAD Climate Prediction and Applications Centre (ICPAC)
ICPAC is the Regional Climate Centre designated as World Meteorological Organisation - Regional Climate Centre (WMO-RCC) that provides climate services and knowledge to enhance community resilience and support sustainable development in the Greater Horn of Africa. icpac.net

Indian Ocean Commission (IOC)
The IOC is an intergovernmental cooperation organisation strengthening the links between the islands of the Indian Ocean region and supporting its Member States in establishing the South-West Indian Ocean Regional Climate Centre Network for sustainable development. commissionoceanindien.org/en/

Southern African Development Community Climate Services Centre (SADC-CSC)
SADC-CSC is the Regional Climate Centre that provides regional climate monitoring, forecasting, and early warning services to support climate resilience and disaster risk reduction across Southern Africa. csc.sadc.int/en/

Secretariat of the Pacific Regional Environment Programme (SPREP) Pacific RCC-Network
The Pacific RCC-Network is a virtual centre of excellence that supports Pacific island National Meteorological and Hydrological Services (NMHS) in improving climate services, products and their capacity to meet national climate information needs. pacificmet.net/rcc

MULTILATERAL ORGANISATIONS

African Union Commission (AUC)
The AUC is the executive branch of the African Union (AU), responsible for implementing AU decisions. Among others, it provides political leadership and guidance, policy direction and advocacy in providing weather and climate services that meet societal needs through the African Ministerial Conference on Meteorology (AMCOMET) au.int/en/commission

European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
EUMETSAT is the European operational satellite agency for monitoring weather, climate and the environment from space. eumetsat.int/

World Meteorological Organization (WMO)
The WMO is a specialised agency of the United Nations responsible for promoting international cooperation on atmospheric science, climatology, hydrology and geophysics. wmo.int/

OTHER CATEGORIES

Joint Research Centre (JRC)
The JRC is the European Commission's science and knowledge service mandated to carry out research providing independent scientific advice and support to European Union policy. https://joint-research-centre.ec.europa.eu/index_en

AESA Consortium
International consultancy consortium specialising in environmental engineering, climate change and sustainable development solutions.

Enhancing Climate Services for Agriculture and Food Security in Africa, the Caribbean and the Pacific. The Intra-ACP Climate Services and related Applications Programme (ClimSA).

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Abbreviations

ACMAD	African Centre of Meteorological Applications for Development
ACP	African, Caribbean and Pacific
ACR	African Risk Capacity
AGRHYMET	Centre Régional AGRHYMET CCR – AOS
AI	Artificial Intelligence
AMCOMET	African Ministerial Conference on Meteorology
AMMA-CATCH	Analyse Multidisciplinaire de la Mousson Africaine – Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique
ANAM	Agence Nationale de la Météorologie du Burkina Faso
ARBE	Department of Agriculture, Rural Development, Blue Economy, and Sustainable Environment
AU	African Union
AU-IBAR	African Union – Interafrican Bureau for Animal Resources
AUC	African Union Commission
BRCCC	Building Regional Climate Capacity Programme
CAMI	Caribbean Agro-Meteorological Initiative
CARDI	Caribbean Agricultural Research & Development Institute
CariCOF	Caribbean Climate Outlook Forum
CariSAM	Caribbean Society for Agricultural Meteorology
CBA	Cost Benefit Analysis
CCCCC	Caribbean Community Climate Change Centre
CERF	Central Emergency Response Fund
CGMS	Coordination Group for Meteorological Satellites
CHIRPS	Climate Hazards InfraRed Precipitation with Station Data
CIMH	Caribbean Institute for Meteorology & Hydrology
CIS	Climate Information Services
ClimSA	Climate Services and related Applications Programme
COF	Climate Outlook Forum
CO2M	CO2 Monitoring Mission
CPT	Climate Predictability Tool
CREWS	Climate Risk and Early Warning Systems
CSIS	Climate Services Information System
DRR	Disaster Risk Reduction
DSR	Daily Severity Rating
DSS	Decision Support System
EAAH	East Africa Hazard Watch
EADW	East Africa Drought Watch
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECVs	Essential Climate Variables
ENSO	El Niño Southern Oscillation
EPS-SG	EUMETSAT Polar System-Second Generation
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EWISACTs	Early Warning Information Systems Across Climate Timescales
FAO	Food and Agriculture Organization of the United Nations
FCFA	Franc of the African Financial Community
FEWSNET	Famine and Early Warning System Network
FSL	Food Security and Livelihoods
GCCA+	Global Climate Change Alliance Plus
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GFCS	Global Framework for Climate Services
GHACOF	Greater Horn of Africa Climate Outlook Forum
GHG	Greenhouse Gas
GLDA	Guyana Livestock Development Authority
GWIS	Global Wildfire Information System
GLORIA	Global Resource Input Output Assessment
GMet	Ghana Meteorological Agency
GTP	Groupe du travail pluridisciplinaire
ICPAC	IGAD Climate Prediction and Applications Centre

ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFRC	International Federation of Red Cross and Red Crescent Societies
IGAD	Intergovernmental Authority on Development
IO	Input/Output
IRI	International Research Institute for Climate and Society, Columbia University
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre, European Commission
LDC	Least Developed Country
LLDC	Landlocked Developing Country
LTAC	Local Technical Agroclimatic Committee
MHEWEAS	Multi-Hazard Early Warning and Early Action System
MSD	Midsummer Drought
MTAs	Mesas Técnicas Agroclimáticas
MTG	Meteosat Third Generation
NAPs	National Adaptation Plans
NASA	National Aeronautics and Space Administration
NCOF	National Climate Outlook Forum
NDCs	Nationally Determined Contributions
NFCS	National Frameworks for Climate Services
NMHSs	National Meteorological and Hydrological Services
NMME	North American Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
OACPS	Organisation of African, Caribbean and Pacific States
OCHA	Office for the Coordination of Humanitarian Affairs
ONACC	Observatoire National sur les Changements Climatiques au Cameroun
PAFO	Pan-African Farmers' Organization
PICSA	Participatory Integrated Climate Services for Agriculture
PSP	Participatory Scenario Planning
PUMA	Preparation for Use of Meteosat in Africa
RAAWG	Regional Anticipatory Action Working Group (Southern Africa)
RADA	Rural Agriculture Development Authority, Jamaica
RAM	Resource Allocation Map
RCC	Regional Climate Centre

RCOF	Regional Climate Outlook Forum
RCP	Representative Concentration Pathways
REC	Regional Economic Community
SADC	Southern Africa Development Community
SARCOF	Southern African Regional Climate Outlook Forum
SDG	Sustainable Development Goal
SEB	Socio-Economic Benefit
SIDS	Small Island Developing State
SMAP	Seasonal Media Action Plan
SNA	System of National Accounts
SPI	Standardized Precipitation Index
SSPs	Shared Socioeconomic Pathways
THI	Temperature Humidity Index
ToT	Training of Trainers
UIP	User Interface Platform
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WASH	Water, Sanitation and Hygiene
WFP	World Food Programme
WMO	World Meteorological Organization
WMO-RCC	World Meteorological Organization – Regional Climate Centre

Foreword

H.E. Moussa SALEH BATRAKI

Secretary General, Organisation of African, Caribbean and Pacific States (OACPS)

The 79 Members of the Organisation of African, Caribbean and Pacific States (OACPS) are a crucial global constituency, with a combined population of approximately 1.5 billion people. They are among the world's most vulnerable countries and communities, spanning across six regions, and comprise 39 Small Island Developing States (SIDS), 37 Least Developed Countries (LDCs) and 15 Landlocked Developing Countries (LLDCs). Many face a myriad of development challenges, with the ongoing climate crisis poised to exacerbate their situations and severely impede the attainment of the 2030 Agenda for Sustainable Development and its seventeen Goals.

Members of the OACPS are on the frontline of the escalating climate crisis, suffering the brunt and bearing some of the heaviest of burdens due to the increasingly frequent and more intense weather and climate-related shocks.

The recent catastrophic impacts of hurricanes in the Caribbean, droughts and floods across African regions, as well as tropical cyclones in the Pacific, are testament to the devastating, lived experiences that are wreaking havoc on the lives, livelihoods and well-being of OACPS' peoples, and on the economies and long-term sustainable development prospects and aspirations of OACPS countries.

Unfortunately, the findings of the most recent report from the Intergovernmental Panel on Climate Change (IPCC) are of grave concern, as they indicate that the frequency and severity of numerous extreme events are expected to increase further as a consequence of climate change, while the risk of slow-onset events, such as sea level rise, desertification, loss of biodiversity, land and forest degradation, are set to accelerate.

In this context it is reassuring that the OACPS Secretariat signed the Financing Agreement with the European Union under the 11th European Development Fund (11th EDF), to implement the €85 million, Intra-ACP Climate Services and related Applications Programme – ClimSA.

ClimSA has, since its inception in 2020, contributed to improved access and use of climate information while promoting the development of climate services and applications for informed decision making, at all levels. Improving the quantity and quality of climate services offered by regional climate centres and hydrometeorological organisations in Members of the OACPS is critical to the global effort of combating climate change and building capacity to advance climate change adaptation initiatives.

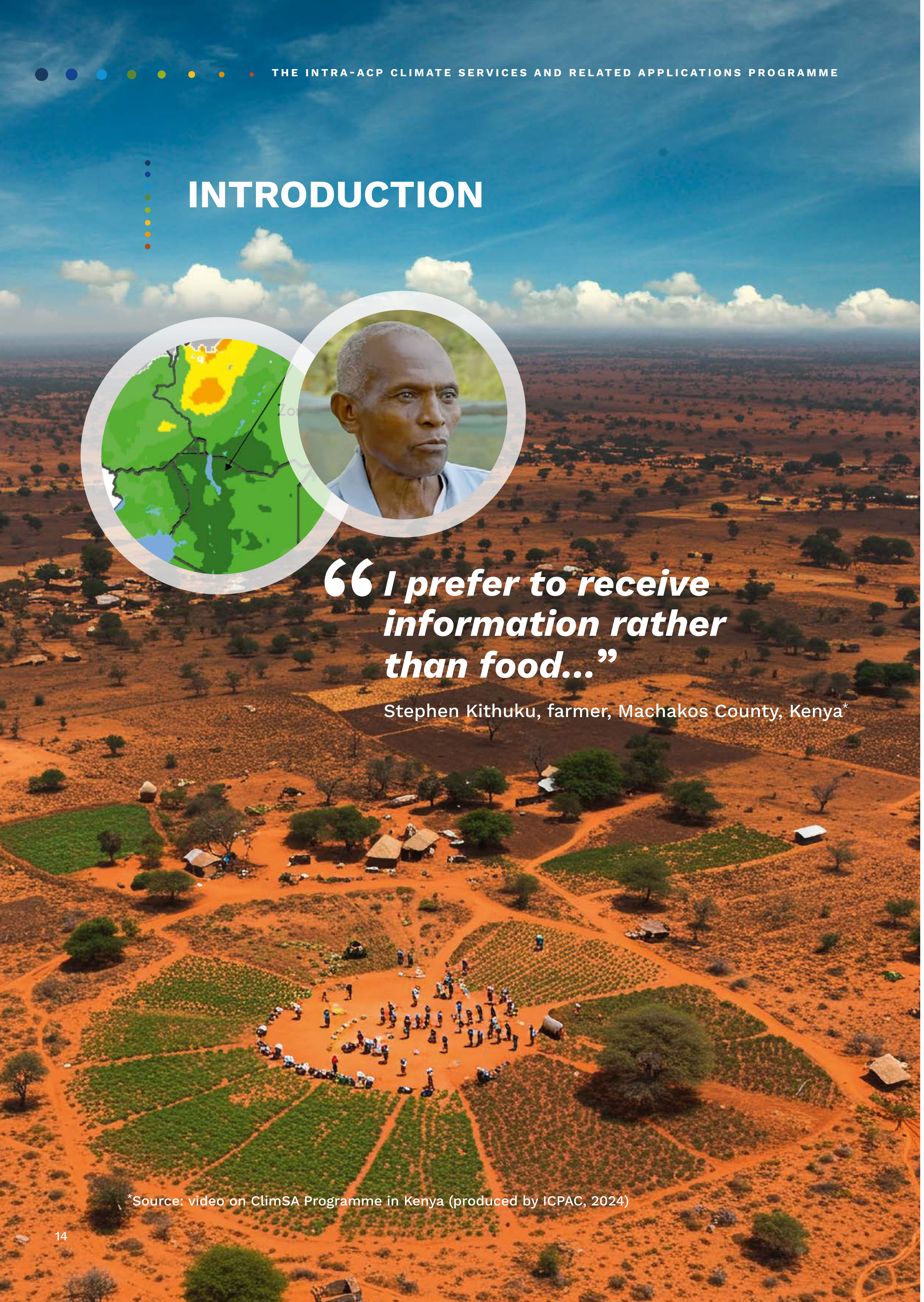
The ClimSA Programme is also instrumental in the global efforts of the United Nations World Meteorological Organization (WMO), which is mandated to report regularly on the global status of climate services, in accordance with relevant decisions of the United Nations Framework Convention on Climate Change (UNFCCC). ClimSA also provides the opportunity for Member of the OACPS and regional organisations to carry out regular assessments of their adaptation needs and application, as well as to identify and address related gaps, good practices, lessons learned, and guidelines.

This compilation of case studies is a concrete and effective demonstration of South-South and Triangular Cooperation, which is a hallmark of the ClimSA Programme. The case studies have benefitted from a wide range of contributions by ClimSA's implementing partners, including by regional organisations (Regional Economic Communities - RECs), Regional Climate Centres (RCCs) and technical implementing agencies such as the WMO, the European Commission Joint Research Centre (JRC), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the African Union Commission (AUC), as well as the OACPS Secretariat and the European Union Directorate-General for International Partnerships (DG INTPA).

The purpose of this document is to help decision-makers, both in the public and private sectors, to identify and manage the risks and opportunities induced by climate change in the field of agriculture and food security. It highlights lessons learned, best practices, and ongoing challenges. By focusing on key results achieved with ClimSA support in strengthening the climate services value chain in the OACPS regions, the publication seeks to build on and share some of the success stories from pilot countries that participated in the ClimSA Programme.

The focus on agriculture and food security reflects the sector's strategic importance and cross-cutting relevance across all OACPS regions. The document examines how users and climate services providers are engaging with each other via User Interface Platforms (UIPs) and how users' needs are being addressed through climate data and information products (climate services and related applications). It analyses how climate observations and monitoring are being improved to deliver more timely and accurate products and services, for social, economic and environmental benefits. The case studies also provide an overview of how climate research, modelling and prediction are tailored to different user requirements, and how capacities are enhanced to improve the long term sustainability and ownership of climate services and related applications.

I highly commend the efforts made within ClimSA, as a timely source of information, inspiration and reference on the types of investment that may be needed to support and assist governments, businesses and households in making better, more timely decisions. These efforts will be crucial in managing and mitigating the impacts of climate change as they endeavour to build resilient, safe and secure societies, and achieve their sustainable development objectives, goals and aspirations now and into the future.



INTRODUCTION

> **"I prefer to receive information rather than food..."**
>
> Stephen Kithuku, farmer, Machakos County, Kenya*

*Source: video on ClimSA Programme in Kenya (produced by ICPAC, 2024)

Climate Services for Agriculture and Food Security in Member States of the Organisation of African, Caribbean and Pacific States

Cristelle PRATT, Peter Nyongesa WEKESA

OACPS Secretariat

The intensification of climate change and variability demand urgent climate action to strengthen adaptation, mitigation and the development of sustainable blue and green economies in Member States of the Organisation of African, Caribbean and Pacific States (OACPS). In the agriculture and food security sector, providing healthy food for all, today and tomorrow, is critical, as is aligning the transformation of agri-food systems with climate action. However, agricultural and food systems face a dilemma: produce more now to meet immediate needs while potentially compromising future food security and nutrition - or curb production to reduce emissions.

Climate change disrupts food markets, posing population-wide risks to food supply. Indeed, widespread changes in rainfall and temperature patterns threaten agricultural production and increase the vulnerability of people dependent on agriculture for their livelihoods, which includes most of the ACP's poor population. These threats can be reduced by strengthening the adaptive capacity of farmers through climate information services.

The Intra-ACP Climate Services and Related Applications Programme

The OACPS Secretariat, funded by the European Union, in partnership with the African Union Commission (AUC), the World Meteorological Organization (WMO), the European Commission's Joint Research Centre (JRC) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) - have committed to build the capacity of Regional Climate Centres (RCCs) of the African, Caribbean and Pacific (ACP) regions to design, develop and tailor climate services which meet the needs of the users on the ground in various climate sensitive sectors.

To help unlock the potential of agriculture, food security and other sensitive sectors, while driving their transformation to address common environmental and climate change challenges, the OACPS is implementing the Intra-ACP Climate Services and related Applications (ClimSA) Programme. Timely and actionable weather and climate services are fundamental to progress on key global and regional or national policy agendas.

The ClimSA Programme is a €85 million initiative, funded under the 11th European Development Fund (EDF) framework of the European Union and OACPS cooperation. The objective is to strengthen the production, availability, delivery and application of science-based climate predictions and services. The successful implementation of the Programme relies on collaboration among various stakeholders and beneficiaries, including governments, research institutions and local communities, to ensure that climate services are tailored to the specific needs of the different partners involved.

The intervention provides technical support, capacity building, institution strengthening and awareness for eight RCCs in the ACP regions. As main users of climate services and the bridge to other final users, the African Regional Economic Communities (RECs), the African Union Commission (AUC), the Caribbean Meteorological Organisation (CMO) and the Secretariat of the Pacific Regional Environment Programme (SPREP), have been the focus of the action to ensure sustainable utilisation of climate services.

The ClimSA Programme focuses on enhancing the capacity of decision-makers at all levels to make effective use of climate information and services. This includes bridging the gap between climate science and policy, which is essential for effective agricultural planning and food security strategies. The Programme is aligned with the broader goals of sustainable development, particularly in addressing the impacts of climate change on food systems and ensuring food security across the ACP regions.

The main expected results of ClimSA Programme are: (1) the engagement of stakeholders through the user interface platform (UIP); (2) provision of climate services through Climate Services Information Systems (CSIS) at regional and national levels; (3) improvement of access to data and information; (4) building capacity to generate and apply climate information and products; (5) mainstreaming climate into policy and programmes through climate-informed decision-making (Figure 1).

Figure 1. Main expected results of the ClimSA Programme.

1. **Interaction between the users, researchers and climate services providers** in ACP regions is structured.
2. **Provision of climate services** at regional and national level is effectively guaranteed and secured.
3. **Access to climate information** is improved.
4. **Capacity of ACP regions is enhanced** to generate and apply climate information and products relevant to their particular concerns.
5. **Climate-informed decision-making is enhanced** and climate services are mainstreamed into policy processes at regional and national levels.

The resilience of our society to increasing climate risk depends on the ability to improve the quality and the quantity of climate services and the uptake of climate knowledge into decision-making processes. Climate services are key inputs for the climate adaptation strategy of OACPS countries in all sensitive sectors. In the case of agriculture and food security, climate services are crucial in developing innovative climate adaptation measures to improve crop production and improve food diversification. In this sector, the Programme in collaboration with Regional Climate Centres (Figure 2), has been working towards climate-resilient pathways through four main action areas: (i) strengthening the scientific base of climate information; (ii) increasing local uptake of climate information for climate risk management; (iii) fostering effective evaluation of the benefits of climate information for user productivity; and (iv) linking climate and agricultural financing with policy development.

Figure 2. Regional Climate Centres involved in the implementation of the ClimSA Programme.

This Publication

The present publication aims to showcase the achievements of ClimSA's products and services, with a focus on the agriculture and food security sector. The Programme has worked to strengthen the climate services value chain: from access to information, to generation of climate services, engagement and capacity strengthening of users, through to ensuring the utilisation of climate services that help farmers and policymakers make informed decisions.

The publication has been structured according to five main sections, loosely based on the key components of the Global Framework for Climate Services (GFCS)[1], with contributions from a variety of partner institutions and stakeholders of the ClimSA Programme.

Section 1. Engaging Users and Climate Services Providers. The section examines how engagement between users and providers of climate services can make users have their voice heard and make sure climate services are relevant to their needs. The first chapter reviews the last 25 years of operations of the Greater Horn of Africa Climate Outlook Forum (GHACOF), extrapolating lessons on the access and uptake of climate services being advanced at regional and national levels through GHACOF's regional User Interface Platform (UIP). The second chapter describes the operationalisation of a continental UIP for the agricultural sector in Africa, analysing how the platform facilitates the co-design and co-production of climate services, while enhancing the collaborative development, delivery and use of climate information for early warning and adaptation to climate change. The final chapter in the section, drawing on long-term experience from the Caribbean region, examines the design and implementation of Participatory Integrated Climate Services for Agriculture (PICSA), as they successfully lead farmers to identify and better plan farm and livelihood options that are suited to the local micro-climate and the farmers' own circumstances and contexts.

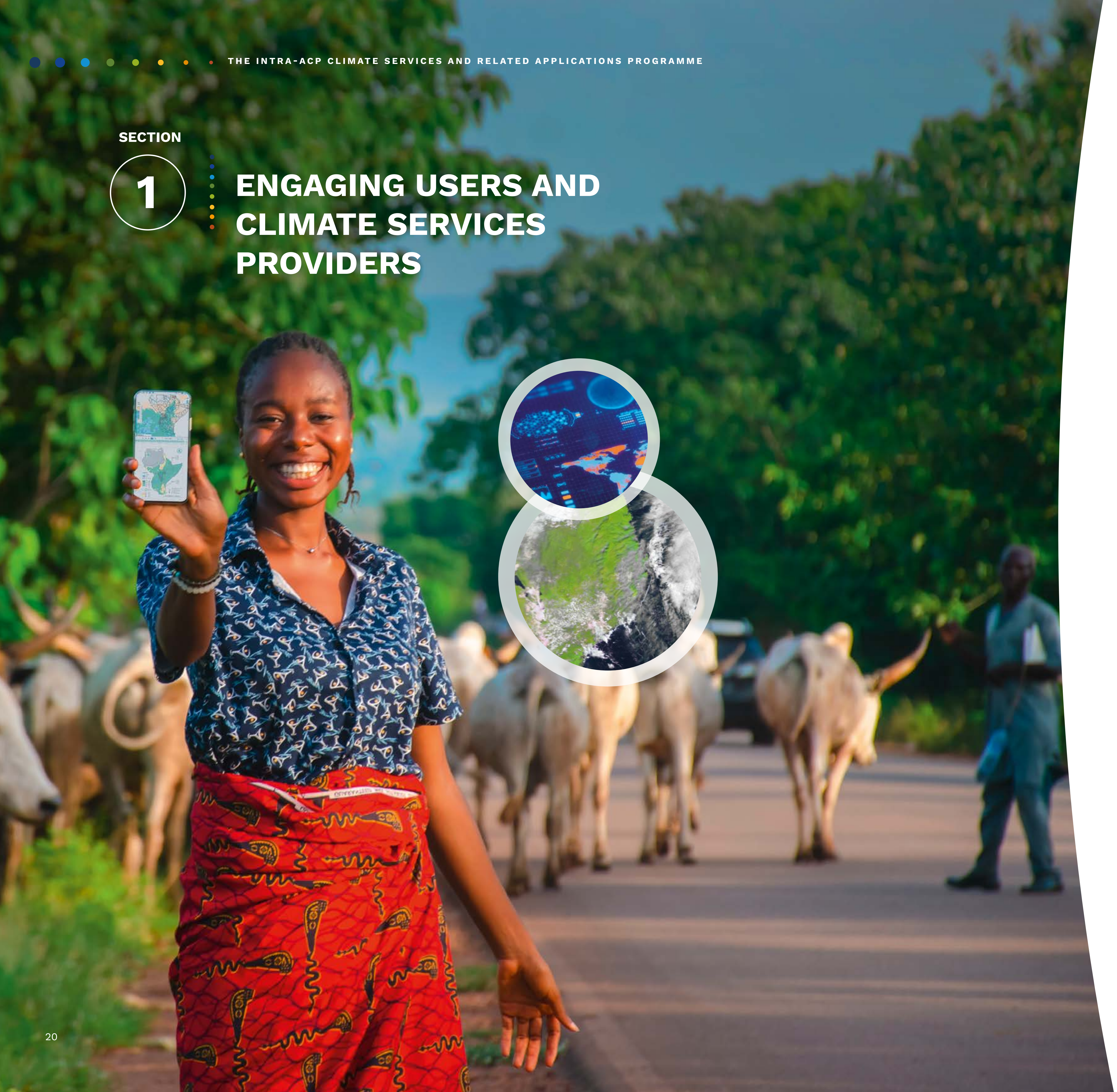
Section 2. Addressing User Needs through Climate Data and Information Products. This section focuses on how climate services are designed and implemented for the production and distribution of climate data and information products addressing user needs. The first chapter provides a detailed account of the impact of climate services on agricultural production in Burkina Faso, showing that farmers can boost agricultural productivity and improve their resilience to climate variability by making use of climate information. The second chapter examines the integration of climate services with the UN Early Warning System in Eastern Africa, through the dissemination of climate information, early warnings and advisories through various online platforms reaching a large number of users. The final chapter examines early warning systems for the agricultural sector in the Caribbean and how these favour the development of climate-smart agriculture and long-term strategies to secure sustainable food security.

Section 3. Improving Climate Observations and Monitoring. This section looks at how systematic observations and monitoring are used to generate the data required for the development and implementation of effective climate services. The first chapter, by taking as a case study the Southern African Regional Climate Outlook Forum (SARCOF), draws important lessons for the agriculture and food security sector in the region. The second chapter examines heat as a hazard in the Caribbean, in view of the rapidly increasing heat risk in the region, with a particular focus on the prediction of extreme heat, including heat waves, and forecasting potential heat stress. The final chapter in the section assesses the role of space-based climate monitoring in tracking atmospheric, oceanic and terrestrial changes over time and how data services are evolving thanks to the latest generation of satellites and to recent scientific and technological advances.

Section 4. Tailoring Climate Research, Modelling and Prediction. This section investigates how research, modelling and prediction advance the science needed for improved climate services that meet user needs. The first chapter presents upgraded climate projections and their spatial distribution for Africa in the near future (2041-2060); by alerting policymakers against the impending future climate disasters, this information is likely to become increasingly important as African nations make efforts to respond to the growing effects of climate change over the coming decades. The second chapter examines the role of climate change in intensifying the 2015/16 El Niño and its implications for Southern Africa; it explores how lessons from such recent El Niño events and attribution studies can inform current forecasting practices, improve resilience and contribute to international loss-and-damage discussions, particularly for ACP countries that are disproportionately affected by climate variability and change.

Section 5. Enhancing Capacity Development. The section aims to review how capacity development supports the systematic development of the institutions, infrastructure and human resources needed for effective climate services. The first chapter hinges on the need to invest in improved Decision Support Systems (DSSs) for agricultural policy development; by integrating advanced technologies, enhancing data management, focusing on user-centric design, incorporating scenario analysis and aligning with policy frameworks, stakeholders can significantly enhance the effectiveness and impact of agricultural policies. The second chapter presents a new Socio-Economic Benefit (SEB) tool for the assessment of climate services in the OACPS regions; the model's methodology, based on the input-output system dynamic, is able to compute the damage effects of various scenarios, and when adapted and calibrated to represent a specific country, it becomes a critical element in a DSS supporting the actions and decisions to be taken by decision makers. The final chapter in the section examines policy and practice implications for enhancing climate services targeting the agriculture sector, by assessing key advances since the establishment of the GFCS in 2012, which laid the foundation for a more systematic and coordinated approach to climate services worldwide; the chapter also looks ahead at how the development of more user-centric, inclusive and participatory climate services could enhance opportunities for further policy integration and financial support, both from national and regional governments as well as the international climate finance instruments.

1 *https://gfcs.wmo.int/site/global-framework-climate-services-gfcs/components-of-gfcs (accessed 15 January 2025).*



SECTION 1

ENGAGING USERS AND CLIMATE SERVICES PROVIDERS

The section examines how engagement between users and providers of climate services can make users have their voice heard and make sure climate services are relevant to their needs.

The first chapter reviews the last 25 years of operations of the Greater Horn of Africa Climate Outlook Forum (GHACOF), extrapolating lessons on the access and uptake of climate services being advanced at regional and national levels through GHACOF's regional User Interface Platforms (UIPs).

The second chapter describes the operationalisation of a continental UIP for the agricultural sector in Africa, analysing how such a platform facilitates the co-design and co-production of climate services, enhancing the collaborative development, delivery and use of climate information for early warning and adaptation to climate change.

The final chapter, drawing on long-term experience from the Caribbean region, examines the design and implementation of Participatory Integrated Climate Services for Agriculture (PICSA) which are successfully leading farmers to identify and better plan farm and livelihood options that are suited to the local micro-climate and the farmers' own circumstances and contexts.

CHAPTER 1.1 Capitalising 25 Years of Operations of the Greater Horn of Africa Climate Outlook Forum

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IGAD Climate Prediction and Applications Centre (ICPAC)

In 1996, the World Meteorological Organization (WMO), the International Climate Centres and the National Meteorological and Hydrological Services (NHMSs) launched the first Regional Climate Outlook Forums (RCOFs). These aim to bring together national, regional, and international climate experts to collaboratively produce seasonal climate forecasts for specific regions. By 1998, such forums were established worldwide, enhancing regional networks involving climate service providers and users across various sectors (NOAA, 1988).

The Greater Horn of Africa Climate Outlook Forum (GHACOF) serves the Intergovernmental Authority on Development (IGAD) in Eastern Africa (Box 1). Since 1998, it meets three times a year to release the seasonal climate outlook and develop sector advisories, with partners and stakeholders from eight IGAD Member States (Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda) and three non-IGAD Member States (Burundi, Rwanda and Tanzania).

Box 1. Main objectives of the Greater Horn of Africa Climate Outlook Forum (GHACOF).

- Reflect on the performance and impacts of the previous season.
- Present the consolidated objective regional climate outlook for the upcoming season.
- Discuss the implications of the seasonal climate forecast on key socio-economic sectors and develop management strategies.
- Provide a regional platform for interaction between decision-makers, climate scientists, research scientists, users of climate information and development partners.
- Facilitate the exchange and dissemination of climate information, skills and experiences among participants to enhance collective learning.
- Release and disseminate the outcomes of the forum and the statement.

The regional forum implements an objective seasonal forecast procedure, which ensures that forecasts are traceable, reproducible, and verifiable. The methodology, which emphasises scientific rigor and reliability, was introduced at the 52nd Greater Horn of Africa Climate Outlook Forum in May 2019, marking a significant paradigm shift after 20 years of using a consensus-based approach.[2] Over the past five years, the objective forecast methodology has been refined and maintained, demonstrating its effectiveness and robustness while opening new possibilities for developing more user-relevant climate products. It allows for greater flexibility in tailoring forecasts to specific sub-regional and national needs, thereby enhancing their utility for decision-makers in various sectors (Box 2).

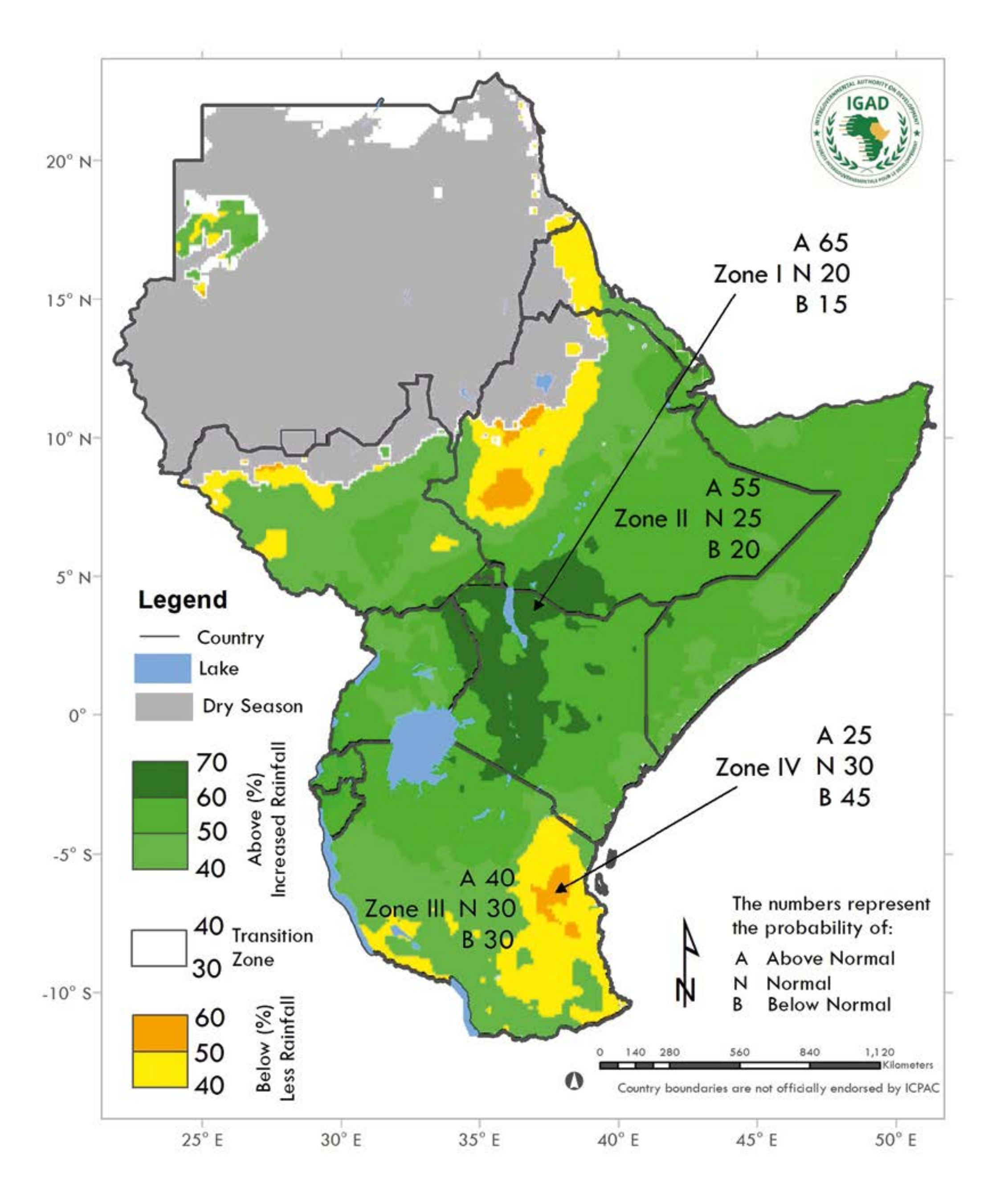
Box 2. Key components of the Greater Horn of Africa Climate Outlook Forum (GHACOF).

- Pre-COF climate prediction development workshop for climate scientists and co-production workshops with key sectors including agriculture, water, energy, health, livestock, media and disaster risk management.
- Impact reporting by the National Sector Focal Points from the GHA region on the past rainfall season performance and its impacts on sectors.
- Forum where the regional seasonal climate outlook is presented to the users who translate the outlook into sectoral impacts and develop management strategies for their respective sectors.
- User interface sessions involving face to face engagement between the providers and multi-sectoral users.
- Development and dissemination of summary for decision-makers across the region.
- Dissemination and press release of the GHACOF outcome through a statement National Climate Outlook Forum in which the regional seasonal climate outlook is downscaled to national and sub-national levels and disseminated to the national and sub-national users.

2 https://icpac.medium.com/building-resilience-across-east-africa-through-the-production-and-communication-of-seasonal-11525bff90f7 *(accessed 15 July 2024).*

Besides the probabilistic rainfall and temperature forecasts, the regional forum also provides sector-tailored climate products. These include forecasts for the onset of the rainy season, the length of wet and dry spells within the season, and the probability of seasonal rainfall exceeding user-defined thresholds. Forecasts of the probability of meteorological droughts are also provided, based on the Standardized Precipitation Index (SPI), which tracks observed and predicted precipitation over periods of 3, 6, 9, 12 and 15-months (Figure 3).

Figure 3. The regional seasonal rainfall outlook for various zones within the Greater Horn of Africa region for March to May 2024.



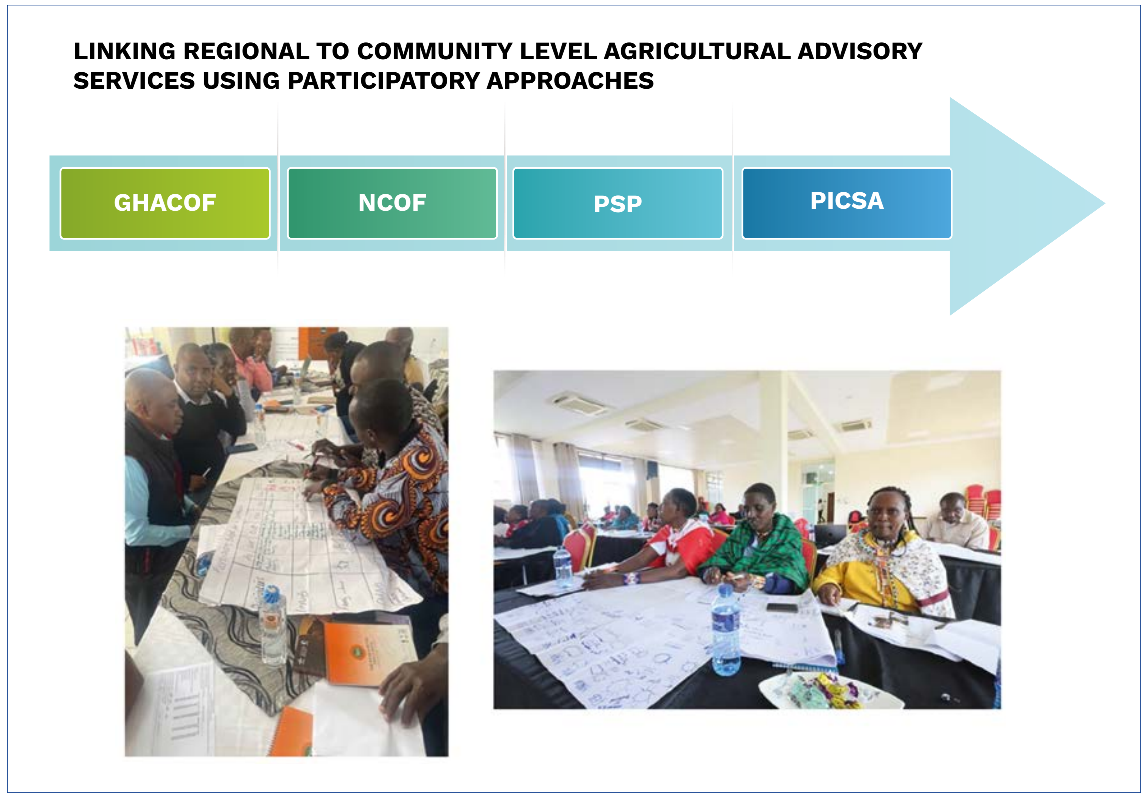
1.1.1 Climate Services Uptake and Outcomes

In Eastern Africa, access and uptake of climate services at regional and national levels is being advanced. through GHACOF's regional user interface platforms such as the ClimSA-supported climate demonstrations pilots in Machakos County, Kenya and Kiboga District, Uganda. The main objective of the demonstrations is to develop and implement adaptation strategies and measures that will strengthen the resilience of vulnerable sectors, particularly in agriculture, food security, water and energy sectors (Figure 4).

This is achieved through the provision of timely and reliable climate information that guides the development of advisories for the season, tailored for the local community. Local capacity in various aspects of climate and sectoral services have been strengthened, particularly by enabling access to collective interpretation and understanding of seasonal climate forecasts which feed into locally relevant sectoral and livelihood decision-making.

The participatory approach underlying these demonstrations entails the production and integration of knowledge to solve rural smallholder farmers' challenges in the face of climate change and variability. The process acknowledges that there is no 'one fit all' solution to smallholder farmers' challenges and as such, knowledge integration and continuous adaptive learning and management are key.

Figure 4. Farmers taken through climate participatory approaches at the community level.



1.1.2 Outcomes and Lessons Learnt

The experience gained over more than 25 years of operations of the regional forum, enhance in multiple ways climate services in the Greater Horn of Africa.

Improving the Climate Services Information System

User Engagement. Bringing together experts and stakeholders to co-produce regional climate information and advisories, actively involves users, such as decision-makers, farmers, and water resource managers, ensuring that climate services align with their needs and priorities.

Regionalisation of Global Climate Information. Global-scale climate information, is made relevant and actionable at local levels, bridging the gap between global climate data and user-specific requirements.

Two-Way Information Flow. Facilitating interaction between climate service providers and users ensures a continuous exchange of information, feedback, and tailored climate services.

Mitigating Climate Change Impacts and Extreme Weather Events

Early Warning and Preparedness. They provide timely and accurate climate outlooks, helping communities prepare for extreme events like floods, droughts, and heatwaves. By anticipating risks, decision-makers can take preventive measures.

Adaptive Strategies. The regionalisation of global climate information, makes it relevant at local levels, enabling tailored adaptation strategies, such as adjusting agricultural practices, water management, and disaster response.

Risk Reduction. Communication between climate service providers and users helps to disseminate accurate climate information, empowering communities to reduce vulnerability and enhance resilience.

Scientific Collaboration. The collective effort of bringing together experts, fosters collaboration on climate research and monitoring, informing policies and actions to mitigate climate impacts.

Cross-learning across the globe. Regional climate outlook forums have been established in various regions across the world. However, in some cases this has occurred in relative isolation and platforms may vary in their capacity to provide information to national meteorological services and sectoral decision-makers. The challenge is now to share best practices across regional forums, namely procedures and regulations for forecasting and projections and for the co-production and communication of high-quality climatological information.

Promoting the co-production of climate services. The outlook forums serve as platforms for scientists, policymakers, and non-governmental actors to interact regularly and collaboratively. By engaging in this iterative process, they co-produce actionable scientific knowledge that informs climate adaptation decision-making. Effective co-production processes within these forums also contribute to better climate information, which can guide adaptation strategies for different sectors.

Monitoring and evaluation of climate services. Climate outlook forums are key in promoting the monitoring and evaluation of climate services. Through interaction with sectoral users, extension agencies, and policymakers, the likely implications of climate outlooks on socio-economic sectors are assessed helping to tailor climate information to stakeholders' needs. Such evaluations can enhance their effectiveness and ensure actionable climate information reaches decision-makers.

Mainstreaming gender in climate action. Gender inequality, fuelled by gender norms, proscribed roles for women and men, unequal access to resources and discriminatory practices, significantly affect women and marginalised groups' vulnerability to climate hazards. It not only increases their exposure to risks but also limits their ability to cope and adapt. For example, in many cultures women are often responsible for household duties, including taking care of children and the elderly, which may cause them to delay evacuating during floods. This delay can significantly increase their risk of injury or even death. Early warning systems that fail to consider gender inequalities can exacerbate these existing vulnerabilities.

Gender considerations are increasingly being integrated throughout the GHACOF process, including gender mainstreaming in pre-fora webinars and workshops and the inclusion of gender in the forum agenda. These efforts resulted in progress towards gender-responsive climate advisories as reflected in recent GHACOF summaries for decision-makers.[3,4]

Building on this success, during 2024 the ClimSA Programme further strengthened gender mainstreaming by supporting participation of seven gender focal points from five member states, training national focal points on gender-responsive reporting, engaging with gender focal points before GHACOF meetings, and involving them in all co-production sessions.

By involving gender focal points/experts across all climate-sensitive sectors (agriculture and food security, livestock, water and energy, disaster risk management, and conflict), gender considerations were integrated into sector-specific climate advisories, leading to more responsive outcomes as reflected in the GHACOF summary for decision-makers.[5]

Promoting the role of media and communication in climate services. A dedicated network of climate journalists and meteorological communication officers is being supported in the Greater Horn of Africa. The aim is to strengthen the link between the producers and users of climate information, ensuring that climate products reach the last mile users, by breaking down the complex climate information into content and languages that are easily understood by the local communities. GHACOFs provide a platform for the media and meteorological communication officers to meet and receive the forecast and come up with a seasonal media action plan for the season. Additionally, the forum provides an opportunity for the media to interact with scientists, building their capacity to better communicate climate information to the end users.

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3 https://www.icpac.net/publications/summary-for-decision-makers-october-to-december-2023-season/ (accessed 15 July 2024).
4 https://www.icpac.net/publications/summary-for-decision-makers-march-to-may-2024-season/ (accessed 15 July 2024).
5 https://www.icpac.net/publications/summary-for-decision-makers-june-to-september-2024-season/ (accessed 15 July 2024).

CHAPTER 1.2 Operationalisation of a Continental User Interface Platform for the Agricultural Sector in Africa

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Climate services providers face growing pressure from users for tailored forecasts and information for decision making and action. Effectively responding to user needs based on credible scientific information is a well-recognised challenge requiring appropriate engagement between users and climate service providers.

To address this challenge and as part of activities for the implementation of the Climate Services and related Applications (ClimSA) Programme, the African Centre of Meteorological Applications for Development (ACMAD)[6] has established and operationalised User Interface Platforms (UIPs) at continental level for agriculture (Box 3), water, health, disaster risk reduction including infrastructure.

This chapter aims at sharing practices from the establishment and operationalisation of such UIPs across climate sensitive sectors in Africa. It analyses how the platforms facilitate the co-design and co-production of climate services, enhancing the collaborative development, delivery and use of climate information for early warning and adaptation to climate change (Hewitt et al. 2017; WMO, 2014, 2018).

The establishment of a platform dedicated to climate services for agriculture was initiated by ACMAD through a consultation workshop, held in Yaoundé-Cameroon from July 26 to 29, 2022, involving farmer groups at national, regional and continental levels (Box 4).

6 *The African Centre of Meteorological Applications for Development (ACMAD) is the WMO designated Regional Climate Centre for Africa since May 2015 and the African Continental Multi-Hazard Advisory Centre of the African Union Multi-Hazard Early Warning and Early Action System (MHEWEAS) since October 2022.*

Box 3. Institutions participating in the establishment of a User Interface Platform (UIP) on climate services for agriculture in Africa.

- **Regional Climate Centre of IGAD** (ICPAC), Nairobi, Kenya. Service provider.
- **Regional Climate Centre for all Africa** (ACMAD), Niamey, Niger. Service provider.
- **Climate Service Centre of SADC** (SADC CSC), Gaborone, Botswana. Service provider.
- **Food and Agriculture Organisation**(FAO), Rome, Italy. Food and agriculture advice and support to farmers.
- **World Food Programme** (WFP), Rome, Italy. Hunger alleviation institution.
- **National climate change observatory** (ONACC), Yaounde, Cameroon. Climate change detection and information dissemination.
- **Famine and Early Warning System Network** (FEWSNET), Washington DC, USA. Food insecurity analysis.
- **Agriculture Development Projects** (ADP) Yaoundé, Cameroon.
- **Institute of Agricultural Research** (IAR) Ibadan, Nigeria. Food quality and soil analysis, pest management.
- **Commercial Farmers**. Trade agriculture products.
- **Pan-African Farmers' Organisation**(PAFO), Kigali, Rwanda. Continental agriculture policy and information services for agriculture development in Africa.
- **African Union - Interafrican Bureau for Animal Resources** (AU-IBAR), Nairobi, Kenya. Coordination of use of animal resources (fisheries, wild animals and livestock).
- **Sustainable Agricultural Development and Esteemed Farming Profession** (OSACA) Akure, Ondo State, Nigeria
- **Department of Agriculture Rural Development, Blue Economy and Sustainable Environment, African Union Commission** (ARBE), Addis Ababa, Ethiopia. Agriculture policy development.

1.2.1 Establishment and Operationalisation of the User Interface Platform

The workshop reviewed existing mechanisms for climate services generation and delivery, the range of products and services provided to the agriculture sector, as well as use practices and challenges to demonstrate effective added value. Discussions guided the assessment of stakeholders' capacity gaps and the identification of relevant capacity building programmes. The engagement of participants throughout the consultation in monitoring, evaluation and review, helped to generate feedback and suggestions for future and iterative improvements.

Terms of References and Rules of Procedure

A key outcome of the consultation was the development and adoption of the terms of reference of the UIP on climate services for agriculture development in Africa. The composition of the platform, its rules of procedure, the work programme, climate products and services for the agriculture sector were equally defined and adopted. A chair of the UIP was elected and the secretariat is to be supported by ACMAD.

Risk Causes and Events in the African Agriculture Sector

Risk events and causes were identified, analysed and assessed, following recognised standards for risk assessment (Figure 5). Droughts, heat waves, floods, dry and wet spells, disruptions on the start and end of the agriculture season and calendar, hailstorms, strong winds and thunderstorms were identified as risk causes impacting the agriculture sector. These often lead to inflation in agriculture commodity markets, reduction in food production, scarcity of water for irrigation, losses of production due to high humidity and rainfall during the harvesting period, losses of yield with locust invasion.

Box 4. Specific objectives of consultation sessions involving agriculture stakeholders.

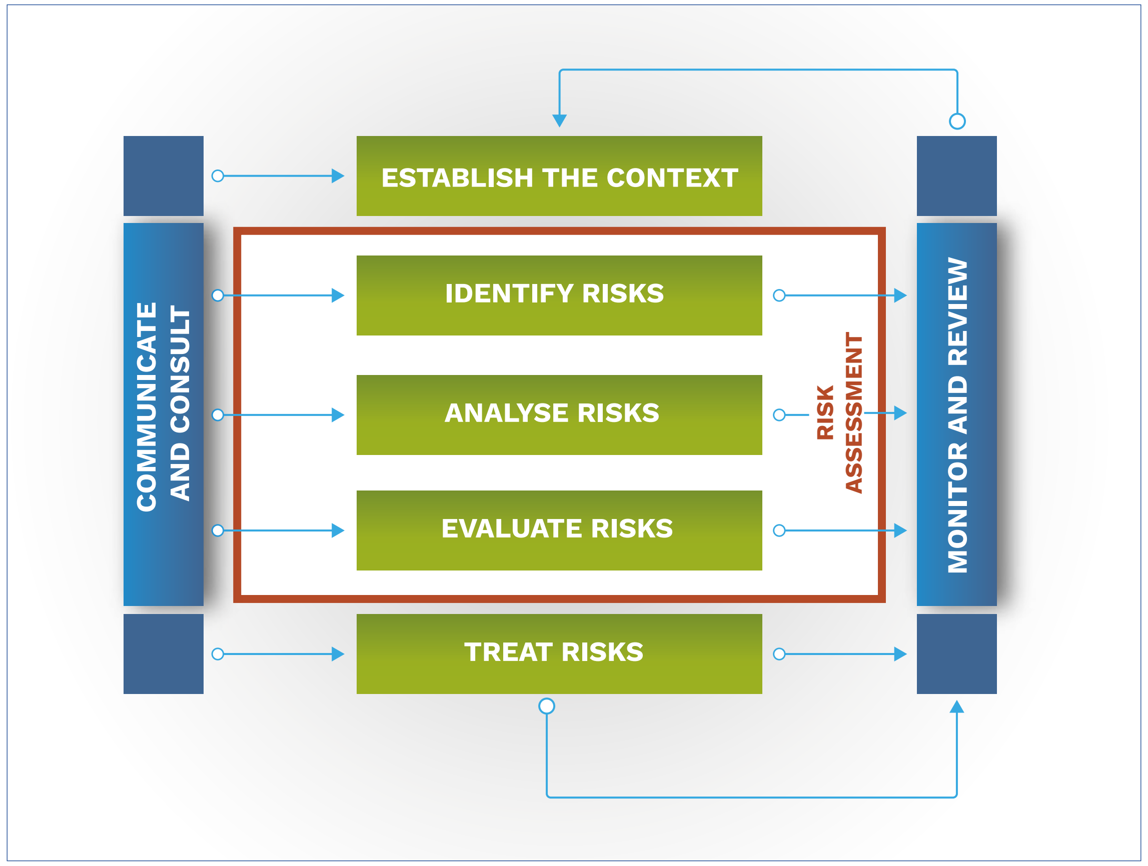
- Engage with the agriculture community at continental level.
- Assess the agriculture sector stakeholders' perspectives on climate risks.
- Map existing climate risks and opportunities management options and solutions.
- Take stock on climate products and services for risk and opportunities management.
- Formalise arrangements to establish and operate the UIP delivering climate services, collecting and reviewing feedback supporting regular improvements.

Climate Products and Services Required for the Agriculture Sector

Discussions and dialogue between stakeholders supported the identification of climate products and services requirements to address climate risks. These include seasonal total precipitation and temperature outlooks, start and end of agriculture season, dry and wet spells, advice for land preparation, sowing, fertiliser spray, weed control and management, harvesting, crop conservation, optimal crop varieties for agroclimatic zones, warnings and alerts for pests and diseases.

The joint work programme to operate the platform was based on the analysis of climate information needs along the agriculture value chain. The main products and services identified include impact-based climate monitoring and forecasting information, climate risk assessment for each commodity, the estimation of demand and supply in agriculture commodity markets, and the preparation of advices for farmers, herders, fishermen and other stakeholders on all relevant aspects of the value chain.

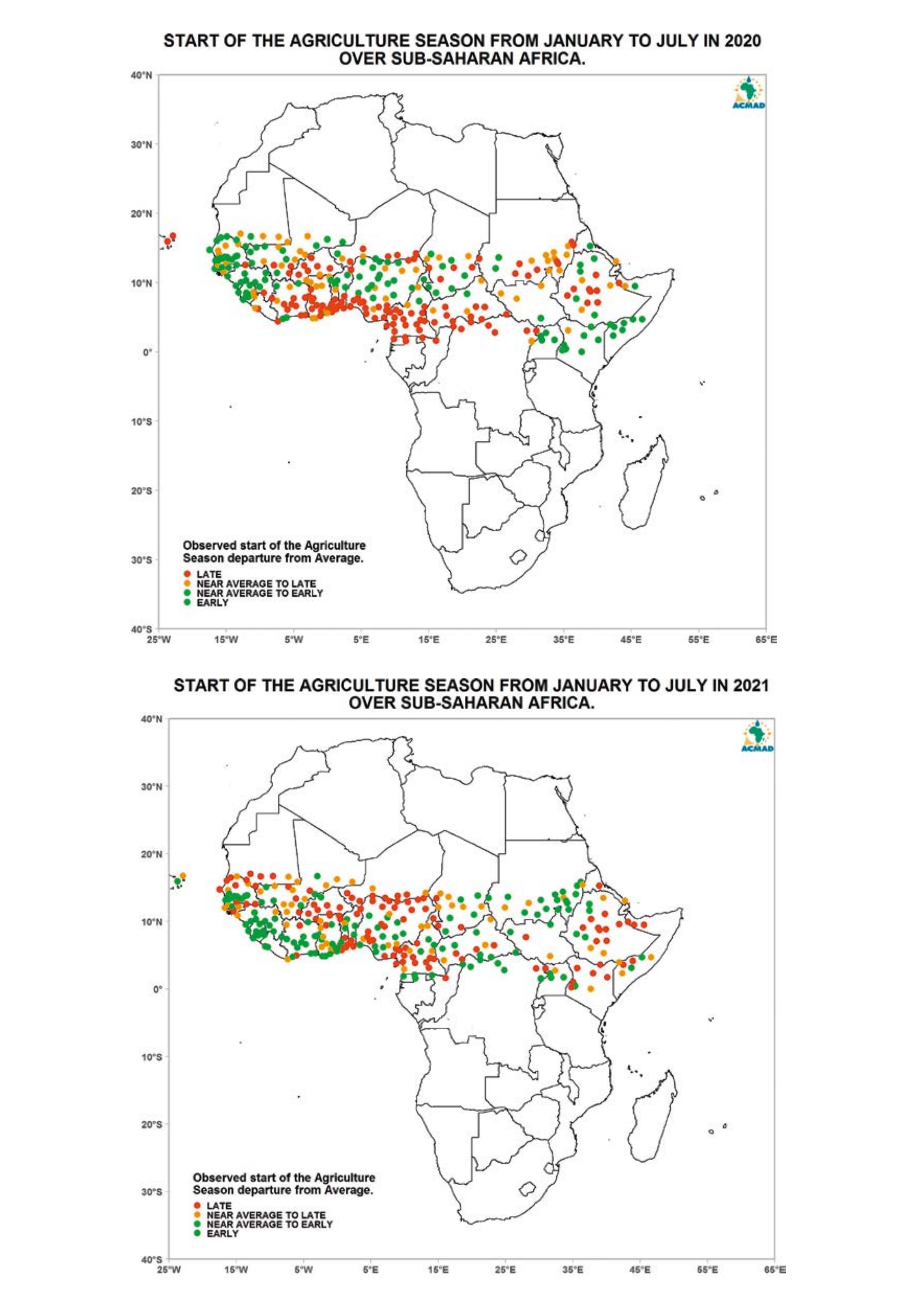
Figure 5. Description of risk assessment steps following ISO 31000 standards.



Flagship Service for the Agriculture Sector

ACMAD and its partners have developed a product for the detection and forecasting of disruptions at the start of the agriculture season. This product has become a flagship service for the agriculture sector, with regular weekly updates guiding the agriculture calendar, based on needs expressed by the Pan-African Farmers' Organisation(PAFO). For example, at the start of the agriculture season in Africa during the first half of 2021, most stations in Niger recorded a late start of the season, which led to a slowdown of the Gross Domestic Product (GDP) growth for 2021 (Figure 6).

Figure 6. Start of the agricultural season in Africa during the first half of 2020 (above) and 2021 (below).



Source: http://sgbd.acmad.org:8080/thredds/fileServer/ACMAD/CDD/climatemonitoringservice/season_onset_monitoring.html

1.2.2 Emerging Lessons

The agriculture sector, the major contributor to employment and GDP in Africa, is under serious pressure from climate variability and climate change and seeks to undergo transformation toward climate smart and resilient agriculture systems.

Define climate services with specific agriculture user needs in mind. Activities and interactions on the platform have provided evidence of the wide diversity of user needs within the agriculture sector. The start of the agricultural season product developed by ACMAD through the ClimSA Programme (see above) is becoming a flagship service for PAFO. Climate services value is progressively being identified and socio-economic benefits case studies are emerging to accelerate the development of new economic activities.

Enhance resolution of climate services. Vulnerable populations in need of climate services often live in poor rural communities. User Interface Platforms at regional, national and local levels are still to be established and operationalised. These would accelerate the uptake of downscaled climate services with high potential to address the climate adaptation and resilience needs of the most vulnerable.

Foster interactions between service providers and users. Cross-institutional engagement is increasing, with international virtual conferences accelerating the operationalisation of networks and platforms. For example, ACMAD's collaboration with PAFO has opened the possibility to reach more than one hundred million African farmers, sharing climate services to update agriculture calendars.

Further long-term investments are required for the establishment and operationalisation of platforms across sectors and within sectors to accelerate adaptation to climate change and resilience to extreme events. These platforms should advocate, develop and deliver impact-based climate services, building trust and reaping the benefits of user engagement.

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CHAPTER 1.3 Participatory Integrated Climate Services for Agriculture in the Caribbean

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1.3.1 Introduction

Participatory Integrated Climate Services for Agriculture (PICSA) is a holistic, integrated approach developed to address the challenges posed by climate variability and change in the agricultural sector, particularly at the level of production on smallholder enterprises in low-income countries. PICSA, which has now been implemented in at least 23 countries (Clarkson et al., 2022), makes use of historical climate records, simple, easily understood participatory decision-making tools and seasonal climate and shorter-term forecasts. As a result, farmers are equipped to identify and better plan farm and livelihood options that are suited to the local micro-climate and the farmers' own circumstances and contexts (Clarkson et al., 2022; Staub and Clarkson, 2021; Clarkson et al., 2019, Dayamba et al., 2018; Dorward et al., 2015). Using climate information in decision making is not straightforward but is made feasible using context-specific participatory whole-farm approaches (Staub et al., 2020), like PICSA.

One of the reasons for PICSA's success is that it centres on active engagement with farmers, providing them with the necessary tools and information to make informed decisions in a changing climate. Lack of direct engagement with farmers has been deemed as one of the failures of climate services to agriculture, with more top-down approaches used (Clarkson et al., 2022). The engagement follows the philosophy that agricultural extension officers play significant roles in enhancing productivity at the farm level in many areas of agriculture, but now with an additional focus on the delivery of weather and climate service to farmers. These officers are the ones farmers often rely on for support when challenges arise, and advice is needed. Implementation includes training workshops for extension staff who then work with established groups of farmers ahead of and during the agricultural season (Clarkson et al., 2022). Community leaders, who are well trusted in their communities, can also play a significant role alongside or in lieu of extension officers (Staub and Clarkson, 2021; Clarkson et al., 2019).

Climate services providers, whether national or regional, are critical to the success of the PICSA approach. National Meteorological and Hydrological Services (NMHSs) and Regional Climate Centres (RCCs) play vital roles in rescuing, cleaning, organising and analysing their climate data to deliver the products and services that are essential for farmers and facilitators as well as preparation and production of seasonal and shorter-term forecasts (Clarkson et al., 2022). Through their involvement in the PICSA implementation process, climate services providers have also become more aware of farmers' requirements, and the challenges they face, which enables them to carry out key functions of their service more effectively.

Before the PICSA approach can be implemented there are several important activities required, to tailor the approach to any new location. Preparing for implementation typically involves scoping and relationship-building activities. These activities are essential to understand farm management practices, crops typically grown, livestock reared, technologies in use, agricultural services and information and the actors surrounding these. It is also necessary to understand the agro-ecology and (micro) climate of the area and the location of meteorological stations that aid in understanding the climatic contexts (Clarkson et al., 2022), and how producers perceive these conditions influence production. Clarkson et al. (2022) identified the need to have stations at or near the location, with quality datasets to facilitate production of historical climate information. It is also paramount to assess the availability and skill of national seasonal forecast information. Finally, building a relationship between the various actors is fundamental to the success of PICSA - between climate services providers (national and regional), agricultural services providers and community leaders - engaging in regular dialogue and planning implementation together.

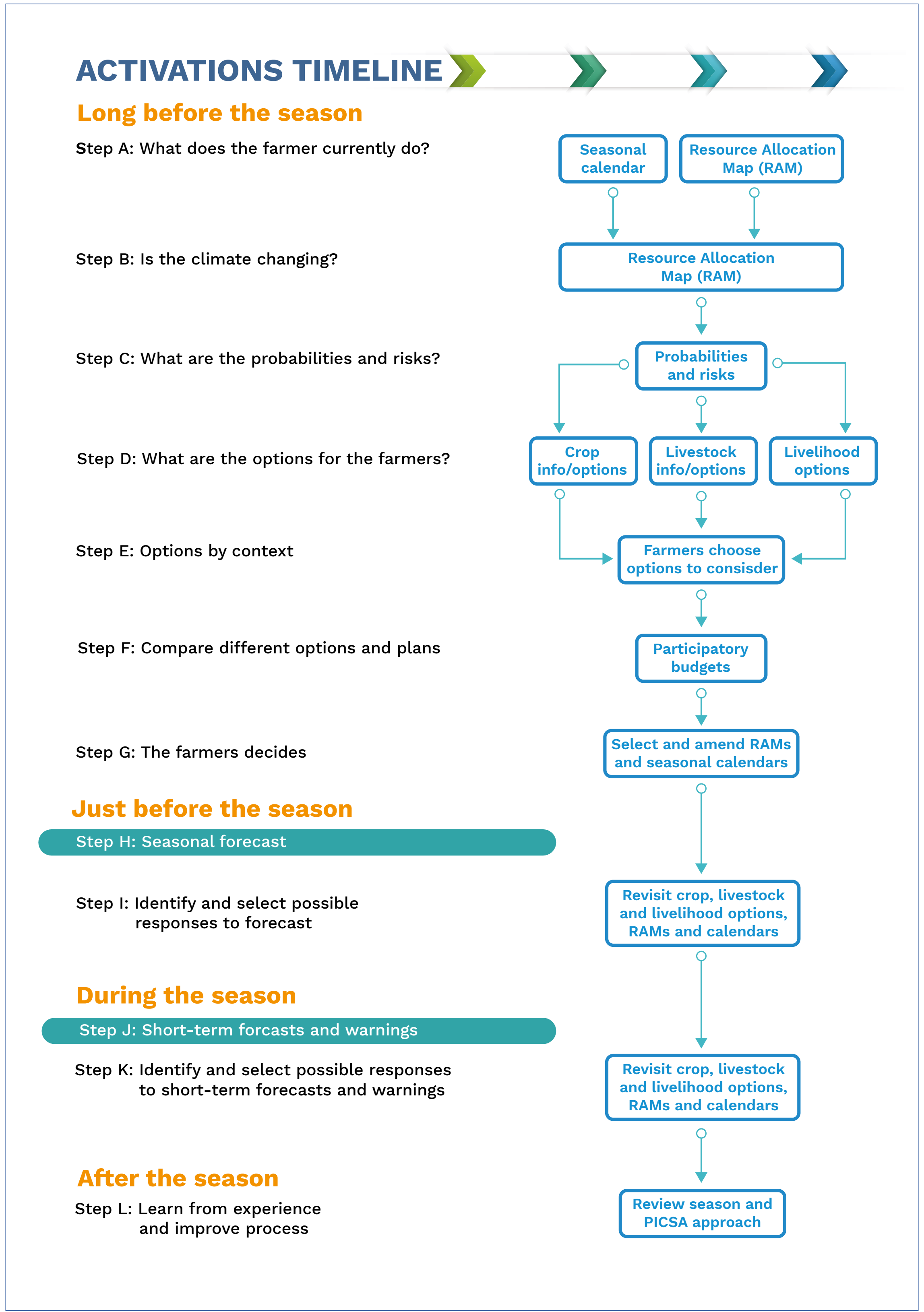
1.3.2 The PICSA Twelve Step Approach

With a tailor-made design for the new location emanating from the scoping and relationship building exercises, implementation commences with training of agricultural extension officers, climate services providers (National Meteorological and Hydrological Services) and/or community leaders (these essentially will be trained trainers) on a 12 step approach (Figure 7) for a period of one week (Staub and Clarkson, 2021; Clarkson et al., 2019; Dayamba et al., 2018; Dorward et al., 2015). It is also essential that the trained trainers get the opportunity to practice and test what they have learnt. To satisfy this, the fourth day is typically spent in the field with a group of farmers going through the steps of the approach and the simple tools used (Figure 8). On the fifth and final day, the field day is reviewed, and time spent shoring up where the trainees might recognise they needed additional assistance regarding the methodology or tools.

The 12 steps are divided into four phases (Figure 7):

- Long before the growing season;
- Just before the growing season;
- During the growing season;
- Shortly after the growing season.

Figure 7. Twelve step PICSA approach, with its four phases (Dorward et al., 2015).



After extension staff have completed their one week training, they then train farmers in groups. To complete the 12 steps normally takes about four three-hour meetings with farmers. These start long before the season when farmers explore the historical climate information produced by the climate services providers. Characteristics of rainfall and temperatures, including historical extreme weather and climate events that may well be in living memory of the participants, are examined by the farmers with the facilitation of the extension worker, enhancing farmer climate literacy and knowledge of local climate and trends. They also discuss crops and livestock produced along with other livelihood options, and how these are managed with influences from weather and climate. Farmers also learn how to use participatory tools such as Resource Allocation Maps (RAM) to consider what is done on their own individual farms and by whom, along with seasonal calendars to explore when activities are performed, by whom and how these activities relate to or are influenced by the typical conditions at the different times during the season. Having considered their own individual farm conditions and the resources they have, together with the climate characteristics, including variability and trends, farmers with the support of the extension worker identify a range of possible options that could help address challenges and opportunities. These include new crop, livestock and non-farming enterprises, and/or changes to their management. Farmers discuss and evaluate the options together using another participatory tool (options matrix). Farmers identify which options they each consider to be suitable to their individual contexts (e.g. soils, land size, labour and capital availability, objectives, risk attitudes) and then plan implementation of each option in more detail using participatory budgeting (Figure 8).

Figure 8: Simple participatory tools used by farmers in Jamaica.

Just before the season comes the seasonal forecast. If the outlook suggests that important aspects of the climate will be atypical, there might be a need for adjustments to on-farm or livelihood plans to reduce any potential negative impacts or to take advantage of opportunities. The farmer would weigh his options and decide. During the season, short term weather forecasts allow for responses to imminent conditions, and further adjustments can be made accordingly. At the end of the season the process is reviewed. Important to the continued process, is whether the information, both historical and forecast, triggered a change in activity, and if these changes impacted positively on the livelihoods of the farmers.

After the season, the process is reviewed and evaluated on site (Staub and Clarkson, 2021; Clarkson et al., 2019, Dayamba et al., 2018). The aim is to see if farmers made any changes on their farms with the information they were exposed to and the use of participatory planning tools, what effects this had on their production and livelihoods, and what lessons can be drawn from the process.

1.3.3 The ClimSA PICSA Experience in the Caribbean

The Caribbean Institute for Meteorology & Hydrology (CIMH), in partnership with the University of Reading, the Caribbean Agricultural Research & Development Institute (CARDI) and the Hydrometeorological Service of Guyana (Hydromet Guyana), piloted the first PICSA in the English-speaking Caribbean. This was undertaken in Guyana, under the Programme for Building Regional Climate Capacity in the Caribbean (BRCCC Programme). Implementation in this case included a scoping exercise and a fact-finding workshop with the participation of agricultural stakeholders (national and regional, including CARDI) and staff from Hydromet Guyana. Participants sitting in the same room discussed agriculture in Guyana, setting the stage for collaboration between climate scientists and the agriculture community. Training for agriculturists (including extension officers) and Hydromet Guyana followed the recommended format as described above. However, there was no monitoring and evaluation.

The CIMH through the implementation of the Intra-ACP Climate Services and related Applications (ClimSA) Programme continued the expansion of the PICSA approach across the Caribbean. Under the ClimSA Programme, the approach expanded to Jamaica as well as other locations in Guyana, with the objective to tailor the training to the specific needs identified by the farmers. The following section focuses on the implementation in Jamaica as, unlike thus far in Guyana, it benefitted from the monitoring and evaluation of the full PICSA approach.

PICSA in Jamaica

Jamaica is the third largest island in the northwest of the Caribbean Sea. The climate of Jamaica is mainly tropical with the northeast trade winds and the island's orographic features - the central mountain ridge (CSGM, 2022) - being key influences on rainfall and temperature variation across the country. These influences, along with atmospheric phenomena like the El Niño Southern Oscillation account for a variable climate with impactful extremes manifesting as droughts, floods, heatwaves and strong winds that reduce on-farm production and negatively impact livelihoods.

As in the case of most Caribbean Small Island Developing States (SIDS), there are two seasons defined by its rainfall (wet and dry seasons), with, in general about 70 % of the rainfall in the wetter half of the year (Enfield and Alfaro, 1998). However, in western areas of the Caribbean, like Jamaica, the rainy season is bi-modal spanning April-November, which can be divided into an early rainfall season (April-June) and a late rainfall season (September-November) (CSGM, 2022). Like most of the Caribbean (Jury et al., 2007; Taylor et al., 2011; Trotman et al., 2018; Van Meerbeeck, 2020), most of the rainfall occurs during the late season (CSGM, 2022). A mid-summer minimum in July, termed the Midsummer Drought (MSD), separates the early and late wet seasons (CSGM, 2022; Gamble et al., 2008).

The highest temperatures occur during the summer months from June to September and the lowest temperatures occur from December through March. The annual range of mean monthly temperatures is small, ranging from 23.0 to 27.1°C for the period 1990-2019. The mean maximum (daytime) temperatures can reach up to 31°C during the warmest months for some locations, while mean minimum (night-time) temperatures can be as low as 18.4°C during coolest months. Over the past few decades, temperatures in the Caribbean basin have been rising, with frequency of warm days and warm nights increasing by 3.31 and 4.07% per decade, respectively, between 1961 and 2010, while the frequency of cool days and cool nights has decreased by 1.80 and 2.55% per decade (Stephenson et al., 2014). These changes have spawned increases in heat waves in the region, which in the 1980s were mainly confined to August and September, but now being felt from as early as May until October (Van Meerbeeck et al., 2020), making conditions quite uncomfortable for ruminants and poultry.

A scoping exercise included a half-day workshop that assisted in understanding farm management and practices, and provided a basic understanding of the country's climate and its agro-ecological zones. Importantly, the workshop also brought climate service providers and agriculturists around one table to discuss climate concerns in the industry. A series of field trips to view the farming systems and converse with farmers followed during the rest of the week. After these, a tailored training approach for the Jamaica context was agreed upon.

From the 27th of February to the 3rd of March 2023, a one-week Training of Trainers (ToT) workshop was held at the Twickenham Farmers Training Centre in St Catherine. A total of 26 participants from various organisations were trained, including 16 from the Rural Agriculture Development Authority (RADA), two from the Agro Invest Corporation (AIC), three from the 4H Clubs, four from the Jamaica Agricultural Society (JAS), and one from CARDI. Subsequently, farmer group trainings were scheduled and executed during April to May 2023. The aim of the group trainings was to empower farmers with the requisite knowledge and skills to make informed decisions, reduce risk, and build resilience on their farms.

It is noteworthy that an online session prior to the 2023 Wet Season was held providing insights to the trained trainers and other key stakeholders as to what the upcoming season would likely offer (Step J). Such sessions would not only provide additional training on climate information and products, but also strengthen the dialogue and engagement between the climate services providers and agriculturists. An important outcome was that agriculturists and farmers were not simply sent or provided with access to the climate information for the upcoming season, but also had the opportunity to discuss the forecasted conditions and together propose possible responses to mitigate any potential negative impacts. A key part of the discussion was how the forecast for the upcoming season might have differed from the typical wet season outlined earlier.

The trained trainers from RADA and other agencies worked with seven farmer clusters across seven parishes, which include Portland, S. Catherine, St Elizabeth, Manchester, Clarendon, St Andrew, and St Mary (as shown in Table 1). Through the training, farmers learnt practical techniques to mitigate the effects of climate variability and extremes on their crops and livestock to improve their overall production. This is expected to contribute significantly to their livelihoods and of the wider community. The training activities were successfully completed for all the farmer groups, and the farmers provided exceptional feedback and testimonials regarding the quality of the training they received.

Table 1. List of farmer groups engaged for the PICSA trainings.

Parish	Farmer Group	Number of Farmers Targeted
Manchester	Sea Air Farmer Group	15
St Andrew	Brandon Hill Farmers Group	30
Portland	Mahoe PMO	20
St Mary	Jeffry Town Farmers Group	30
Clarendon	Clarendon Park Farmers Group	15
St Catherine	Guinep Ridge Farmers Group	20
St Elizabeth	Bull Savannah Farmers Group	20
TOTAL	**7 groups**	**130**

Source: Farmers Training Report 2023, Rural Agriculture Development Authority, Jamaica.

Training Results

The PICSA training programme has achieved remarkable success as it concluded its pilot project phase implementation across the seven parishes, positively impacting approximately 160 farmers. The programme was structured with an average of four weekly sessions per farmer group. The program's success was evident through the active participation of the farmers, who eagerly embraced this valuable training opportunity. Key results shared from the monitoring and evaluation exercise (95 participants) undertaken in April 2024 highlighted the following successes:

- **79% of trained farmers made changes** in their crops, livestock and / or other livelihoods as a result of the PICSA training (87% of women and 71% of men);
- **60% made a change in crops** (63% of women and 57% of men);
- **31% made a change in livestock** (41% of women and 20% of men);
- **7% made a change in other livelihoods** (9% of women and 6% of men);
- **81% of trained farmers reported that their confidence in planning and decision making had improved** as a result of the training (85% women; 78% men);
- **60% of trained farmers reported that their household food security had improved** as a result of the decisions they had taken because of the training (72% women; 49% men);
- **59% of trained farmers reported that their income had improved** as a result of the decisions they had taken because of the training (65% women; 53% men);
- **76% of trained farmers reported that their ability to cope with bad years caused by the weather had improved** as a result of the decisions they had taken because of the training (87% women; 65% men).

1.3.4 Conclusions

Based on the feedback during and after their training and from the evaluation exercise, farmers found the PICSA approach beneficial and enlightening. The resource allocation maps, seasonal calendars and climate graphs and maps seemed to be amongst the most popular tools for the extension officers and the farmers they trained. Part of the success and popularity is because these tools were easily understood and made climate services delivery to producers far more palatable and simpler to apply in their on-farm decision making. PICSA also adds a new dimension to extension services in the Caribbean where climate information provision, its implications and climate smart innovations in response to impending conditions becomes key to the success of farmers.

There were several reasons for success of PICSA in Jamaica, and certainly most, if not all these were reasons for success in other English-speaking territories such as Guyana and Dominica[7]:

Simplicity of use. Simple tools that the farming community (and even the extension officers and other agriculturists) can use, in some cases, even beyond climate-related decision making, e.g. the Resource Allocation Maps (Figure 9) and Seasonal Calendars (Figure 10) that are very popular with the farmers.

Participation and engagement. Through the training process, farmers are engaged in dialogue not only with the extension officers who customarily serve them, but also with their national meteorological service that support them in the understanding of climate related information. At the same time farmers exchange climate smart responses to challenging climate related conditions. Using simple participatory tools, the trained farmers are also able to work out their solutions to the conditions based on their individual contexts - these solutions and responses to the information provided (see above).

Figure 9: Extension officer in Jamaica showcasing the Resource Allocation Map (RAM) of one of the farmers.

7 https://dominicanewsonline.com/news/homepage/news/women-farmers-in-dominica-collaborate-to-boost-local-capacity-at-undp-symposium/.

Integrated approach. The entire process from training of the extension officers to the training of the farmers, involves participation and support from actors with a variety of backgrounds but all significant to the process, including local, national and regional participants.

The challenge for the future is the sustainability of PICSA in Jamaica. A commitment by the Ministry of Agriculture through RADA to build this approach into its programming as a climate smart activity that assists in farmer decision making is paramount. This commitment would also need to be supported by the Jamaica Meteorological Services. It is also suggested that other agriculture entities, such as the Jamaica Agricultural Society, should join the partnership with RADA in these efforts.

Figure 10: An extension officer reviews the seasonal calendar prepared by a Jamaican farmer.

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SECTION

2 ADDRESSING USER NEEDS THROUGH CLIMATE DATA AND INFORMATION PRODUCTS

This section focuses on how climate services are designed and implemented for the production and distribution of climate data and information products addressing user needs.

The first chapter provides a detailed account of the impact of climate services on agricultural production in Burkina Faso, showing that farmers can boost agricultural productivity and improve their resilience to climate variability.

The second chapter examines the linking of climate services with the UN Early Warning System in Eastern Africa, through the dissemination of climate information, early warnings, and advisories through various online platforms reaching large number of users.

The final chapter examines Early Warning Systems for the agricultural sector in the Caribbean and how these favour the development of Climate Smart Agriculture and long-term strategies to secure sustainable food security.

CHAPTER 2.1 The Impact of Climate Services on Agricultural Production in Pilot Sites of the ClimSA Programme in Burkina Faso

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2.1.1 Introduction

Most agricultural activities in Africa, and more particularly in Burkina Faso, rely on rainfed crops and are hugely impacted by the often-unfavourable hydrometeorological conditions, such as rainfall deficits, long dry spells, floods and high temperatures. For enhanced management of these risks, it is necessary to support the production of scientific knowledge designed for decision-making purposes and to strengthen the operational systems for the prevention and management of such risks. Hence the overall objective of the Climate Services and related Applications Programme (ClimSA), which is to contribute to sustainable development by improving access to climate information and use of climate services and applications in decision-making processes at all levels in West Africa and the Sahel.

Studies have shown that the use of agro-climatic and meteorological information can reduce the vulnerability of farmers, while enabling them to maximise opportunities when conditions are favourable (Ingram et al., 2002; Hansen, 2002; Roncoli et al., 2009; Sultan et al., 2008; Crane et al., 2011; Roudier et al., 2014; Bacci et al., 2020). It has also been shown that African end-users are interested in agro-climatic information in order to better manage their living environment and improve crop yields. Thus, cropping patterns integrating seasonal forecasts of certain agro-climatic parameters, such as cumulative seasonal rainfall, season start and end dates, season length and duration of drought periods (Tinni et al., 2021), can translate forecasts of weather anomalies into predicted impacts on production and economic results (Hansen and Indeje, 2004). However, agro-climatic information has no intrinsic value, it is rather used as a basis for decision-making and is not a direct climate solution (Hammer et al., 2000). It is therefore important to tailor this information to the needs of users so as to generate objective or economic results.

To this end, the ex-ante method is generally used to assess the potential benefits of support, targeted interventions and use of information in the agricultural sector (Hansen and Indeje, 2004; Tinni et al., 2023).

Climate services are a decision support tool that forms part of efforts to implement mitigation and adaptation strategies and actions under the Global Framework for Climate Services (GFCS). The use of climate services tailored to the needs of end-users is a relatively recent innovation, referred to as Climate Smart Agriculture when applied to the agricultural sector. It involves deploying an early warning system that can help communities cope with the negative effects of droughts and floods. It offers potential benefits, such as increased income for farmers. An increase in income of around 6.9% was observed in certain regions of Niger under the AMMA-CATCH project[8] (Roudier et al, 2011; 2016). Following this experiment, farmers in the area changed their cropping practices (choice of millet variety, date for sowing and for applying fertiliser) based on agro-climatic information. Furthermore, agro-climatic information received and considered during planning processes in some municipalities in south-west Niger resulted in an increase in production and a reduction in many forms of disaster risk, including floods and droughts, which often lead to loss of property and lives (Tinni et al., 2023).

The rapid and timely dissemination of agro-meteorological information plays a very important role in agricultural risk management (Meza et al., 2008), as it not only makes it possible to anticipate the adverse effects of extreme rainfall conditions but also allows decisions to be made on the best agricultural practices to adopt (Gunda et al., 2017). This could inform tactical choices in the short term (selection of varieties, sowing dates) and/or strategic choices in the longer term. In this regard, rural community radio stations are the main information relay channels for farmers, followed by extension services and social networks. This dissemination gives farmers rapid access to up-to-date, high-quality agro-meteorological information, as well as practical advice on how to make the most of the forecasts. Under the ClimSA Programme, agreements for the dissemination of agro-meteorological information were signed with community radio stations broadcasting in the pilot areas in Burkina Faso. The information was broadcast by the most popular community radio station, not only in French but also in the most widely spoken local language at each pilot site. In addition, this information was transmitted via WhatsApp to farmers identified as leaders, who had been issued with smartphones by the ClimSA Programme. This also enabled these leaders to receive near-real-time information from Burkina Faso's national meteorological agency (ANAM-BF) and the Regional Climate Centre for West Africa and the Sahel (AGRHYMET CCR-AOS), which they in turn could share with other farmers in their respective villages. Accurate and timely agro-meteorological information can boost the impact of good farming practices, ensuring high and sustainable yields.

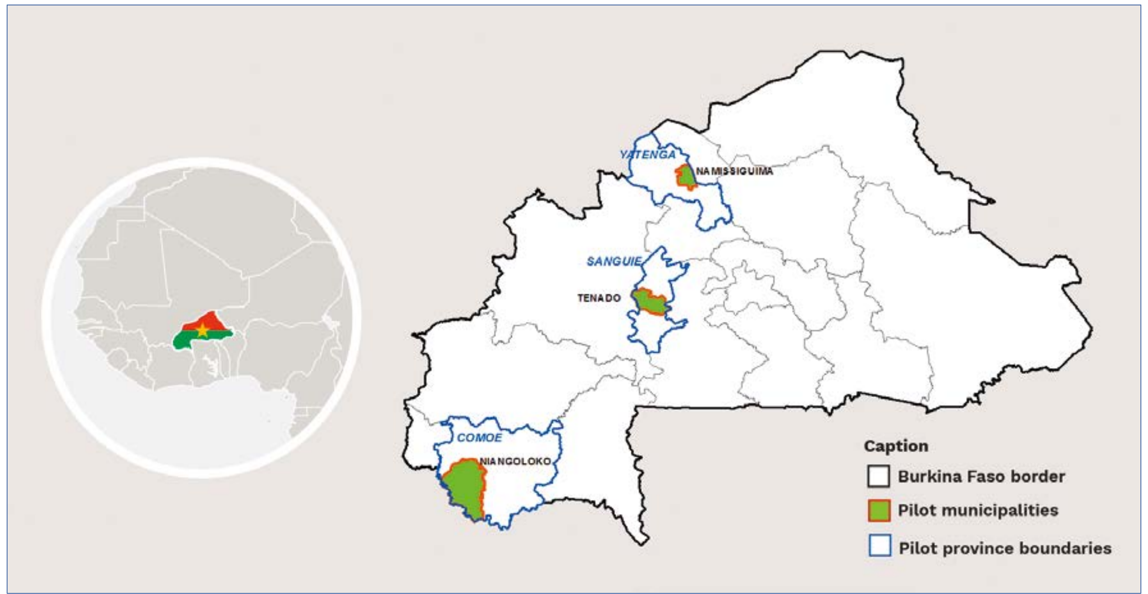
The main objective of climate services for agriculture, as outlined in the ClimSA Programme, is to help farmers adapt to climate change by disseminating and contextualising climate information. This work aims to demonstrate the hypothesis that agro-meteorological services can effectively improve agricultural productivity and sustainability, provided that appropriate mechanisms are in place to ensure access, use and action. A survey was thus conducted to analyse the impact of climate services on agricultural production during the implementation of ClimSA in Burkina Faso.

8 Analyse Multidisciplinaire de la Mousson Africaine - Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique (AMMA-CATCH project).

2.1.2 Methodology

The ClimSA pilot sites are located in the three agro-climatic zones of Burkina Faso: the Sudanian zone, the Sudano-Sahelian zone and the Sahelian zone (Figure 11).

Figure 11. Location of ClimSA pilot municipalities of Niangoloko, Tenado and Ouahigouy in Burkina Faso.



The economy in these areas is based on primary sector activities, mainly agro-sylvo-pastoral production, with agriculture being the most predominant. Agriculture in the region consists mainly of rainfed subsistence systems, characterised by small family-run farms. Manual labour is generally prevalent and animal traction rarely used. Key agricultural constraints include the spatial and temporal distribution of rainfall and the inherent poor fertility of soils. Despite these constraints, cereal farming and cash crops are common. Cereals (rice, sorghum, millet and maize), cash crops (cotton, groundnuts, sesame, fonio, cowpeas, Bambara groundnut and potatoes) and trade are the main economic activities.

The Ténado site is located in the centre-west region of Burkina Faso. It is in the Sudano-Sahelian climate zone, with total rainfall ranging from 600 to 900 mm/year. In this pilot municipality, the rainy season extends from May to October and is characterised by a high degree of spatio-temporal variability (Figure 12), with recurrent dry spells. These often long dry spells can have an impact on crop yields (Barron et al., 2003).

The municipality of Niangoloko lies in the south-west region of Burkina Faso and is within the southern part of the Sudanian climatic zone. It is characterised by highly variable annual rainfall, with an average of 1,120 mm (Figure 13), and two distinct seasons: a six-month rainy season (May to October) and a six-month dry season (November to April).

The Namissiguima region has a sub-Sahelian climate, with two alternating seasons: a long dry season generally from October to May and a short rainy season from June to September. Annual rainfall is highly variable, averaging around 675mm (Figure 14). The region's economy is based on primary sector activities, mainly agro-sylvo-pastoral production, with agriculture being the most dominant activity. Agriculture in the region consists mainly of rainfed subsistence systems, characterised by small family-run farms. The main staple crops are sorghum and millet. Cowpeas, sesame, groundnuts and vegetables are the main cash crops.

Key agricultural constraints include the spatial and temporal distribution of rainfall and fertility.

Figure 12. Inter-annual rainfall trends in Ténado.

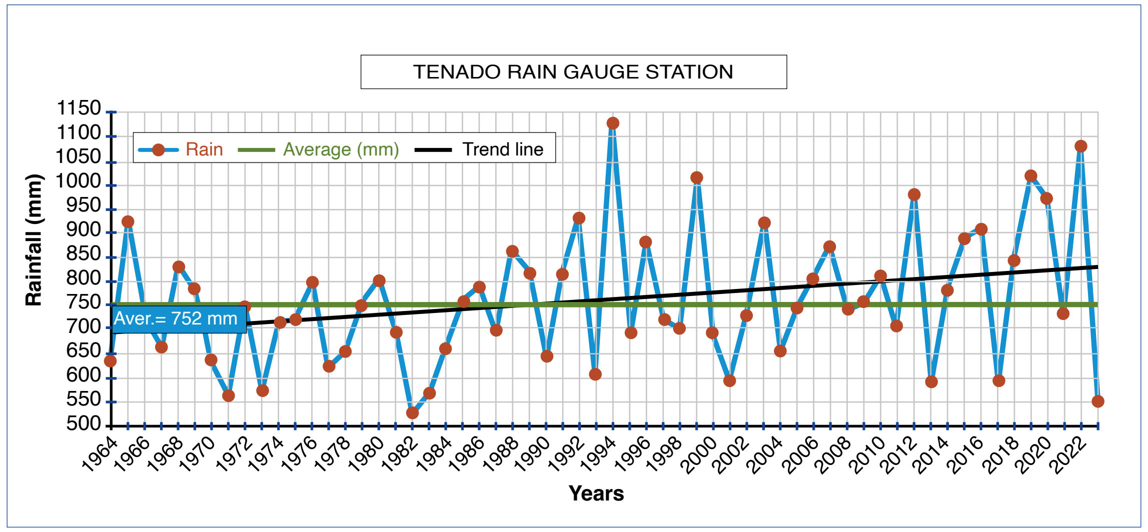


Figure 13: Inter-annual rainfall trends in Niangoloko.

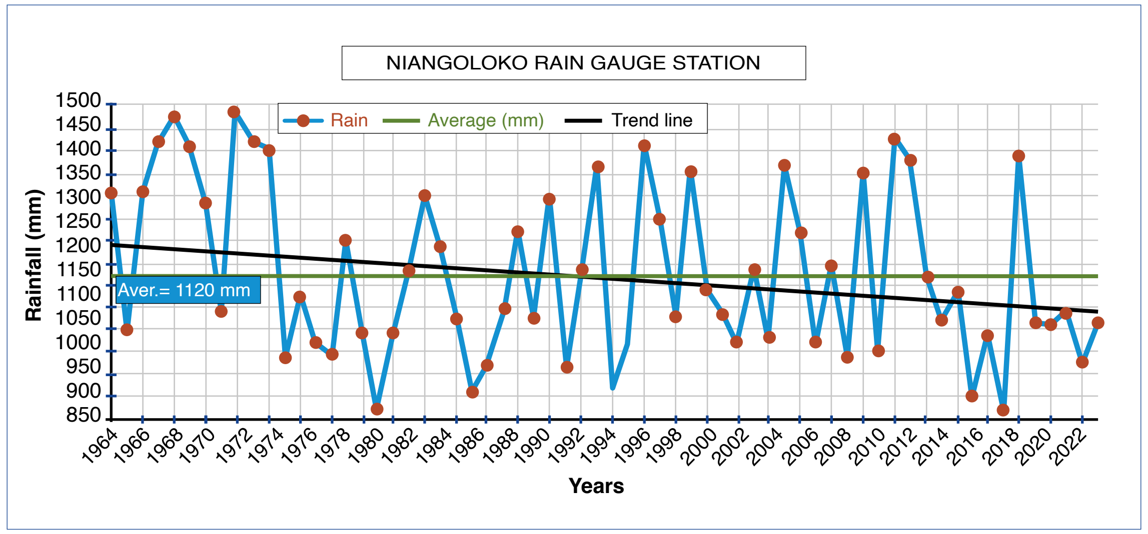
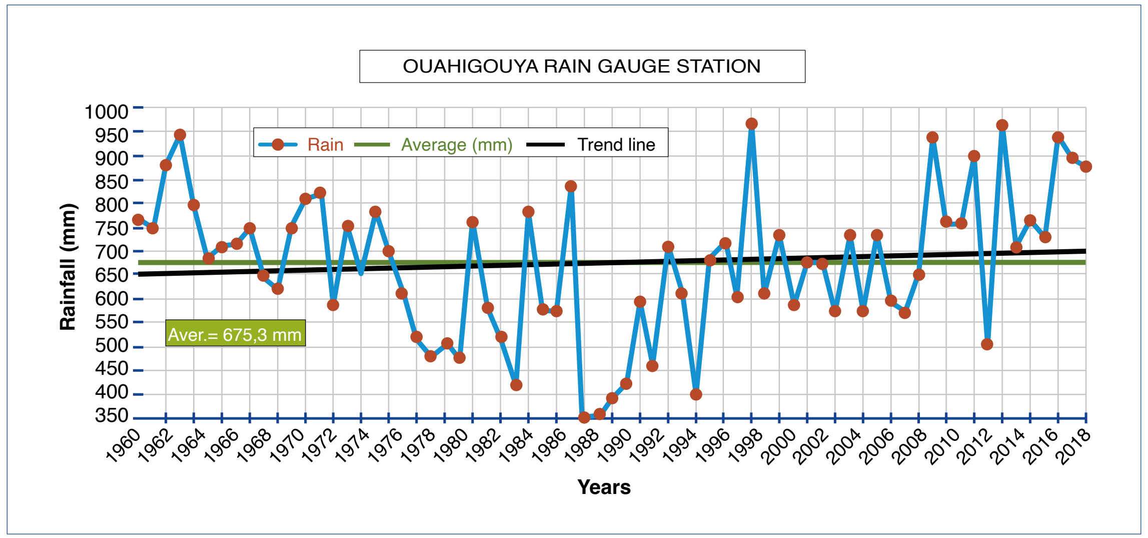


Figure 14. Inter-annual rainfall trends in Ouahigouya, the nearest rainfall station to Namissiguima with long-term records.



2.1.3 Data

Survey Data

Two surveys were conducted in the pilot sites of Ténado, Namissiguima and Niangoloko. The first consisted of establishing yield measurement plots during the three consecutive agricultural seasons in which ClimSA activities were being implemented, i.e. 2021, 2022 and 2023. The activities were carried out in 30 villages, i.e. ten villages per site. In each village, two groups of farmers were selected, including two "model or pilot" farmers and two "control" farmers.

The second survey was conducted during the monitoring of agro-meteorological activities at the pilot sites. The purpose was to find out how satisfied farmers were with the agro-meteorological products made available to them by ANAM and the AGRHYMET Regional Centre and also, whether the farmers interviewed took agro-meteorological information into account when planning and carrying out their agricultural activities and whether this had a real impact on their production levels. The survey also shed light on the preferences of local male and female farmers about the dissemination of climate-related information and the resulting strategic and tactical decisions in their farming practices.

These activities had to be scaled back with respect to the planned methodology, due to a lack of time to fully implement the monitoring and evaluation system from the start of the project, and also due to the prevailing security situation in the country.

Data from Measurement Plots

The second set of data concerns yields measured in farm plots in 2021, 2022 and 2023 in the pilot municipalities of Niangoloko and Ténado. It consisted of systematic sampling of around 120 yield plots, including 80 in the municipality of Ténado and 40 in the municipality of Niangoloko. These samples were taken from 60 farmers selected for the purposes of evaluating the impact of agro-climatic information. From among these groups of farmers, two farmers who had been trained and two farmers who had not undergone training were selected at random from villages in each of the ClimSA pilot sites with a view to measuring crop yields. It is therefore important to note that the control group is random and represents the entire population. The experimental group was also randomly selected from participants who had taken part in the training on the introduction and use of agro-meteorological products. Maize was used in Niangoloko, while sorghum was the main crop in Ténado. The yield plots at the Namissiguima pilot site were not monitored because of the difficult security situation in the locality.

2.1.4 Findings and Discussion

Improving Access to Climate Information

Rural community radio stations are still recognised as the main information relay channels for farmers, followed by extension services and social networks. Under the ClimSA Programme, yearly agreements (three per year since the start of the project) were signed with the most popular community radio station in each pilot site for the dissemination of agro-meteorological information (Figure 15). Information was broadcast in French as well as in the most widely spoken local language. This information was also passed on to farmers identified as leaders via WhatsApp, to whom the ClimSA Programme had allocated around fifty mobile phones. This allowed these leaders to receive near real-time agro-meteorological information from ANAM-BF and AGRHYMET CCR-AOS, and in turn share it with other farmers.

Figure 15. Discussing climate services needs with local communities.

Building the Capacities of Key Stakeholders to Use Agro-meteorological Information

In order to achieve its various objectives, the ClimSA Programme sought to build the capacities of local farmers through on-site training in Niangoloko, Ténado and Namissguima, so that they may respond effectively and in a timely manner to the vagaries of the agro-hydroclimatic environment, while also enabling them to derive benefits from such weather events. Following the forums on seasonal forecasts, ANAM-BF in collaboration with AGRHYMET CCR-AOS, organised about five awareness-raising workshops as well as itinerant seminars. The aim of these workshops was to show farmers, extension workers and media professionals how to interpret seasonal forecasts and how to use each type of product, so that the main local players could incorporate them into their climate adaptation strategies.

Operationalising Climate Services for Decision-making

Appropriate use of reliable agro-climatic and meteorological information enables end-users (farmers) to make decisions aimed at reducing the impact of adverse weather conditions and provides a sound basis for planning. Research has confirmed that adopting such practices can increase productivity, improve food security in rural areas (Partey et al., 2018) and incomes, and also reduce the impact of disasters (Tinni et al., 2023).

In line with the approach of the ClimSA Programme, a field survey was carried out at the start of activities to ascertain the agro-climatic information needs of the key stakeholders so as to ensure that the agro-meteorological products developed and delivered met their requirements. Following this stakeholder analysis, it emerged that agro-climatic information was needed on the probable start and end dates of the rainy season, cumulative rainfall and duration of dry spells. This confirms the work of Roudier et al. (2011b) and Ingram et al. (2002) on the needs of farmers in the Sahel in terms of climate information and forecasts, which highlighted the variables most relevant to agricultural strategies. In response to this demand, ANAM-BF in collaboration with AGRHYMET CCR-AOS through ClimSA:

- **Provided the communities at the pilot sites, before and during the rainy season, with agro-climatic information to help them make the best choices.** This information included seasonal forecasts (next 3 months), short-term 24-hour forecasts and sub-seasonal 7-day forecasts, including practical advice and alerts relating to the forecasts. The choice of sowing date is a crucial factor in the strategy of a farmer, who must ensure that sowing is not followed by a long dry spell and that the plant reaches maturity at the end of the rainy season;
- **Allocated smartphones equipped with the e-Agrimet and ClimObs applications to model farmers**. These applications can be used to exchange messages and share data between model farmers and ANAM;
- Provided farmers with **rain gauges**;
- **Provided training on**: (i) how to use rain gauges to take daily readings and share the information with other members in their localities for decision-making purposes; (ii) how to use the e-Agrimet and ClimObs applications to transmit data and information using smartphones; and (iii) the interpretation and dissemination of agro-climatic information for local media (Figure 16).

Figure 16. Training on operationalising climate services.

Using Agro-climatic Information

Throughout the 2021, 2022 and 2023 agricultural seasons, ANAM continued disseminating agro-meteorological information and products (including seasonal forecasts) to local farmers through itinerant seminars, awareness campaigns, community radio stations and by telephone. Systematic sampling was conducted by means of a questionnaire containing around 30 questions, which was administered to around one hundred farmers at the Ténado and Niangoloko pilot sites, 37% of whom were women. According to the results, 82% of the farmers surveyed were very satisfied that agro-meteorological information was made available, and 18% were satisfied. The clarity of the translation of information into local languages by community radio stations was very satisfactory according to 72% of respondents, compared to 28% who said they were satisfied. The majority of respondents (99%) stated that weather and climate information provided was satisfactory or very satisfactory. Specifically, between 96% and 97% of respondents felt that seasonal forecasts and daily agro-meteorological information were accurate (Figure 17).

Figure 17. Level of satisfaction of farmers with respect to the information made available (in %).

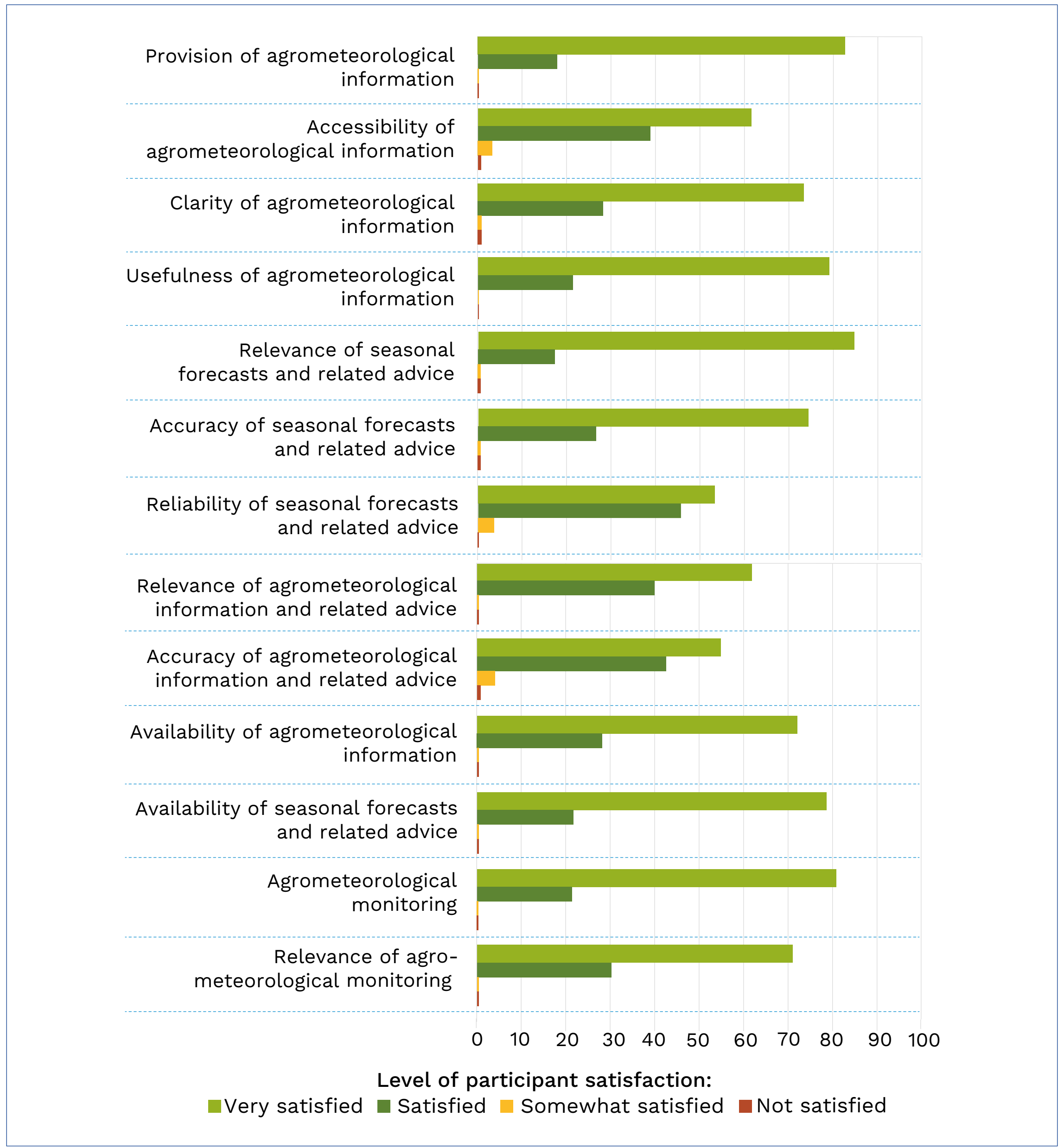
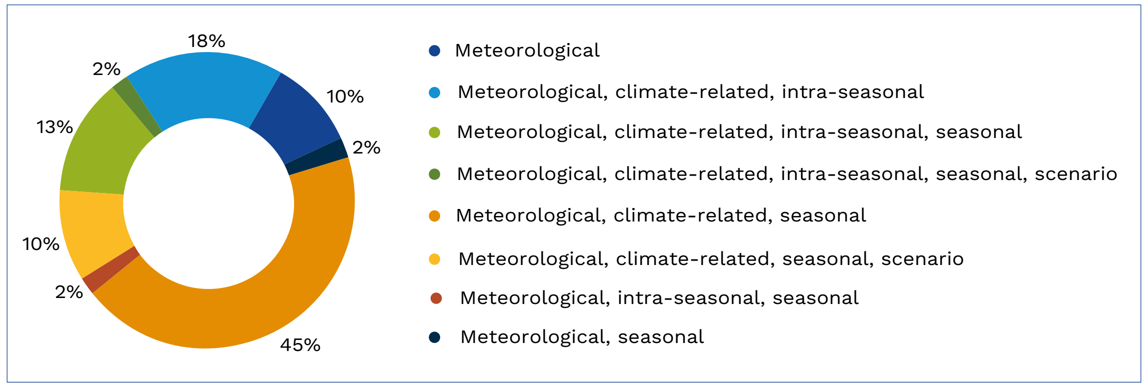


Figure 18. Preferences and types of information made available to end users in ClimSA pilot sites.

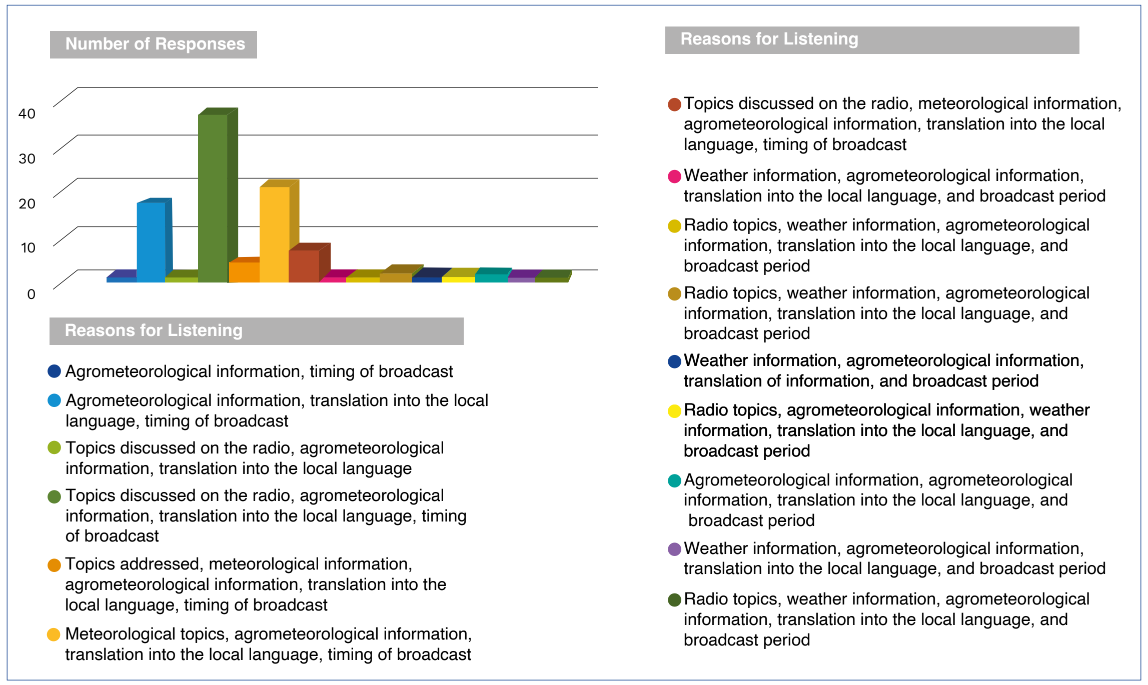


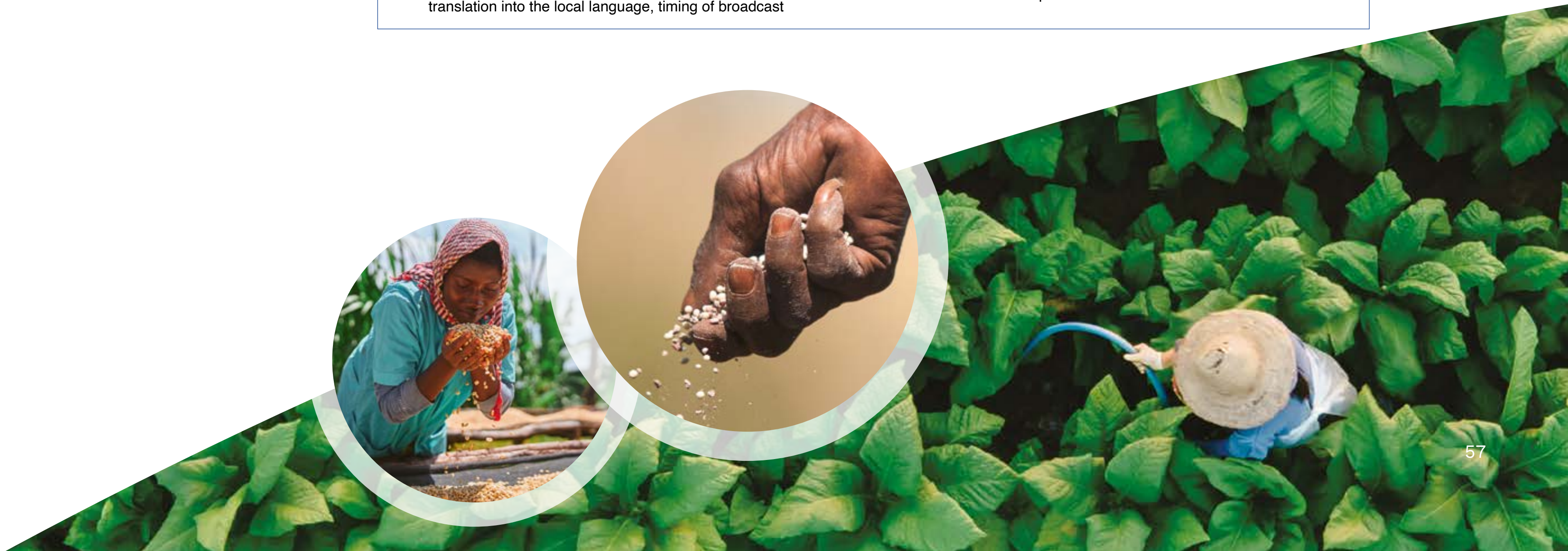
Various types of climate-related information were made available to farmers, but the most sought-after were seasonal forecasts, followed by daily agro-meteorological information and intra-seasonal forecasts (Figure 18).

Almost all respondents (99%) received the information sent by ANAM and the AGRHYM-ET Regional Centre and took it into account in their agro-pastoral activities. This guided them in their farming activities, such as crop maintenance, fertiliser application and phytosanitary treatment, all of which have a positive impact on crop production.

Radio was the most popular medium for disseminating agro-meteorological information. Of the total number of respondents, 37% said they listened to the radio because of the reliability of weather information and 21% because of the relevance of agro-meteorological information. Also, 17% of respondents listened to the radio because of the accurate translation of information into the local language, thereby facilitating its use in farming activities and improving yields (Figure 19).

Figure 19. Level of use and appreciation of agro-meteorological information by farmers.





Impact of Climate Services on Yield Measurement Plots

At the Niangoloko pilot site, maize was used, while sorghum was the main crop at the Ténado site. The yield plots at the Namissiguima pilot site were not monitored because of the difficult security situation. For the purposes of this description, we will primarily use data from the Niangoloko site. The table below shows the statistics for each attribute.

Table 2. Statistics on maize cultivation at Niangoloko, per attribute.

FARMER TYPE	N	MEAN	MEDIAN	SD	VAR	MIN	MAX	Q1	Q3
Pilot	30	4.37	4.36	0.53	0.28	3.48	5.53	3.93	4.78
Control	30	2.14	1.77	0.80	0.64	0.89	3.51	1.49	2.87

Performance. The 'pilot' group showed a significantly higher level of performance on average (4.37) compared to the 'control' group (2.14). A similar pattern is seen in the median, at 4.36 for the pilot group and 1.77 for the control group.

Distribution of values. The distribution of values in the 'pilot' group was more concentrated around the mean, as evidenced by a lower standard deviation (0.53) compared to that of the 'control' group (0.80). This means that the values in the 'pilot' group are more homogeneous.

Variability. Variance in the 'control' group (0.64) was more than twice that of the 'pilot' group (0.28), indicating a wider range of results for the 'control' group. In other words, yields varied significantly from one control farmer to another. On the other hand, the yields of pilot farmers hardly varied at all, i.e. the yields were virtually the same.

Data range. The 'pilot' group had a narrower range of data (max - min) (2.05) compared to the 'control' group (2.62). The values for the 'pilot' group ranged from 3.48 to 5.53, while those for the 'control' group varied between 0.89 to 3.51.

Quartiles. The interquartile ranges reveal a significant difference. The 'pilot' group had an interquartile range (IQR) of 0.85 (4.78 - 3.93) while the 'control' group had an IQR of 1.38 (2.87 - 1.49), indicating a wider range of central values for the 'control' group.

These observations suggest that the 'pilot' group not only performed better overall but also more consistently than the 'control' group (**Table 2**). The results of this statistical analysis show that the use of agro-climatic information significantly helps to improve the yields of farmers. The average yield for the pilot farmers was 4.37 t/ha compared to 2.14 t/ha for the control farmers. Statistical analyses comparing the two groups of farmers ('pilot' and 'control') revealed significant differences in yield in favour of the 'pilot' group.

Impact on Maize Yields at Niangoloko

The maize yields of model or pilot farmers following the use of agro-climatic information and the average yield at the Niangoloko site are shown in Figure 20. Production in 2022 was slightly higher than in 2021, and in 2023 slightly higher than in 2022. Yields were above average throughout these seasons (**Figure 20**). They were also significantly higher than those of control farmers at all sites for the three consecutive years (**Figure 21**). This progressive increase is partly due to favourable climatic and weather conditions, but also and above all to the fact that farmers at the pilot sites put into practice in a more effective manner, agro-meteorological advice based on the results of the PRESASS (Regional Forums on Climate Outlook for the Sudano-Sahelian Region) and daily and weekly agro-meteorological bulletins.

Figure 20. Average maize yields in Niangoloko for pilot and control farmers from 2021 to 2023.

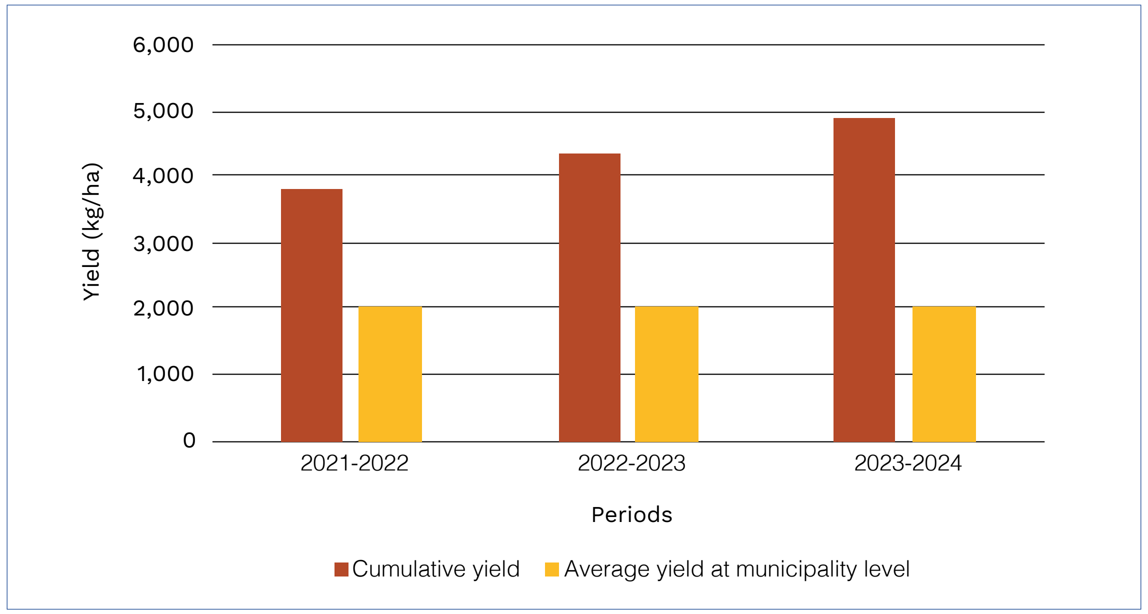


Figure 21. Average maize yields of 'pilot farmers' in Niangoloko from 2021 to 2023, compared to the average yields for the municipality.

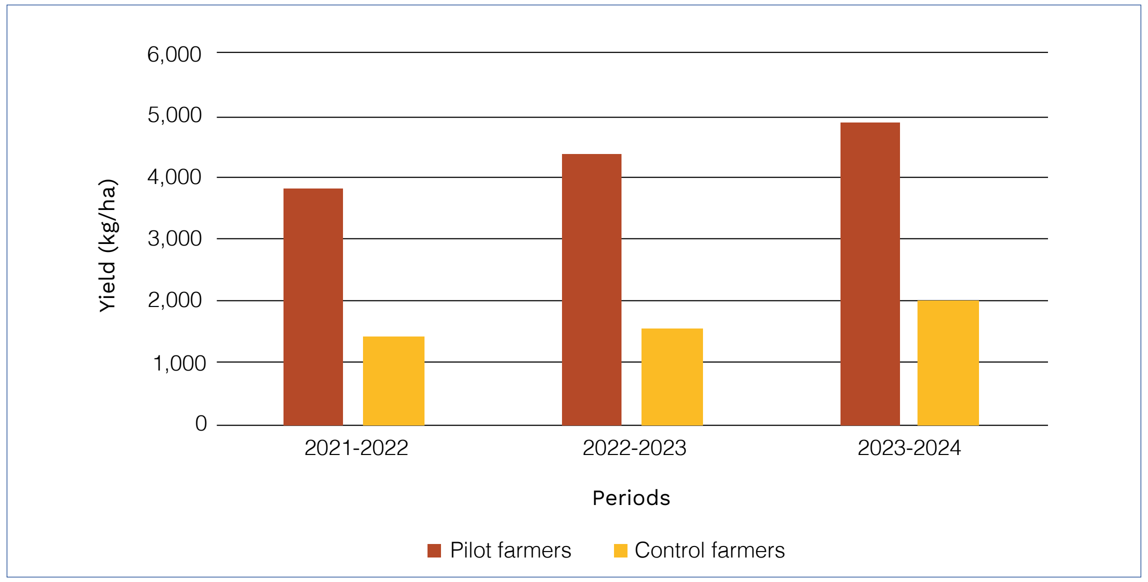


Figure 22. Average sorghum yields at Ténado from 2021 to 2023, compared to the average yields for the municipality.

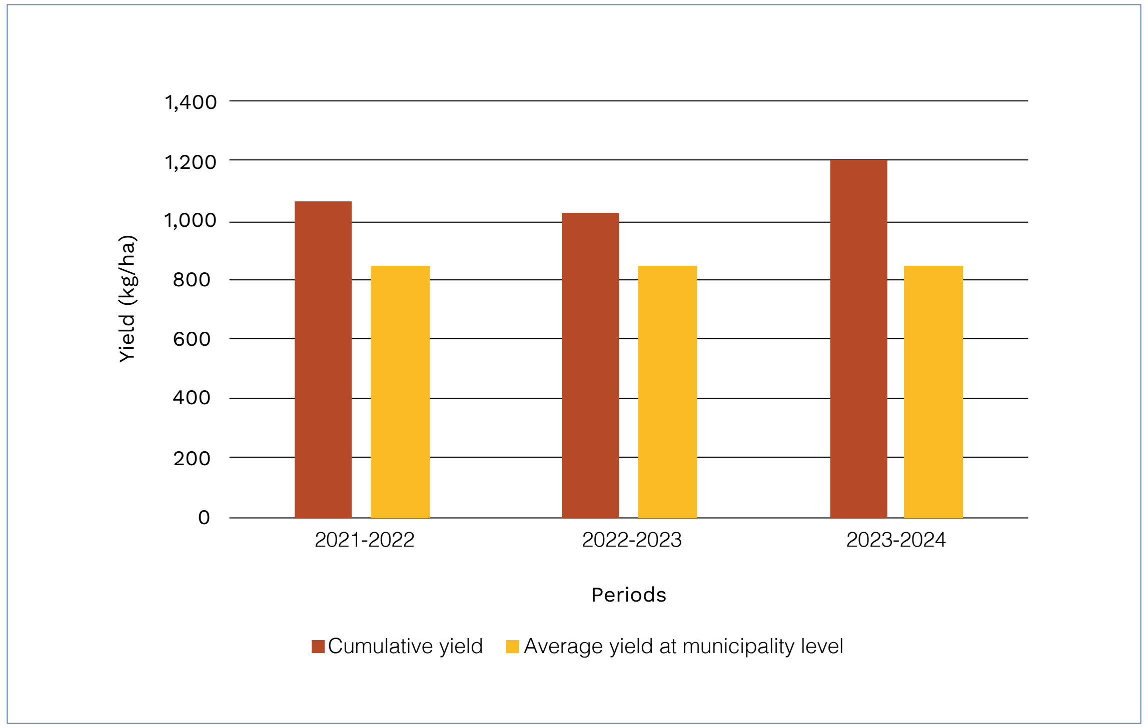
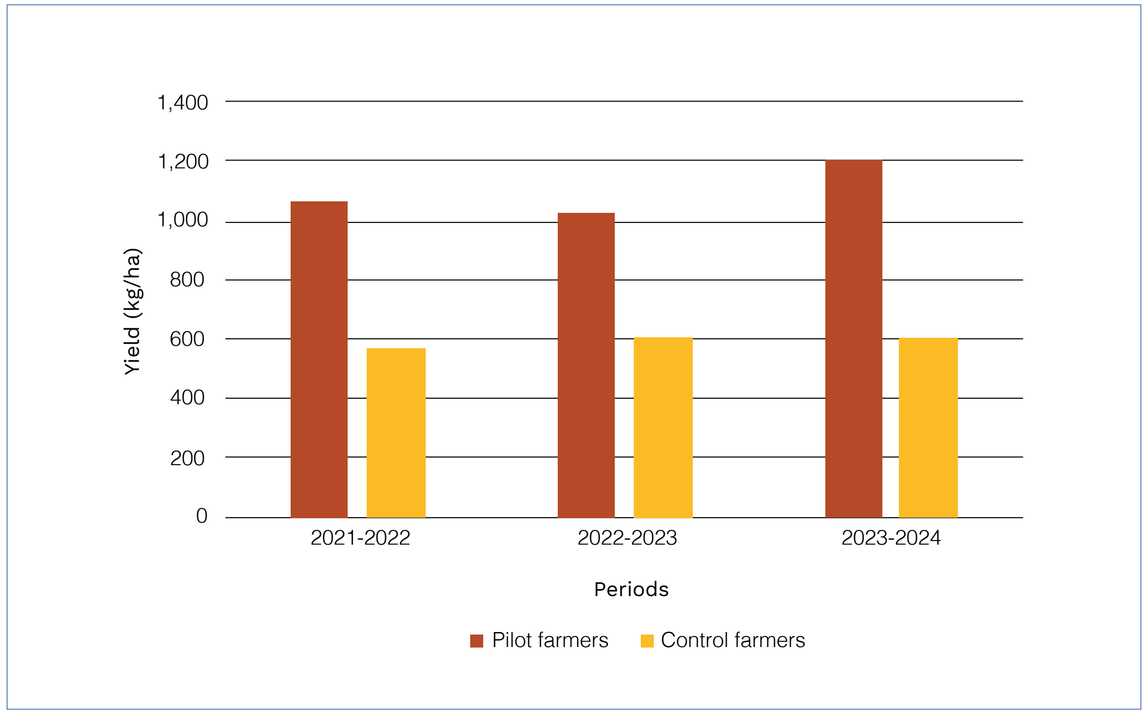


Figure 23: Average sorghum yields at Ténado for pilot and control farmers from 2021 to 2023.



At the Ténado site, sorghum production in 2022 was slightly lower than in 2021. This could be explained by the fact that the area experienced very high levels of rainfall, with the occurrence of extreme rainfall events that had an impact on crop yields. Yields in 2023 were however higher than in 2022, despite the lower rainfall recorded during the 2023 agricultural season (Figure 22). The impact on yields is certainly because of the adoption of farming practices based on seasonal forecasts of cumulative rainfall, the start and end dates of the agricultural season, as well as many other adaptation strategies taught to farmers during the training courses. This confirms the example of Mauritania, where sorghum yields increased by 64% owing to the use of climate information and services (Tarchiani et al., 2018).

Impact on Sorghum Yields at Ténado

The yields of pilot farmers at the Ténado site were not only higher than average, but also higher than those of control farmers (Figure 23). The pilot farmers stated that the forecasts informed their decisions when they were planning their farming activities.

Farmers who benefited from training and who received the appropriate climatic and agro-meteorological information changed the way they managed their crops. Experience has shown that the changes observed in the plots of pilot farmers and the improvement in crop yields have had positive impacts for farmers and have sparked the interest of other farmers in the same villages who were sceptical at the start of the project. This interest is undoubtedly due to observations of improved crop yields in the fields of pilot farmers. It is worth noting that today, in the pilot sites of the ClimSA Programme, farmers no longer simply wait to receive climatic or meteorological information but go in search of it. These results confirm the previous experience of Climate Risk and Early Warning Systems (CREWS) project in the pilot sites of the ClimSA Programme in Ténado, maintaining that climate information has a positive impact on agricultural yields. It also helps reduce loss of earnings and the number of sowings, optimises the use of fertiliser and number of work days, etc.

2.1.5 Conclusions

Agro-climatic and agro-meteorological services encourage the adoption of strategies aimed at adapting to climate variability and increasing agricultural production. However, for climate services to be effective, they must be accessible and adapted to the needs of agricultural users, as was the case at the ClimSA Programme sites. The study showed that farmers who receive and adopt agro-climatic services adjust their farming practices based on the information received through various dissemination channels, resulting in better management of inputs and better planning of activities to boost agricultural productivity and improve their resilience to climate variability. The adoption of climatic practices has had a positive impact on food crop yields. Analysis also reveals that the majority of farmers need climatic and agro-meteorological information to inform their decisions when planning their farming activities.

The behavioural changes observed also illustrate that training on agro-meteorological practices and awareness-raising campaigns carried out in the project's pilot sites can effectively strengthen relations and trust between farmers and the entities that produce climatic information, such as the AGRHYMET Regional Centre and ANAM. As a result, these actions require greater support for sustainability and scaling up so as to further reduce the vulnerability of communities to the impacts of climate on agricultural production systems.

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CHAPTER 2.2 Linking Climate Services with the United Nations Early Warning System in Eastern Africa

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Early Warning Systems (EWS) aim to provide timely alerts about impending hazards such as floods, droughts, or storms and reduce their impacts by empowering communities to take preventive actions, evacuate, or prepare for emergencies. Collaboration between various actors such as the United Nations (UN) Early Warning System, regional and national agencies greatly enhance preparedness and response.

Linking climate services with the Early Warning Systems in Eastern Africa can significantly enhance the region's ability to anticipate, prepare for, and respond to climate-related risks by providing accurate climate information for risk assessment, enabling early warnings based on climate data, supporting adaptation strategies and facilitating risk-informed decision-making.

However, this calls for a concerted effort to translate early warnings into concrete action, constructing a continuum from humanitarian assistance to development. The impacts of disasters, including those related to climate change and environmental hazards, require increased resilience in the region that is aligned with the multi-hazard early warning systems including the utilisation of digital platforms.

For early warning to be truly effective, it must be timely, accessible and easily understandable. The IGAD Climate Prediction and Applications Centre (ICPAC) is actively involved in the dissemination of Climate Information, Early Warnings, and advisories through platforms like the East Africa Hazards Watch, the ICPAC website, MailChimp, X (formerly known as Twitter), LinkedIn, and Facebook. These efforts have reached approximately 2 million users across the various online platforms, with a combined following of about 155,000 users.

2.2.1 The East Africa Hazards Watch

Through support from the ClimSA Programme, ICPAC has developed important digital tools to improve early warning services in the Eastern Africa region. The East Africa Hazard Watch is a "one-stop shop", focusing on climate thematic areas and a few prioritised hazards for climate and weather predictions, forecasting, and early warning dissemination (Figure 24).

The mechanism is built to strengthen the resilience of member countries within the IGAD region through the issuing of early warning information and advisories for early and anticipatory actions as well as preparedness and response. For instance, the weekly rainfall forecasts show the expected amount of rainfall in a particular week, including areas forecasted to receive heavy, very heavy, and extremely heavy rainfall. This information is crucial for identifying vulnerable populations exposed to potential flash floods in flood-prone areas (Figure 25).

The East Africa Hazards Watch platform hosts several specialised early warning tools, which fit well in the digital ecosystem of ICPAC, constituting a suite of different early warning geospatial services that effectively complement the visualisation and analytics system [(https://eahazardswatch.icpac.net/)](https://eahazardswatch.icpac.net/).

The East Africa Agriculture Watch

This specialised early warning tool was launched in February 2021, during the 57th Greater Horn of Africa Climate Outlook Forum (GHACOF 57), a triannual regional event organised by ICPAC to co-produce and issue the seasonal climate forecast and related sectoral advisories for the region. The Agricultural monitoring tool is vital in detecting short-term deficits in crop production in response to a range of drivers, especially in areas frequently impacted by high cases of food insecurity.

Figure 24. The East Africa Hazard Watch (EAHW) interface.

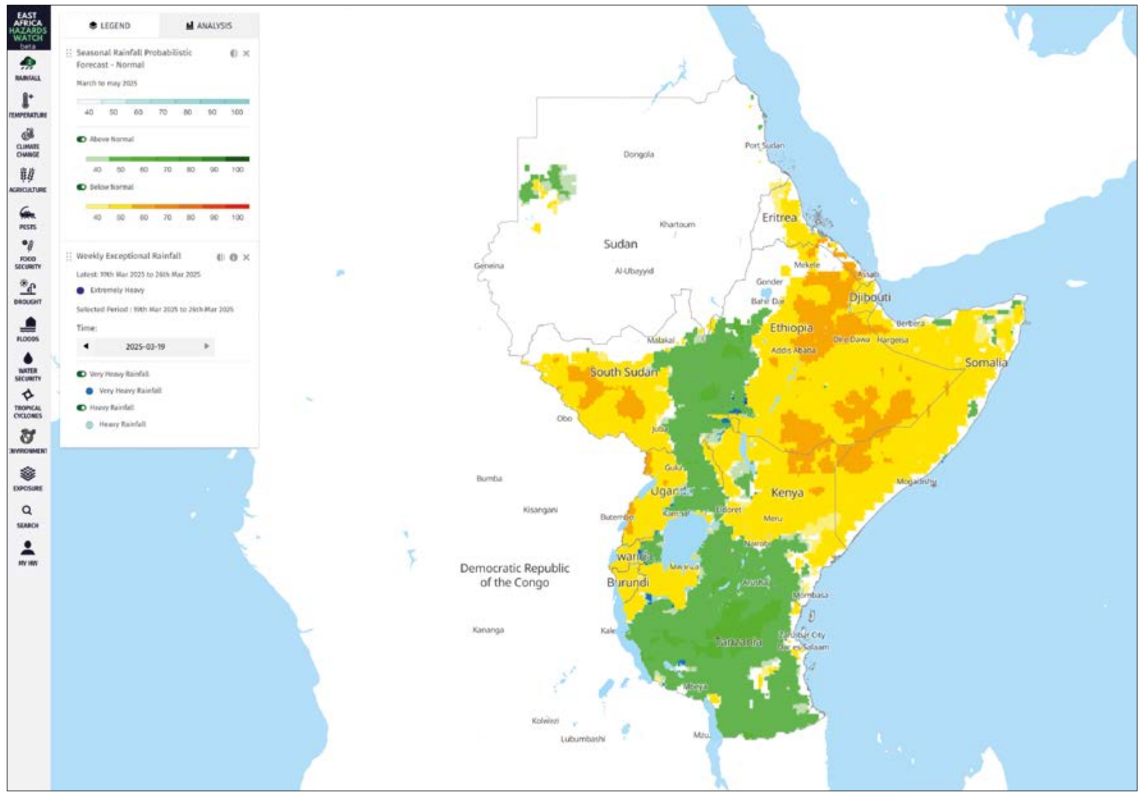
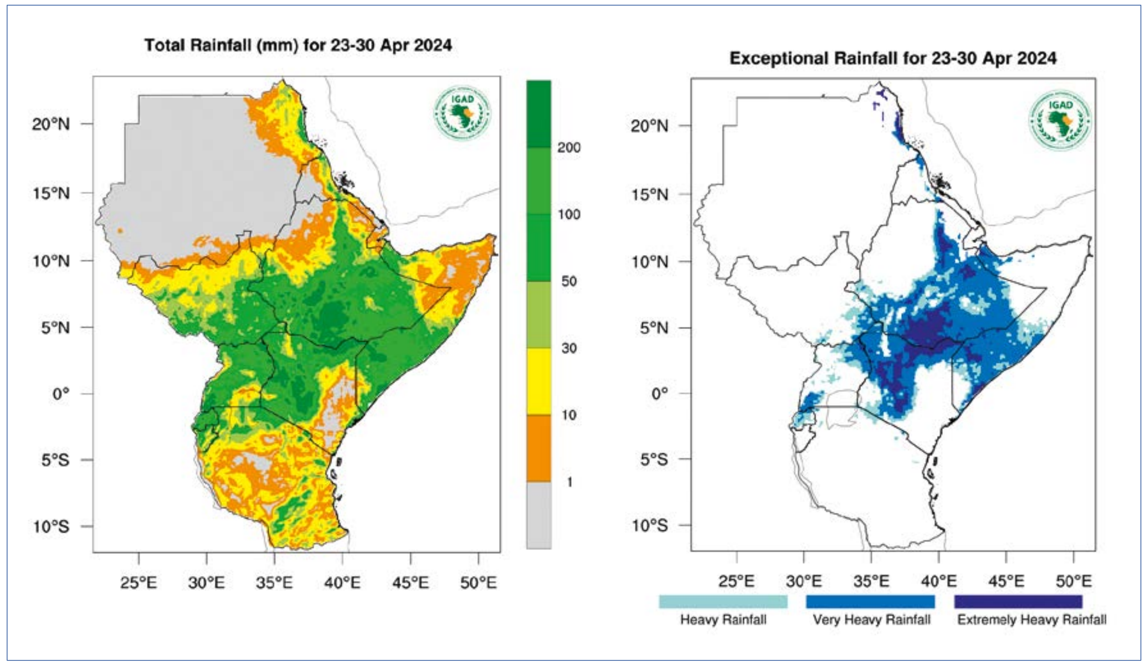


Figure 25. Weekly forecasts of total rainfall (left) and exceptional rainfall (right) available in the East Africa Hazard Watch.



For the Eastern Africa region, which is highly vulnerable to food insecurity resulting from exposure to multiple shocks including climate extremes and conflicts, Earth Observation (EO) offers an unprecedented opportunity for large-scale remote monitoring of agriculture conditions in near-real time, providing timely early warning information.

In this context, ICPAC in collaboration with the European Joint Research Centre (JRC) is implementing a thematic service on agriculture monitoring in the Eastern Africa region. The objective is to strengthen the capacity of member states to use EO data to improve decision making in agriculture and food security sectors at regional, national, and sub-national levels including cross border areas of IGAD countries (i.e., Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda).

In 2020, a team of scientists and developers at ICPAC in collaboration with the JRC Anomaly hotspot of Agriculture Production team, transferred and adapted the JRC system to the region. The cus-tomised system, named "East Africa Agriculture Watch" (https://agriculturehotspots.icpac.net/), features most of the functionalities of the original and remains synchronised with its database (Figures 26, 27).

This platform informs existing working groups that meet regularly to update the latest information on climatic hazards and food security vulnerabilities. The information is shared with key actors across the climate, humanitarian, and development sectors such as the Greater Horn of Africa Outlook Forum, the Food Security and Nutrition Working Group, the GEOGLAM regional Crop Monitoring for Early Warning, the ministries of agriculture at member state level, the national drought monitoring agencies and the national meteorological and hydrological services. The system has also been adopted as the food security monitoring system within the IGAD Disasters Operations Centre, mandated with providing comprehensive and integrated situational analysis of different multiple hazards occurring in the region. A series of training workshops have been organised on the system for ICPAC technical staff and users.

Figure 26. The East Africa Agriculture Watch interface (ICPAC - Warning Explorer).

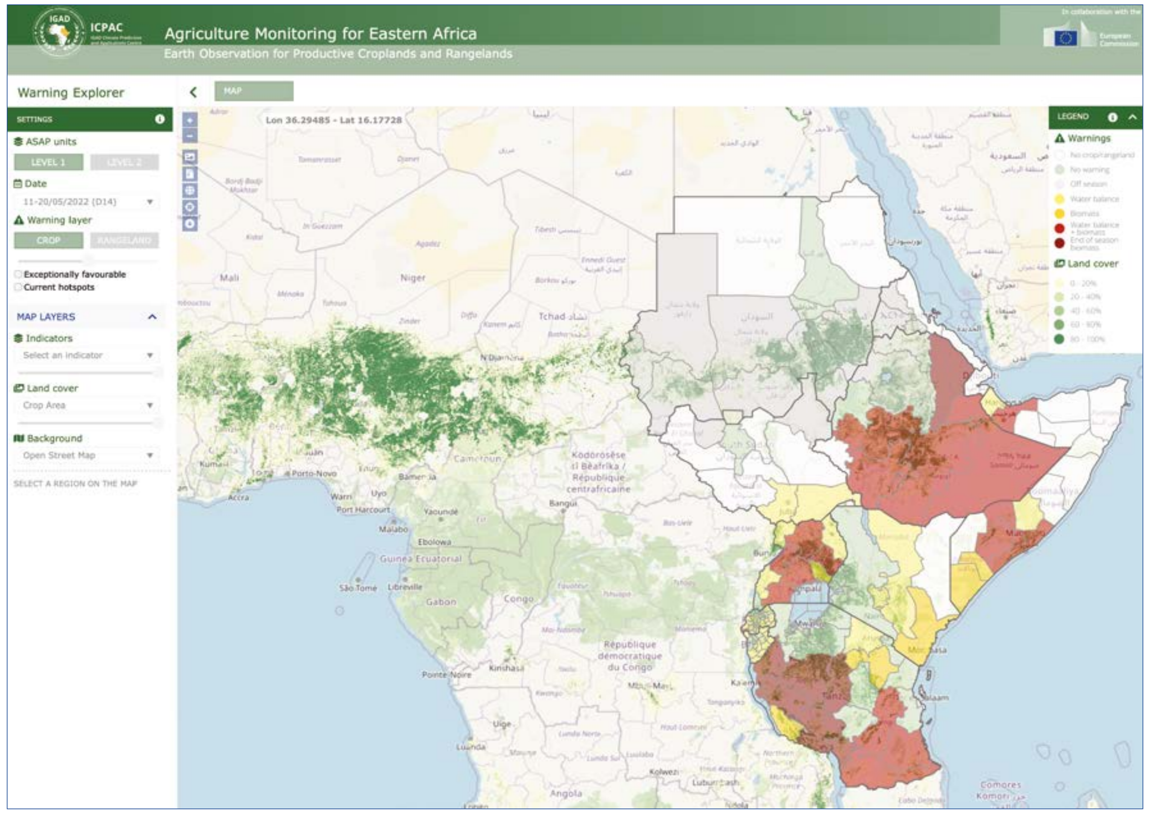


Figure 27. System statistics interface from the East Africa Agriculture Watch.

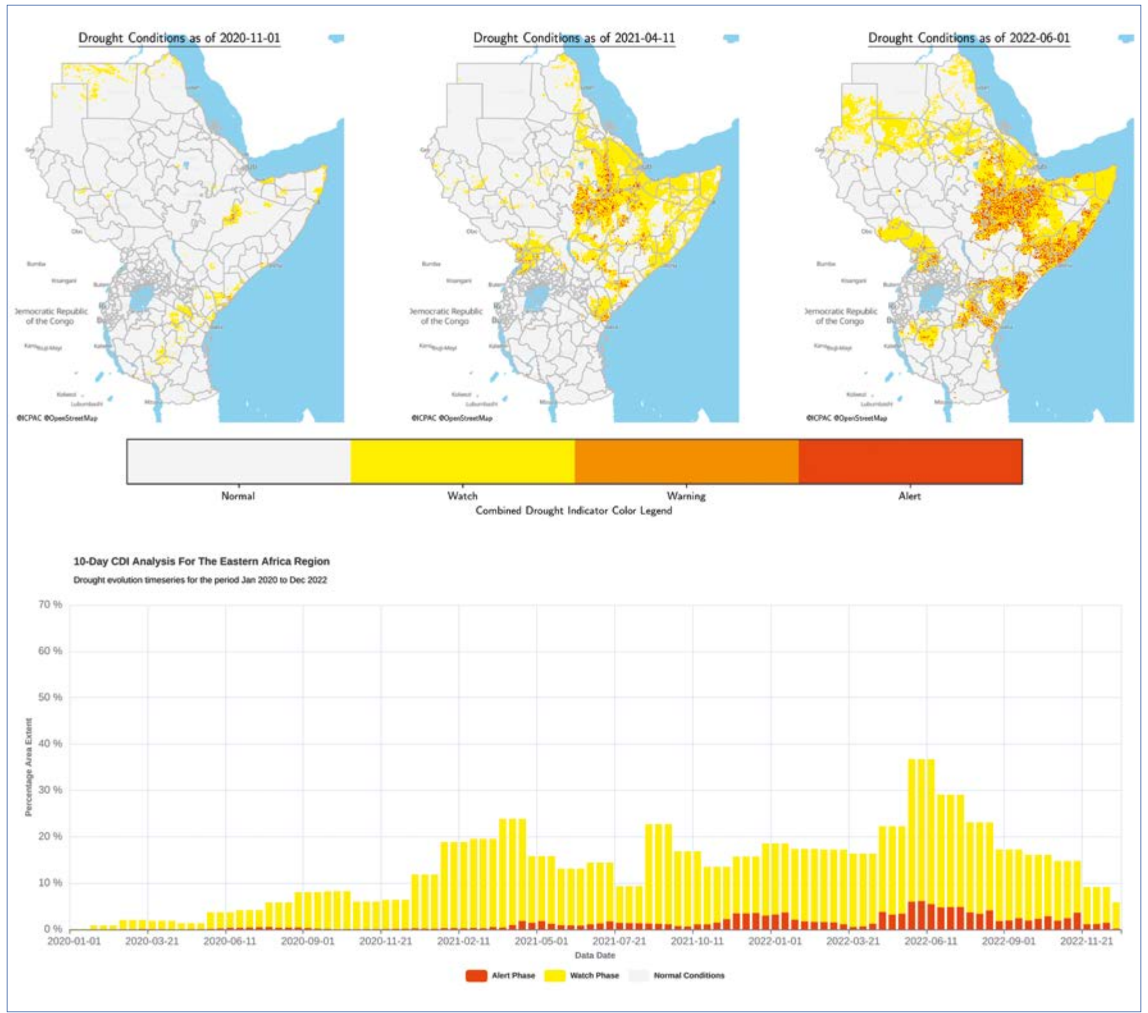
The East Africa Drought Watch

The East Africa Drought Watch is determined using the combined drought indicators over a period of ten days to months and years using key indicators such as precipitation, soil moisture and vegetation.

The Combined Drought Indicator is based on the Standardized Precipitation Index (SPI), Soil Moisture and Vegetation Condition, to identify areas with the potential to experience agricultural drought, areas where the vegetation is already affected by drought conditions, and those in the recovery process to normal conditions after a drought episode.

The drought impact and forecast are best described using a timeseries graph showing the evolution of the Combined Drought Indicator (CDI) for the monitoring period. The times series of a given location (IGAD region for instance) are generated based on the CDI which are graphically described using different alert levels depicted in colour codes (Figure 28).

Figure 28. Sample products extracted from the East Africa Drought Watch (EADW).



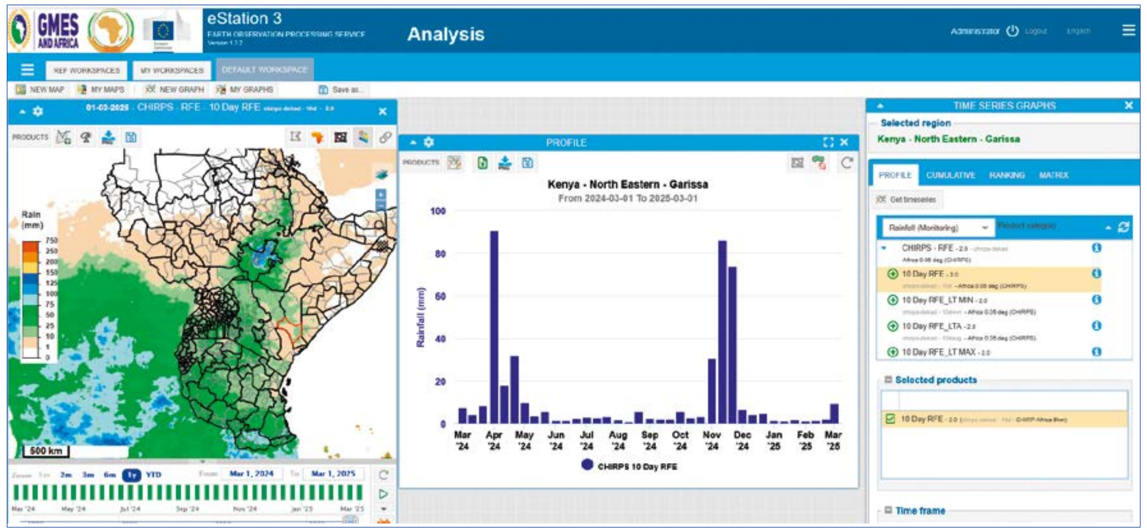
ClimSA Climate Station

The new climate station, successfully installed at ICPAC, is a climate-oriented version of the eStation, developed by the Joint Research Centre (JRC) through the ClimSA Programme. The climate station is designed to automatically deal with the acquisition, processing, visualisation and analysis of key environmental parameters derived from remotely sensed data, as well as reanalysis and select model outputs (Figure 29).

In addition to the processing services, the system offers a highly customised web client, made available to different end-users for computing ad-hoc thematic products and environmental indicators. All processing steps are easily configurable allowing the user to modify the generated environmental indicators and to implement new ones.

It includes forecast and projection products, remote sensing data products, local station data, and additional features like Jupyter Notebooks. It is designed to provide climate-related data and information to support climate change research, policy-making, and decision-making.

Figure 29. Climate Station analysis interface (ICPAC-Climate Station).



CHAPTER 2.3 Climate Early Warning for the Agricultural Sector – the Caribbean Agroclimatic Bulletin

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2.3.1 Introduction

Extreme weather and climate events, climate variability, and long-term climate change pose significant challenges to agriculture and food security. Climate-related disasters such as strong winds, droughts, floods and excessive marine and terrestrial heat can lead to crop failure, heat stress in ruminants and poultry, reduction in fish catches, loss of forest and biodiversity, food insecurity, hike in food prices, negative impacts on livelihoods, and economic slowdown. Trends in the Caribbean already show an increase in temperature across the region (Climate Studies Group Mona 2020; Stephenson et al. 2014), with the warming projected to continue through the century (Climate Studies Group Mona 2020; Van Meerbeeck 2020). All components that influence food security - availability, access, stability and utilisation – are impacted by climate related events (FAO 2019a).

Climate information and its sectoral applications, including for agriculture and food security, underpin many of the UN Sustainable Development Goals (SDGs) including Climate Action, Zero Hunger, Good Health and Well-Being, Clean Water and Sanitation, No Poverty[9], with each of these directly or indirectly impacted by weather and climate-related events. In many Caribbean countries, agriculture contributes between 7% and 17% of GDP but has a significantly larger share of employment - between 10% and 25%, and almost 50% in Haiti (FAO, 2019b). As a major employer, including of women and the rural poor, agriculture plays a critical role in Caribbean islands to achieve the SDGs.

In Guyana in particular, the percentage GDP from agriculture has been close to 20% in past years, but more recently, this has declined to 14% (FAO 2019b) - employing about 13.4% of the population in 2017, with 3.4% of the population being female. Sustaining and expanding agricultural production is central to enhancing lives and livelihoods in the Small Island Developing States (SIDS) of the Caribbean region.

The production and use of climate information and services can facilitate the transition to a resilient and sustainable future. Agriculture, including the management and production of crops, livestock and fisheries, is arguably the most vulnerable sector to climate variability and climate change. Certainly, in the Caribbean it is the sector with which the National Meteorological and Hydrological Services (NMHSs) traditionally interact (Mahon et al., 2018). Investments in weather and climate-related sciences and services would enable farmers to make key decisions to increase production – for instance on what to grow, when to plant, when to apply fertilizer and how to protect crops and livestock against pests, diseases and dangerous climate-related hazards such as tropical cyclones, heatwaves, floods and wildfires. Climate information and services are also key ingredients for decision- and policy-making in government and large commercial establishment to enhance food sovereignty and security.

One climate product designed to impart such information to the agri-food community is the Caribbean's monthly agroclimatic bulletin co-developed and co-delivered by the Caribbean Regional Climate Centre and the Caribbean Agricultural Research and Development Institute (CARDI). This article features the products and services in the Caribbean's agroclimatic bulletin and how the ClimSA Programme is seeking to enhance its relevance to the agriculture sector.

2.3.2 Early Warning Information Targeting Agriculture and Food Security in the Caribbean

Climate services providers in the Caribbean – CIMH and the NMHSs – produce seasonal and sub-seasonal information that is well placed to support decision making in the agriculture and food security sector. However, the technical and probabilistic nature of climate information makes it very difficult for non-experts to interpret (Vaughan and Desai, 2014). Therefore, an information source that packages, assists in interpreting, provides implications and recommends climate smart responses based on the climate products was designed to enhance decision making. The first agroclimatic bulletin was produced in 2011 under the Caribbean Agro-Meteorological Initiative (CAMI)[10]. CAMI, which commenced in November 2009, was a partnership between CIMH, CARDI, the World Meteorological Organization (WMO) and 10 Caribbean NMHSs, financially supported by the European Union through the African Caribbean and Pacific (ACP) Group

9 *In the Caribbean, about 26% of the population lives below the poverty line (FAO, 2019).*

10 *https://cimh.edu.bb/cami/ (accessed 27 January 2025).*

of States Science and Technology (S&T) Programme (Trotman, 2012). The CAMI bulletin provided a regional and national summaries of recent climate conditions, as well as seasonal (3-month) regional tercile rainfall forecast and updates on the El Niño Southern Oscillation (ENSO). Some countries were, at the same time, producing their own national bulletins. Under CAMI, the information in the bulletins were key discussion points in farmers forums and the Caribbean Climate Outlook Forum, building climate resilience in the agriculture and food security sector, was significant in breaking ground as agriculturists and climate information providers engaged in meaningful dialogue, but with the recognition that there were still limitations to decision making (Vogel et al., 2017).

In collaboration with international partners such as the International Research Institute for Climate and Society (IRI) of Columbia University, Caribbean climate services providers prioritised developing tailored climate information intended to make it easier for sector practitioners to act. They advanced their seasonal forecast products beyond the more familiar tercile forecast, often deemed insufficient on which to make critical decisions (Hansen et al., 2022). Therefore, the information package would now base much of its interpretation, implications and climate smart responses on tailored products that expose potential climate hazards, such as drought, dry spells, excessive rainfall, flood potential and extreme heat was designed to enhance decision making.

The first such tailored product was the drought outlook in 2014. By the following year the product suite expanded to include forecasts of the frequency of wet days and wet spells. During the process, the Caribbean Consortium of Sectoral Early Warning Information Systems Across Climate Timescales[11] (EWISACTs) was being established to facilitate evidence-based and risk informed decisions in key climate sensitive sectors, including agriculture and food security, in the Caribbean using an integrated approach. It was also clear from the literature that co-producing climate information with sector practitioners at both the national and regional levels would enhance its relevance and uptake (Mahon et al., 2019; Vogel et al., 2017).

Every month since May 2017, CIMH and its partner CARDI have been co-producing and disseminating the Caribbean Society for Agricultural Meteorology (CariSAM) agroclimatic bulletin (Figure 30). Similarly to the CAMI bulletin before it, the CariSAM bulletin packages generic, though now largely tailored, seasonal climate monitoring and forecast information, along with implications and climate smart advisories for crops, livestock and poultry. The bulletin is displayed on the CariSAM platform – a portal that is poised to advance the dialogue and engagement between climate services providers, researchers and agriculturists (including farmers). It will serve as a live forum for discussions, sharing of knowledge and experiences as well as a quick reference point for solutions and challenges faced in agriculture from weather and climate - including challenges which outlooks for the next three to six months may present. The platform also provides linkages to key resource persons and serves as a clearing house for agrometeorological information in the Caribbean.

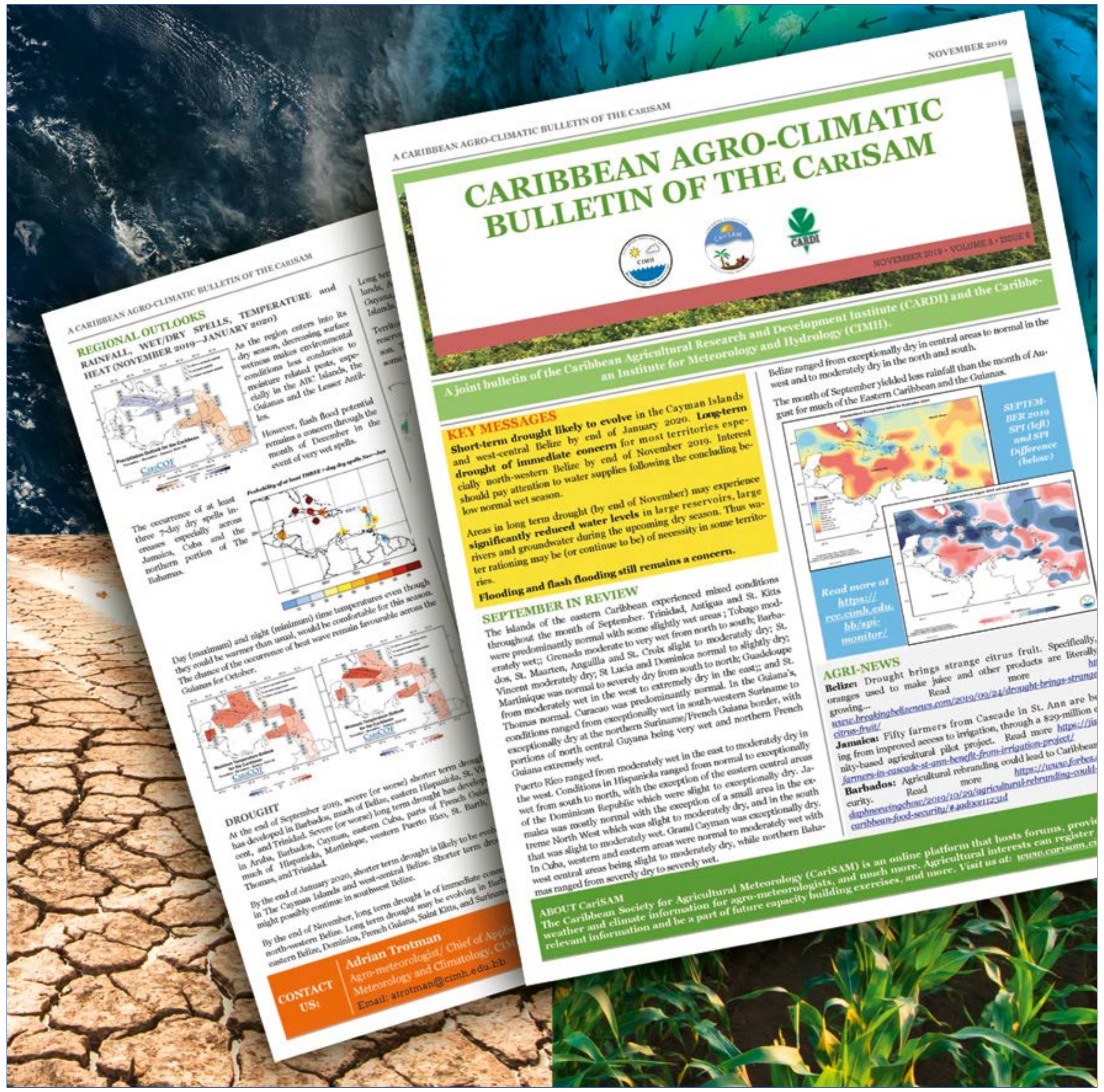
11 https://rcc.cimh.edu.bb/ewisacts/ (accessed 27 January 2025).

The following is a synopsis of the hazard-tailored products presented or referred to in the CariSAM bulletin.

Early Warning Information on Drought and Dry Spells

Drought is a slow onset phenomenon driven by a lack of rainfall, at times accompanied by elevated temperatures and excessive evapotranspiration, resulting in deficient water resources, thereby impacting heavily on crops and livestock globally. Since 2009, the Caribbean has been paying closer attention to this hazard after events that led to significant impacts, including in the agriculture sector (Trotman et al. 2018; Farrell et al. 2010).

Figure 30. The Agroclimatic Bulletin of CariSAM.



In 2014, the CIMH and its partners commenced the development of an early warning alerting system for drought that is widely used across the Caribbean. In the CariSAM bulletin, several drought-related products are presented or referenced and implications for the sector discussed based on those products:

- **The slow onset nature makes monitoring a critical early warning activity**. Climate monitoring products are operationally produced and delivered[12] by the Caribbean RCC each month utilising a customized, in-house built application written in R. These include monthly rainfall totals; monthly and annual mean temperatures, as well as 1-, 3-, 6- and 12-month temperature anomalies; 1-, 3-, 6-, 12- and 24-month Standardized Precipitation Index (SPI) and Standardized Precipitation Evaporation Index (SPEI); and, finally, the month-to-month relative changes of both the SPI and SPEI for each time interval. Apart from providing an indication of severity of deficit and excessive rainfall, SPIs and SPEIs are also used here to identify rainfall anomalies.
- **In collaboration with Caribbean NMHSs, several seasonal climate forecast products are developed that are referenced in the agroclimatic bulletin** (Figure 31). These include seasonal alert information on anticipated 3-month lead short-term drought (typically impacting streams, small rivers and ponds) and long-term drought (typically impacting large rivers and reservoirs, and ground water). The long-term drought forecasts anticipate alert levels at the end of the two rainfall-based Caribbean seasons (wet and dry seasons). These products identify areas with ongoing and emerging drought concerns and are compiled together in the Caribbean Drought Bulletin[13]. The CariSAM Bulletin also gives practical information on how to effectively respond to these situations. Also included is a definition of the relationship between drought alert levels and the action levels they trigger.

Complementing the drought alerts, specifically developed for the agriculture sector, are seasonal forecasts of frequency of dry spells[14], which can induce water stress in crops. Outlooks and implications of frequency of spells of 7, 10 and 15 consecutive dry days - where a dry day is defined as a 24-hour period with less than 1mm of rainfall - can signal the need for irrigation, for example (Figure 32).

12 https://rcc.cimh.edu.bb/climate-monitoring/caribbean-drought-and-precipitation-monitoring-network/ (accessed 25 January 2025).
13 https://rcc.cimh.edu.bb/drought-bulletin-caribbean/ (accessed 25 January 2025).
14 http://rcc.cimh.edu.bb/dry-spells-outlook-experimental/ (accessed 25 January 2025).

Figure 31. Above, observed conditions for SPI6 and SPI12 at the end of May 2024. Below, the forecast alerts produced at the end of February 2024 for both short- and long-term drought at the end of May 2024.

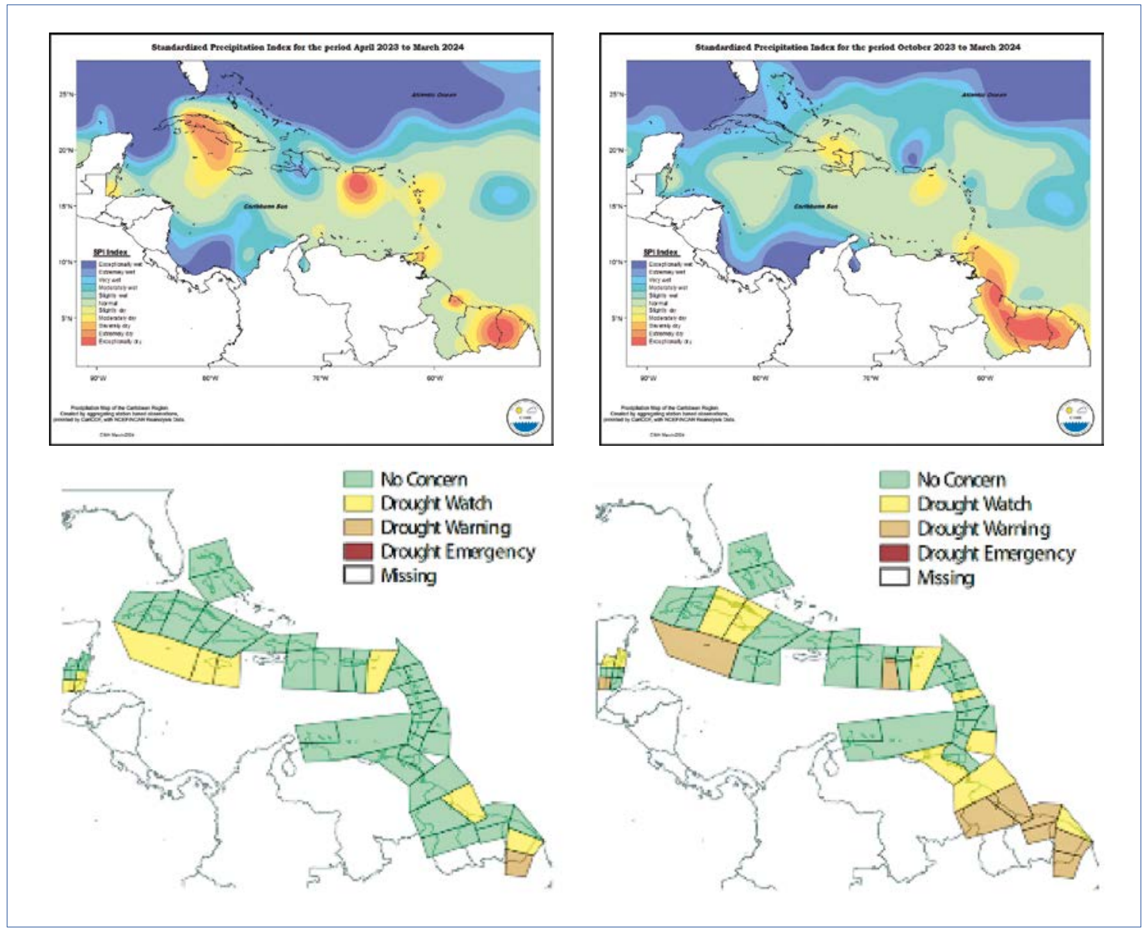
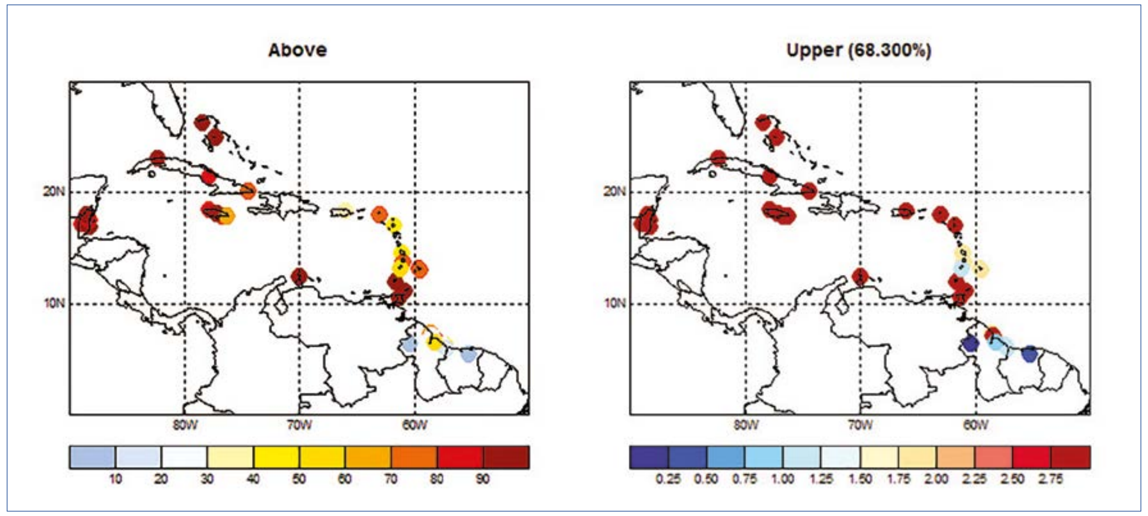


Figure 32. To the left, the probability of at least three 7-day dry spells from March to May 2024 and to the right, the maximum number of 15-day dry spells for the same period.



Early Warning of Excessive Rainfall

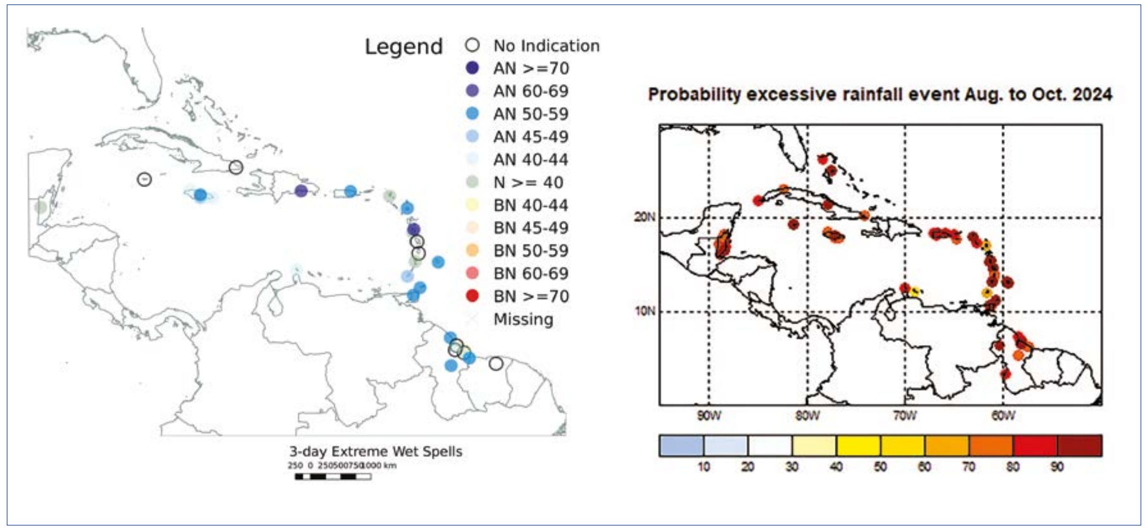
Though water availability is necessary for crop and livestock production, too much water can result in anaerobic conditions in soils, soil erosion, prevalence of pests and diseases and drowning of livestock and poultry. Early warning of such conditions can improve management in the field and enhance productivity.

Products presented or referred to in the Agricultural Bulletin include (Figure 33):

- Seasonal, 0-month lead forecasts and climatologies of the occurrence and frequency of wet days and wet spells of various rainfall intensities and durations[15,16], with the wet spells providing some insight into the potential for groundwater logging or soil desiccation, flooding, among other hazardous conditions.
- Seasonal, 0-month lead forecasts and climatologies of Flash Flood Potential, provide information on excessive rainfall events that can potentially lead to flash floods, along with the number of those excessive[17] rainfall events that could trigger flash floods.

15 http://rcc.cimh.edu.bb/wet-days-wet-spells-outlook/ (accessed 25 January 2025).
16 https://rcc.cimh.edu.bb/climate-outlooks/flash-flood-potential-outlook/ (accessed 25 January 2025).
17 Excessive rainfall defined as events with at least 30mm of rainfall in a day. The Flash Flood Potential Outlooks can be accessed at https://rcc.cimh.edu.bb/climate-outlooks/flash-flood-potential-outlook/

Figure 33. To the left, forecasted shift in frequency of extreme (top 1%) 3-day wet spells, and to the right the probability of an excessive rainfall event from august to October 2024.



Early Warning for High Temperatures and Excessive Heat

High temperatures can reduce productivity in crops, livestock and poultry. Acknowledging this, the Caribbean RCC's 0-month lead tercile forecasts of day-time (maximum) and night-time (minimum) temperatures, are referred to, along with a heat outlook updated monthly ahead of and during the Caribbean Heat Season which, nowadays, spans from about April to October. After October, cooler conditions prevail. Anomalously high temperatures and the potential for impactful, excessive heat due to numerous heat wave days not only affect production directly but also create conditions that stymie physical activity and can threaten the health of farmers, further impacting production levels. The heat outlooks produced by the Caribbean RCC are 0-month lead, 1-month to 6-month duration heatwave days frequency forecasts and climatologies, and heat impact potential[18].

18 http://rcc.cimh.edu.bb/heat-outlook-experimental/ (accessed 25 January 2025).

2.3.3 ClimSA's Contribution to Early Warning for the Agriculture Sector in the Near Future

One of the thrusts of the Caribbean ClimSA Programme, in association with the EWISACTs Consortium, is to develop sector specific climate information for the agriculture sector. This is unlike the generic, though hazard-tailored, information that is currently packaged with messaging and implications specific to the agriculture sector. Efforts to deliver outputs specific to the agriculture sector have begun and are being advanced. Such products and services anticipated to enhance the CariSAM Bulletin, lend to the confidence of decision- and policy-making.

The CIMH is collaborating with stakeholders in the poultry and livestock sub-sectors for the very first time, in the testing of heat indices for forecasting of risk of heat stress. Such work is recommended to be prioritised, as animals, for example in Jamaica, may already be experiencing considerable periods of heat stress even during the relatively cooler northern hemisphere winter (Lallo et al., 2018). Discussions has already begun with the Caribbean Poultry Association, a regional private sector entity, which expressed interest in this type of climate information. Similar interest was expressed by the Guyana Livestock Development Authority (GLDA). This work will also present a new opportunity for strengthening or commencing other partnerships with other relevant Caribbean organisations, such as CARDI and the University of the West Indies (Faculty of Food and Agriculture). Under the ClimSA Programme, it is anticipated that investigations, particularly in the target country Guyana, will lead to a heat stress forecast system for sheep and broiler chickens – most likely via indices such as the Temperature Humidity Index (THI). Key to the early warning approach is the likelihood of these thresholds being reached or exceeded.

The existing drought early warning alerting system will be enhanced by incorporating the results from recent and existing research of the SPI and other indices under the ClimSA Programme. This activity will utilise determined thresholds of the SPI for forecasting levels of impacts of drought on the agriculture sector in Guyana initially, with the intention to expand the approach to other Caribbean countries. The information would also be critical to the development of agricultural drought management plans for Guyana.

During the dry season, bush fires are serious threats to Caribbean agriculture. This is exacerbated during drought (Trotman et al., 2018; Farrell et al., 2010). Thanks to training on the Climate Station developed by the Joint Research Council of the European Commission, fire weather is actively being monitored, the Caribbean RCC and Caribbean NMHSs (Figure 34) and is poised to be frequently referenced during the dry season in the Caribbean.

In another European Union funded initiative – the Global Climate Change Alliance Plus (GCCA+) executed by the Caribbean Community Climate Change Centre (CCCCC), the CIMH, in collaboration with the University of Florence, Italy, led model development of risk models for the development of powdery and downy mildew in squash and whitefly in tomato (Figure 35). With some minimal testing done in Barbados and Antigua and Barbuda, the intention under ClimSA is to test and validate this model in Guyana condition more robustly.

Figure 34. Global Wildfire Information System (GWIS) Daily Severity Rating (DSR) for Barbados to the left, and Guyana to the right in 2024 (red) compared to the maximum (black) minimum (green) and average (blue) climatological ratings. Note the high fire weather.

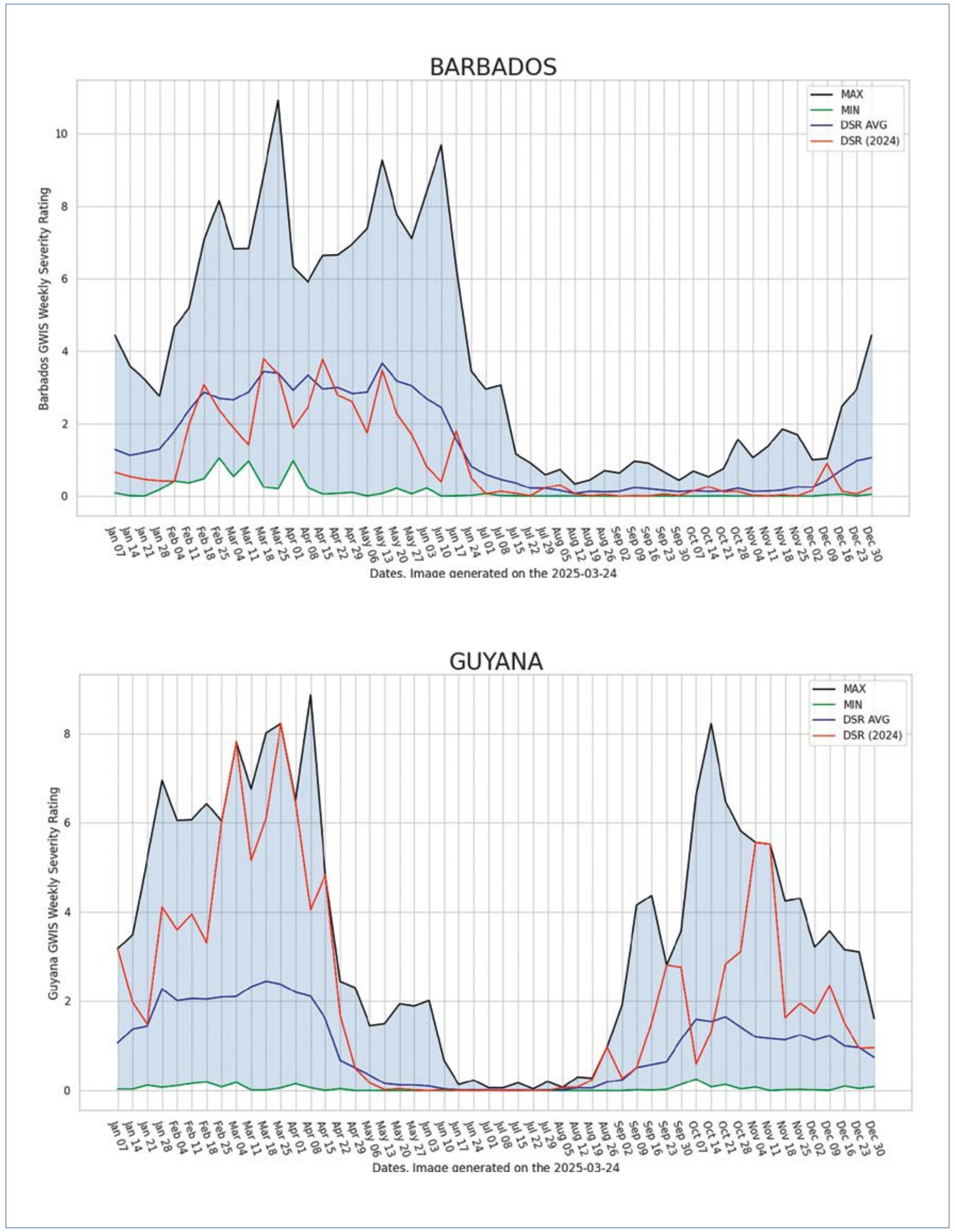
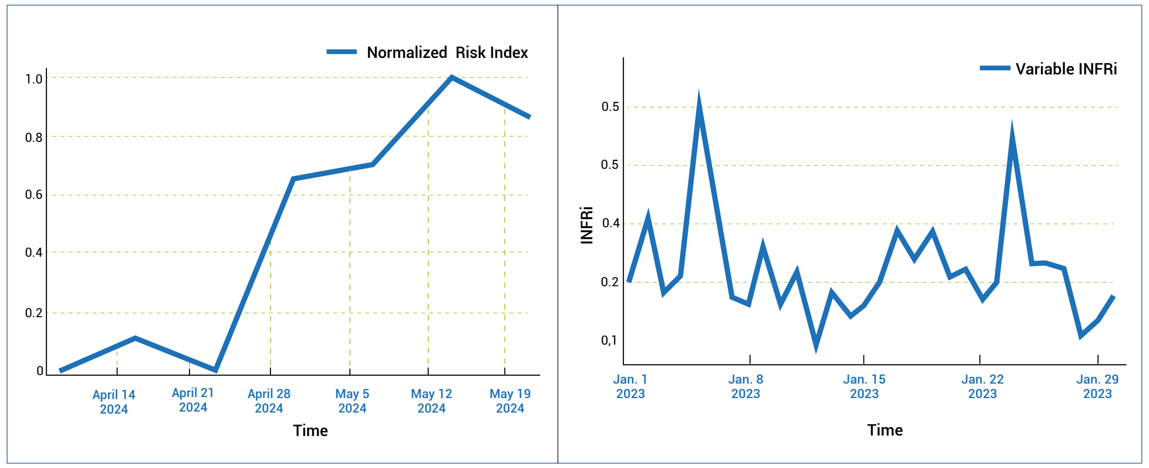


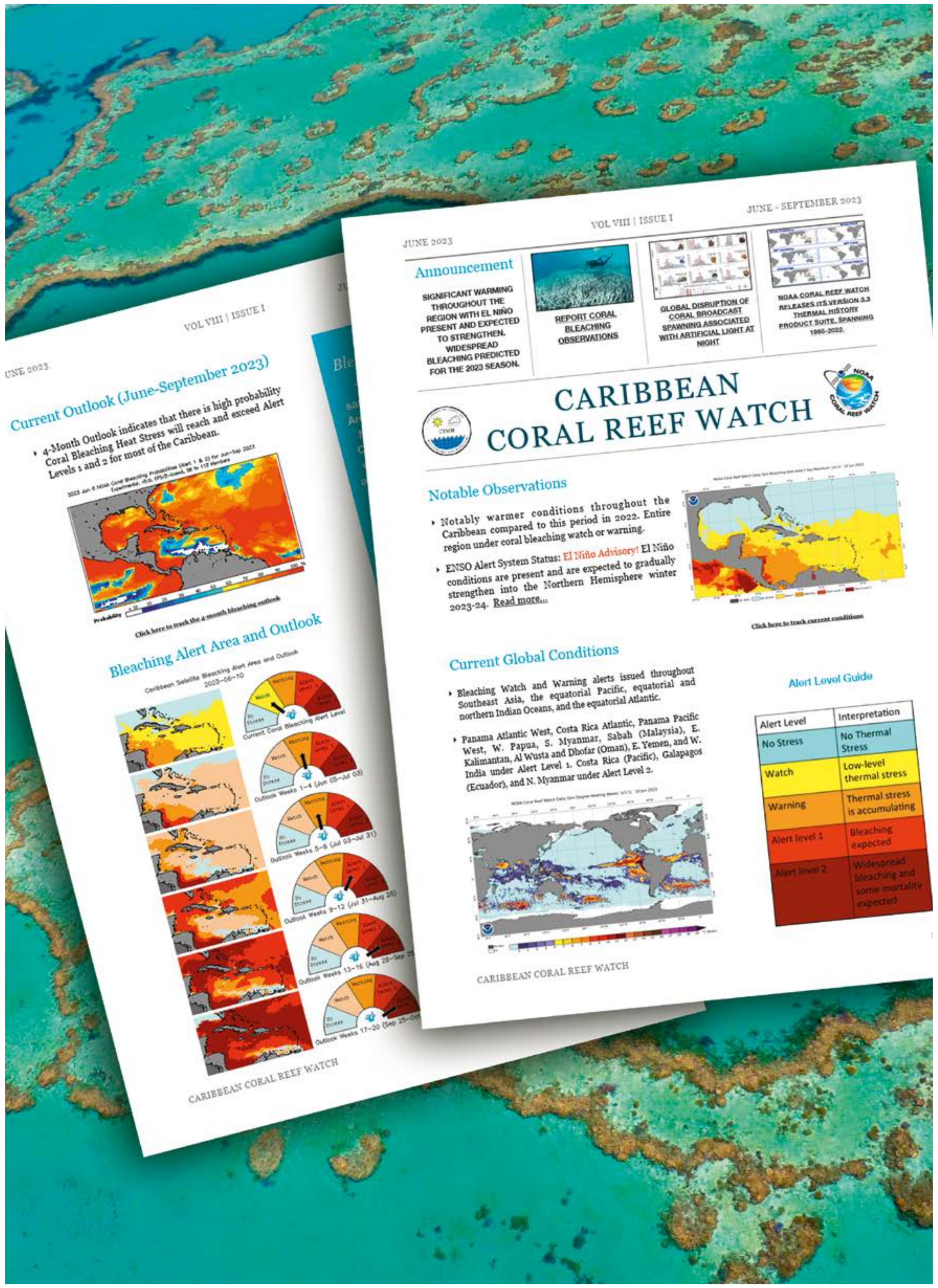
Figure 35. To the left, risk index generated by the whitefly model in tomato, and to the right, infection rate of powdery mildew in squash.



ClimSA is supporting the enhancement of the CariSAM Bulletin and its portal for subsequent re-launching. Enhancing the dissemination and delivery of climate information to the agricultural community includes introducing video summaries of the bulletin. This approach broadens the reach to a more diverse group of agriculturalists, fostering resilience and sustainability. Through Caribbean ClimSA, the agricultural community will soon have access to the monthly bulletin in both print and video formats.

The sea is an important source of food for SIDS around the globe – no less so for Caribbean SIDS. Coral reefs are significant habitats for fish and other sea urchins that form a critical part of the Caribbean diet. Warm marine environments can significantly impact these habitats. Developed by CIMH in collaboration with the National Oceanic and Atmospheric Administration's (NOAA) Global Coral Reef Watch, the Caribbean Coral Reef Watch was first produced in 2015 (Figure 36). The bulletin tracks current sea surface temperatures and the related coral reef health, globally and particularly in the Caribbean. It maps regional thermal stress levels and coral bleaching potential with a lead time of 20 weeks. Also included in this early warning tool is a detailed outlook for countries most at risk of coral bleaching. It is published between May and December to correspond with the season in which bleaching can occur. With fish being a critical protein source in the region, it would not be far-fetched to include marine information, including coral bleaching information, in future agroclimatic bulletins as in many Caribbean countries fisheries is recognised as an important part of agricultural production and food security. Further to this, CIMH in collaboration with Caribbean NMHSs and WMO, has been increasing its efforts in building regional capacity in NMHSs to provide information on marine conditions to stakeholders. Certainly, information on, for example, marine heat waves (and marine cold waves) could become useful information in the management of marine resources, particularly in Caribbean reef systems (Cetina-Heredia and Allende-Arandía, 2023). The marine information mentioned above can also be introduced to the bulletin via video formats.

Figure 36. Caribbean Coral Reef Watch (http://rcc.cimh.edu.bb/caribbean-coral-reef-watch/).



2.3.4 Conclusions

Climate Smart Agriculture is a concept that establishes agricultural strategies to secure sustainable food security under a variable and changing climate that would (i) sustainably increase agricultural productivity and incomes, (ii) strengthen resilience to variable and changing climate, and (iii) reduce the sector's contribution to climate-related impacts (FAO, 2019a). To make climate smart decisions in the agriculture sector, assessment of various types of information - related to dry spells, drought, flood and excess water, and excess heat - to trigger appropriate responses will be needed.

Decision-makers will likely require varying levels of support for making risk-informed decisions based on all the information available to them. The CariSAM Bulletin responds to these needs by tracking and forecasting such potentially hazardous conditions when they present themselves. Responding to the information can certainly help to strengthen resilience to a variable and changing climate, and by extension sustainably increase agricultural productivity.

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SECTION

3 IMPROVING CLIMATE OBSERVATIONS AND MONITORING

This section looks at how systematic observations and monitoring are used to generate the data required for the development and implementation of effective climate services.

The first chapter, by taking as a case study the Southern African Regional Climate Outlook Forum (SARCOF), draws important lessons for the agriculture and food security sector in the region.

The second chapter examines heat as a hazard in the Caribbean, in view of the rapidly increasing heat risk in the region, with a particular focus on the prediction of extreme heat, including heatwaves, and forecasting potential heat stress.

The final chapter in the section assesses the role of space-based climate monitoring in tracking atmospheric, oceanic, and terrestrial changes over time and how data services are evolving thanks to the latest generation of satellites and to recent scientific and technological advances.

CHAPTER 3.1 Lessons for Agriculture and Food Security from the Southern African Regional Climate Outlook Forum

Surekha RAMESSUR

Southern Africa Development Community (SADC)

The Secretariat of the Southern Africa Development Community (SADC) has been convening the Southern African Regional Climate Outlook Forum (SARCOF) since 1997. This Forum is coordinated by the SADC Climate Service Centre (SDC), based in Gaborone, Botswana, and covers all 16 SADC Member States.[19] Meteorologists and representatives of government ministries, nongovernmental organisations (NGOs), and businesses meet to negotiate a seasonal climate forecast of rainfall for the upcoming three to six months that would be useful for climate-sensitive sectors, such as agriculture and food security, health, energy and water resources. Within the framework of the ClimSA Programme, the SADC Climate Service Centre has been convening the SARCOF and has enhanced the Forum by gradually implementing the objective seasonal forecasting and enhancing its climate services. Based on guidelines developed by the World Meteorological Organization (WMO), sector-specific, regional user interface platforms. This process was initiated by co-exploring user needs during SARCOF-26 (held online) in August 2022 and the review meeting which was convened in Johannesburg with regional user consultations in December 2022.

During SARCOF-27 in September 2023 in Mauritius, the SADC Climate Service Centre promoted the regional user interface platforms for the ClimSA priority sectors, namely the Water-Energy-Food nexus and the cross-cutting Disaster Risk Reduction (DRR) sector. Focal points from the SADC Member States for these four sectors were financially supported to attend the Forum through the ClimSA Programme. The engagement with sector-specific users during this event further strengthen climate forecasters' engagement with stakeholders and enhance co-production, which is considered paramount in developing tailored climate services and strengthening of the regional climate services value chain.

By taking SARCOF-28 as a case study, this report summarises the lessons learned engaging the agriculture and food security sector, particularly assessing their sector-specific climate services needs.

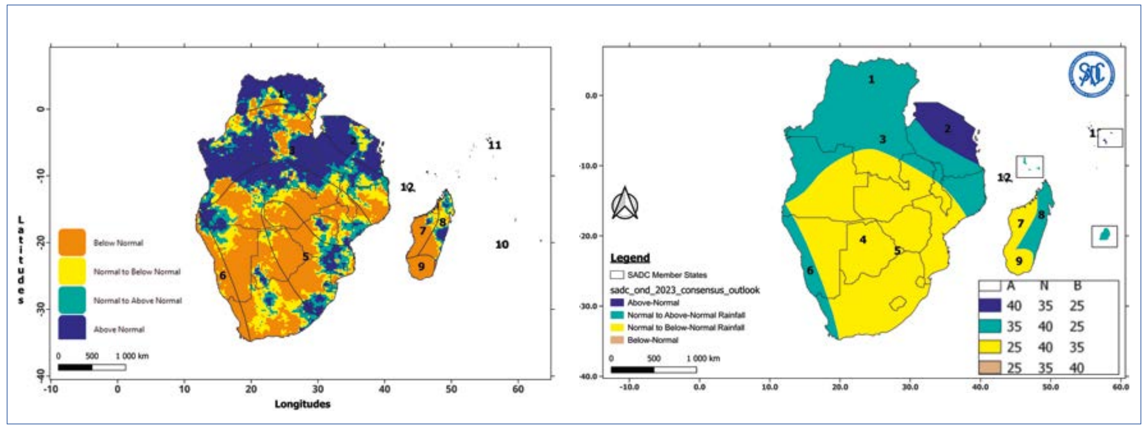
3.1.1 User Community Linkages and Related Platform

SARCOF-28 was convened in Maputo, Mozambique, from 29 January to 2 February 2024 in hybrid format. The Forum was preceded by the Climate Expert Meeting from 22-28 January 2024. During the sessions the sectoral climate outlook advisories produced in September 2023 were reviewed and an updated consensus outlook for the February to June 2024 rainfall season over the SADC region was issued.

During this event, the establishment of the sectoral regional user interface platforms was reinforced, through a set of co-production activities on climate monitoring products, and feedback and updates regarding the platform's Helpdesk and Community of Practice, which were introduced at SARCOF-27.

Users and stakeholders were informed on the enhanced methodology and more information was shared during the plenary session on analogue years and the climate drivers. Other products relevant to the sector were show-cased and users were capacitated to use the tailored products which were co-designed. This included onset of rainfall, consecutive dry days and standard precipitation index, amongst others.

Figure 37. Left: Forecast for October-November 2023 issued in September 2023 and (Right) Observed rainfall categories based on CHIRPS2 data and 1981-2010 long term mean.



3.1.2 Performance of the October-November-December 2023 Rainfall

During SARCOF-27, held in September 2023, climate experts from SADC National Meteorological and Hydrological Services had predicted that the bulk of SADC would receive normal to below-normal rainfall for most of the period October-December 2023, whilst the Democratic Republic of Congo, and United Republic of Tanzania normal to above normal precipitation was forecasted were forecasted (Figure 37a). The observed rainfall for the October-December 2023 period based on CHIRPS[20] data (Figure 37b) agrees to a certain extent with the forecast where normal to above normal conditions were predicted in the northern part of the SADC region and normal to below normal conditions were forecasted in the southern part of SADC.

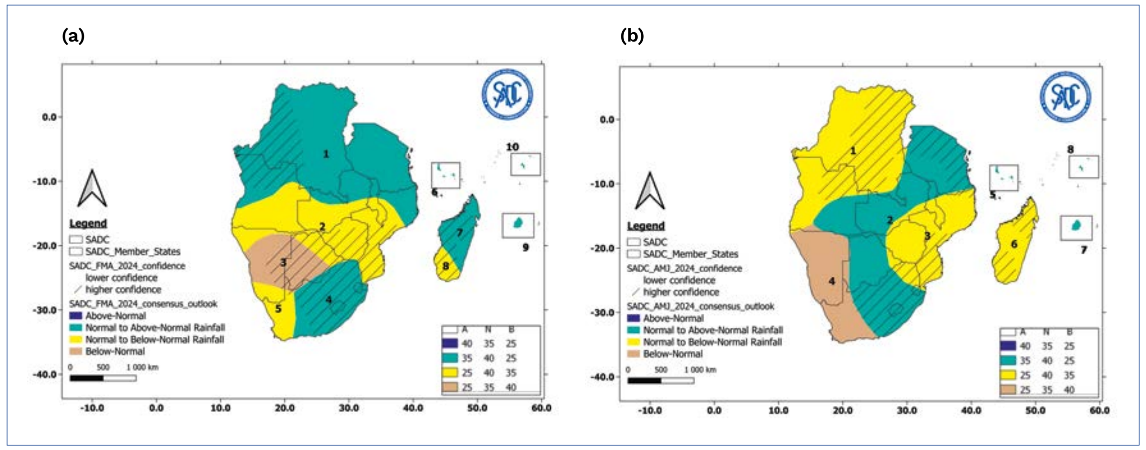
19 SADC member states: Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic of Tanzania, Zambia and Zimbabwe.

20 Climate Hazards InfraRed Precipitation with Station Data (CHIRPS) is a 30+ year quasi-global rainfall dataset, incorporating 0.05° resolution satellite imagery with in situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

3.1.3 Regional Climate Outlook for February to June (2024)

SARCOF-28 also saw the introduction of a new format of forecasts, providing indicators of levels of confidence that the forecasters had in different areas, ranging from higher confidence to lower confidence (Figure 38). This was with the intention of providing guidance to users of the forecast, enabling them to make more informed decisions based on the reliability of the predictions. By understanding the varying levels of confidence, users could better assess risks and plan accordingly, enhancing their ability to mitigate potential adverse impacts and capitalise on favourable conditions.

Figure 38. Rainfall forecast for (a) February-April 2024 (left) and (b) April-June 2024.



3.1.4 Planning and Mitigation Measures

The section provides a summary of what was discussed during the break away session of the agriculture and food security sectors. As per the usual practice, the user communities discuss the planning and mitigation strategies based on the outlook for the forthcoming season. The outcome of the discussion provides guidance on the way forward, rather than a detailed plan of action for each Member State on the use of the Southern African Regional Climate Outlook Forum Statement.

Regions impacted by low rainfall have notably failed the October-December agricultural season due to no rains in the areas. The problem has been exacerbated in regions which had experienced a previous poor season, followed by a lack of relief during the current season.

Implications and Mitigation Measures for the February to May 2024 Rainfall Season Outlook

Wet Forecast Areas

Excessive rainfall was anticipated in Tanzania, Seychelles and Mauritius. These rainfall prospects were considered good for livestock due to better pasture development, although crop yields might be negatively affected as a result of waterlogging. Flash floods were a main concern for the two island states.

Based on the Technical Working Group's findings and recommendations for the February-April Season, the potential mitigations for normal to above normal rainfall are summarised as follows.

- **Investing in water harvesting** and advocating for this through development institutions, including by young water entrepreneurs.
- **Construction of facilities for storage of crops.**
- **Dipping and vaccination of livestock.**
- **Construction of stronger greenhouses** to reduce hail impact.
- **Investing in digital infrastructure** to enable quick dissemination.
- **Undertaking pest control** to mitigate locust outbreak and outbreaks of other pests.
- **Spot application of fertilizers for crops.**
- **Sensitisation for timely harvests in March-May** for above-normal rainfall areas.
- **Unblocking sewage, and sewer and drainage systems** to reduce water contamination.

Dry Forecast Areas

The regional forecast indicated that several regions/countries were likely to be impacted by below normal rainfall for the February - April period, namely : southern half of Angola; north-eastern and most of western Botswana; southern Malawi; most of Mozambique; northern fringes and most of central and southern Namibia; northwestern fringes and south-western South Africa; southern Zambia; Zimbabwe.

The forecast is likely to result in a delayed start of the rainfall season and ultimately a delayed agriculture season, adversely affecting food security in Madagascar.

It is also expected to result in prolonged dry spells and a potential period of drought that would reduce crop productivity. Crop disease outbreaks such as the fall armyworm are also expected during this period.

Mitigation Strategies Based on the Forecast Issued in January 2024

Based on the Technical Working Group's findings and recommendations for the February-April season, the potential mitigations for normal to below normal rainfall which were categories as the dryer areas were as follows.

- **Maintain and increase irrigation.**
- **Stock-up on animal feeds**.
- **Diversify into alternative farming systems** (trees, farming maggots to feed chickens).
- **During drought periods, zoonotic diseases** such as anthrax is possible due to reduced interface interactions between humans and animals.
- **Activation of drought contingency plans** in most of the affected Member States is advised to guide response actions to sustain livelihoods and protect loss of life and assets such as livestock.
- **Increased coordination of the drought response** is also recommended at all levels to ensure effectiveness of response actions.

3.1.5 Lessons and Recommendations

SARCOF provides a critical platform for discussing and addressing climate-related challenges in the agriculture and food security sectors. From the deliberations with agriculture and food security practitioners at SARCOF-28, several key needs and recommendations emerged to enhance the effectiveness of climate services in supporting these sectors.

Rainfall trend analysis. One of the primary needs identified was the necessity for comprehensive research to determine trends in extreme rainfall events. This research is crucial to discern whether the observed changes are part of a long-term trend or merely short-term fluctuations. Accurate trend analysis helps agricultural stakeholders make informed decisions about crop selection, irrigation needs, and overall farm management practices.

National breakdowns of drought-stricken areas. SARCOF-28 was held in January 2024, in the middle of a strong El Niño event, when a number of countries in the SADC region were going through, or at risk of, a severe drought. Users encouraged National Meteorological and Hydrological Services to provide detailed national breakdowns of areas experiencing drought. This granular level of detail is essential for response agencies to target their interventions effectively. By identifying specific regions under threat, resources can be allocated more efficiently, ensuring that aid reaches those in greatest need.

In the context of agriculture and food security, the accurate identification and monitoring of drought conditions are crucial. Farmers and food producers need timely and precise information to make informed decisions regarding planting, irrigation, and harvesting. National breakdowns of drought-stricken areas enable better planning and resource allocation, ensuring that agricultural practices can adapt to changing conditions. This includes selecting drought-resistant crop varieties, optimising water usage, and implementing soil conservation techniques.

Furthermore, real-time drought assessments facilitate the early activation of support mechanisms, such as the distribution of drought-tolerant seeds, provision of emergency water supplies, and implementation of food aid programs. By targeting these interventions accurately, response agencies can prevent significant agricultural losses and support food security for affected communities.

Early warning and risk mapping. Climate services producers make a pivotal contribution to real-time drought assessments, which are instrumental in facilitating the early activation of support mechanisms. These include collection and analysis of data from various sources, including satellite imagery, weather stations, and remote sensing technologies, to detect patterns and trends in weather conditions, soil moisture levels, and precipitation rates. Additionally, it is crucial to predict the onset and severity of drought conditions and issuing early warnings to stakeholders, such as government agencies, farmers, and humanitarian organisations.

Continuous monitoring and detailed risk mapping help identify the most vulnerable areas and populations, guiding targeted interventions and resource allocation. National and regional climate services providers also need to effectively communicate and disseminate these drought information products through multiple channels to ensure that all stakeholders are informed and prepared.

Coordination and communication mechanisms. Users at SARCOF-28 also underscored the importance of collaborative efforts among different sectors and stakeholders. Strengthening coordination and communication mechanisms ensures that information flows effectively from meteorological services to agricultural stakeholders and response agencies. This collaborative approach enhances the overall capacity to respond to drought, leveraging expertise and resources from various sectors to develop comprehensive strategies. Reliable tailored climate data and insights support policy development and advocacy, while training and capacity-building programmes enhance the ability of local communities, farmers, and government officials to interpret climate data and respond effectively to drought conditions. This ensures that real-time drought assessments are robust, timely, and actionable, enabling early activation of support mechanisms, preventing significant agricultural losses, and maintaining food security for affected communities.

Recommendations Related to Anticipatory Action

Users at SARCOF also provided several recommendations that focus on anticipatory action, and offer valuable lessons for climate services producers, particularly in enhancing their support for agriculture and food security. These lessons emphasise the importance of accurate forecasting, continuous monitoring, effective communication, and documentation for improving preparedness and response to climate-related challenges.

Temperature forecasts. Users noted the need for temperature forecasts. Accurate temperature forecasts are crucial for planning and mitigating heat-related problems, such as heatwaves, which can lead to heat stroke and related fatalities. Climate services producers must prioritise the development and dissemination of precise temperature predictions. By providing timely and accurate temperature forecasts, climate services can help farmers and communities implement protective measures, such as adjusting work schedules, improving water management practices, and enhancing public health responses to prevent heat-related illnesses and fatalities. SARCOF currently focuses on rainfall and does not provide much information of temperature forecasts, and this is a gap that can be addressed.

Monitoring of weather and early warning. Users also recommended continuous monitoring of the weather and dissemination of early warning information using all available channels including social media. Continuous monitoring of weather conditions is essential for early detection of extreme weather events. Climate services producers need to ensure that they have robust systems in place for real-time weather monitoring, utilising satellite data, ground-based sensors, and other technologies to track weather patterns and detect anomalies. Once potential threats are identified, it is critical to disseminate early warning information using all available channels, including social media, radio, television, and mobile alerts. Effective use of diverse communication platforms ensures that warnings reach a wide audience quickly, enabling timely action to mitigate impact. This is relevant not just for agriculture and food security users.

Tailoring early warning advisories. Users further recommended the timely dissemination of fit-for-purpose early warning communication. Timely dissemination of early warning information is vital, but equally important is ensuring that the messages are fit for purpose. Climate services producers must craft warnings that are clear, concise, and easily understandable by different audiences, including local communities. Messages should be actionable, providing specific guidance on what steps to take in response to the warning. Tailoring the communication to the local context, including language and cultural considerations, enhances the likelihood that communities will heed the warnings and take appropriate action.

Informing sectoral decisions makers. Support agriculture decision-makers with appropriate and timely information and services to integrate environmental and climate factors into agriculture planning strategies and practice processes at the national, regional, and global levels.

CHAPTER 3.2 Heat as a Hazard in the Caribbean: Developing Early Warning Information

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3.2.1 Excessive Heat as a Hazard in the Caribbean

Air temperature does not vary much between seasons and years across the Caribbean region. Heat in this region is moderated by an easterly breeze, particularly in low-lying areas. Historically, heat has therefore been regarded as a periodic nuisance rather than a major hazard. Arguably, heat was not a major challenge until record-breaking heat experienced in the Caribbean as episodes of physical discomfort started ramping since 1995, particularly during the Heat Season. The Caribbean Heat Season – which, since around 2010, runs from April/May to October – is characterised by recurring heatwaves. However, when record heat in 2023 (i.e. when a majority of monitored Caribbean locations measured record-breaking Heat Season temperatures – Stephenson et al., 2024) continued in 2024, it raised societal awareness of a heat risk.

Vulnerability to heat is currently not monitored in the Caribbean to the level of detail or with the spatial coverage required for detailed heat risk quantification. However, such risk quantification has been done in a multitude of areas of the world, including the tropics, with the first studies becoming available for the Caribbean. Excessive heat exposure impacts a multitude of socio-economic sectors in the Caribbean, and include: te following.

- **Human health:** increased heat-related mortality and morbidity (e.g., in three Eastern Caribbean countries/territories – Pascal et al., 2022); exacerbation of vulnerability in persons with lower fitness levels; increased apathy and aggression; accelerated proliferation of vector borne diseases such as Dengue, etc. (e.g., for Barbados – Lowe et al., 2018).
- **Water management:** increased evapotranspiration rates under warmer conditions contribute to drought by reducing availability of surface water (e.g., for the Caribbean – Herrera et al., 2018).
- **Education:** children's learning ability significantly decreases with increased heat exposure (e.g., for the USA and internationally – Park et al., 2020).
- **Energy:** increased cooling demand and reduced efficiency in energy production.
- **National productivity:** loss of tens to hundreds of thousands of person-hours per Caribbean country/territory, particularly in outdoor workers in the construction and agriculture sectors (e.g., a global analysis – Watts et al., 2020).
- **Environment:** exacerbation of drought (e.g., the Caribbean – Herrera et al., 2018; Van Meerbeeck 2020); facilitation of wildfires; stress on animal populations.
- **Agriculture & Food security:** crop failure due to wilting, or flower drop (as in crops like tomato - Mills et al., 1988); severe heat stress related mortality and morbidity in livestock and poultry, including reduced milk and egg productivity, respectively (e.g. Lallo et al., 2018); reduced labour productivity of farmers (Watts et al., 2020).
- **Urban environment:** increased need for shading and green spaces, and for cooling centres for communities at risk; increased need for cool construction and home cooling techniques (e.g. roofing, efficient ventilation, A/C).

3.2.2 Heat Trends in the Caribbean

Observations and future climate change projections provide ample evidence for increased temperatures, frequency, duration and magnitude of heatwaves in recent and future decades in the Caribbean (Peterson et al., 2002; Stephenson et al., 2014; McLean et al., 2015; Climate Studies Group Mona 2020; Van Meerbeeck 2020; di Napoli et al., 2022) (Figure 39). The most important conclusions about temperatures in the Organisation of Eastern Caribbean States region since the 1960s are as follows (Van Meerbeeck 2020):

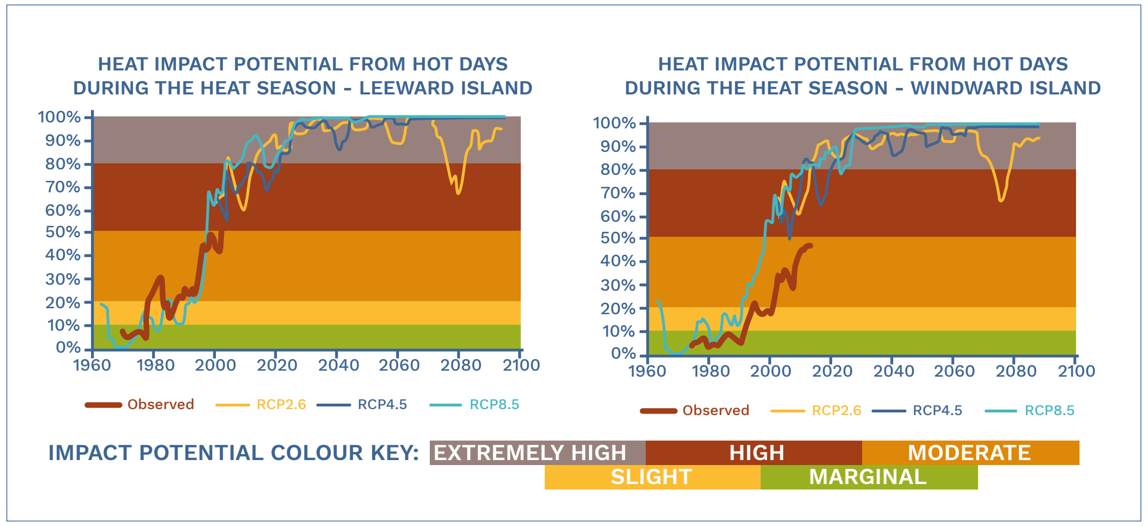
Current nature of and changes in heat as a hazard

- Uncomfortably hot days and nights occur on average 20-50% of the time during the peak of the Heat Season.
- A strong positive trend in the number of uncomfortably hot days (i.e., twelve extra days per decade), and uncomfortably hot nights (i.e., five to nine extra nights per decade).
- A four- to five-fold increase in the annual occurrence of heatwaves between the observed period before and, respectively, after 1995, testifying that heat is a relatively new hazard.

Future nature of heat as a hazard

- Using current metrics for heatwave occurrence, the projected rise in the proportion of time spent in heatwaves between May and October in the OECS region will exceed 80% as soon as the 2040s.
- Heat Seasons with at least 50% of the time spent in heatwaves will very likely manifest as soon as the 2020s, regardless of the future climate change scenario (as confirmed by observations for the years 2023 and 2024 in several Caribbean locations).

Figure 39. Recent and future heat impact potential in the Leeward (left) and Windward (right) islands of the Eastern Caribbean as measured by the percentage of hot days during the annual Heat Season (May to October).



Source: Van Meerbeeck (2020).

3.2.3 A Case for Heat Early Warning Information Provision for the Caribbean

Given the strong trends in heat in the region and the devastating heat impacts on public health, national productivity and agriculture, the development of resiliency to heat in the Caribbean region will require significant investment. In fact, mitigating the worst impacts of a multitude of climate-related hazards requires the adoption of multi-hazard early warning information systems to alert and adequately respond to impending threats. This is particularly the case when climate-related hazards occur in rapid succession, or coincide for instance with heatwaves – e.g., in the immediate wake of hurricanes (Guido et al., 2022). In recent years, the majority of the indirect death toll of several devastating hurricanes were the result of a major hurricane immediately followed by a heatwave in its wake – e.g., Maria (2017) in Puerto Rico (Kishore et al., 2018).

Since 2017, the WMO-designated Regional Climate Centre (Caribbean RCC) – hosted by the Caribbean Institute for Meteorology and Hydrology – has been operationally producing seasonal Heat Outlooks as part of its seasonal outlooks range of products and services. This has been made possible by collaborative work between the Caribbean RCC and the region's National Meteorological and Hydrological Services it serves, under the umbrella of the Caribbean Climate Outlook Forum (CariCOF), as well as with research and development support from Columbia University's International Research Institute for Climate and Society (IRI). These Heat Outlooks are published each month before and during the Heat Season on the Caribbean RCC's website at the dedicated page (rcc.cimh.edu.bb/heat-outlook). They provide information on expected heat impacts (and, qualitatively, impact levels) across multiple socio-economic sectors, as well as historical information, seasonal forecasts of temperatures, and seasonal forecasts of the frequency of heatwave days and the proportion of time spent in heatwaves, during the period of interest.

In addition to offering seasonal forecast information for a multitude of hazards, the Caribbean RCC under the umbrella of the CariCOF has recently started producing experimental sub-seasonal forecasts[21] of the risk of heavy rainfall events and of the number of dry-days. These forecasts were initiated, among other projects, through collaboration under an EU-funded project through the Global Climate Change Alliance Plus (GCCA+) initiative.

In view of the rapidly increasing heat risk in the Caribbean, there is a need for implementing sub-seasonal temperature forecasts, with a particular focus on the prediction of extreme heat, including heatwaves. The research and development, as well as roll-out of such a line of sub-seasonal forecast information, forms one of the core activities of the ClimSA Caribbean project and will be implemented by the CIMH in collaboration with the IRI, starting in 2024. The proposed activity will contribute to the implementation of real-time sub-seasonal forecasts of extreme-heat risk in the region.

21 Sub-seasonal forecasts predict climate conditions and associated hazards occurring within a week-long to two-week period and are made one to four weeks in advance.

3.2.4 Towards Sub-seasonal to Seasonal Heat Stress Prediction in the Caribbean

Redefining heatwaves in view of heat stress in humans

A recent publication by the World Meteorological Organization (WMO) reviewed a list of heat and heat stress indicators (WMO 2024, in press) as it improved on previous attempts to define heatwaves. Heatwave characteristics should ideally include:

- **local reference** – heatwaves are defined with respect to the local climatology rather than by absolute thresholds;
- **excess heat** – the level of heat above a threshold defined primarily with reference to the annual climatology (to distinguish heatwaves from warm spells, the latter of which are periods of excess heat outside of the Heat Season);
- **cumulative heat** (excess heat builds over a sequence of days);
- **sustained heat** (lasting through the night and persisting for a sequence of days).

A multitude of environmental factors (e.g., temperature, wind, humidity, radiation), human physiological factors (e.g., age, pre-existing non-communicable disease, metabolic rate, medication, etc.) and heat adaptation strategies (e.g., clothing type, accessing cooled areas, etc.) determine the level of heat stress experienced by an individual at any point of time. As such, an accurate quantification of heat stress in individuals requires sophisticated models, which are often data intensive. Alternatively, one can characterise the impact level of heat using heat indices that are far less data intensive.

Sophisticated heat stress models are prohibitive for early warning purposes in data-scarce regions such as the Caribbean. Since the overall aim of heat early warning is to inform the adoption of adequate anticipatory (preparedness and response) actions, the option of using simple heat indices to characterise heat stress may prove a feasible and effective alternative.

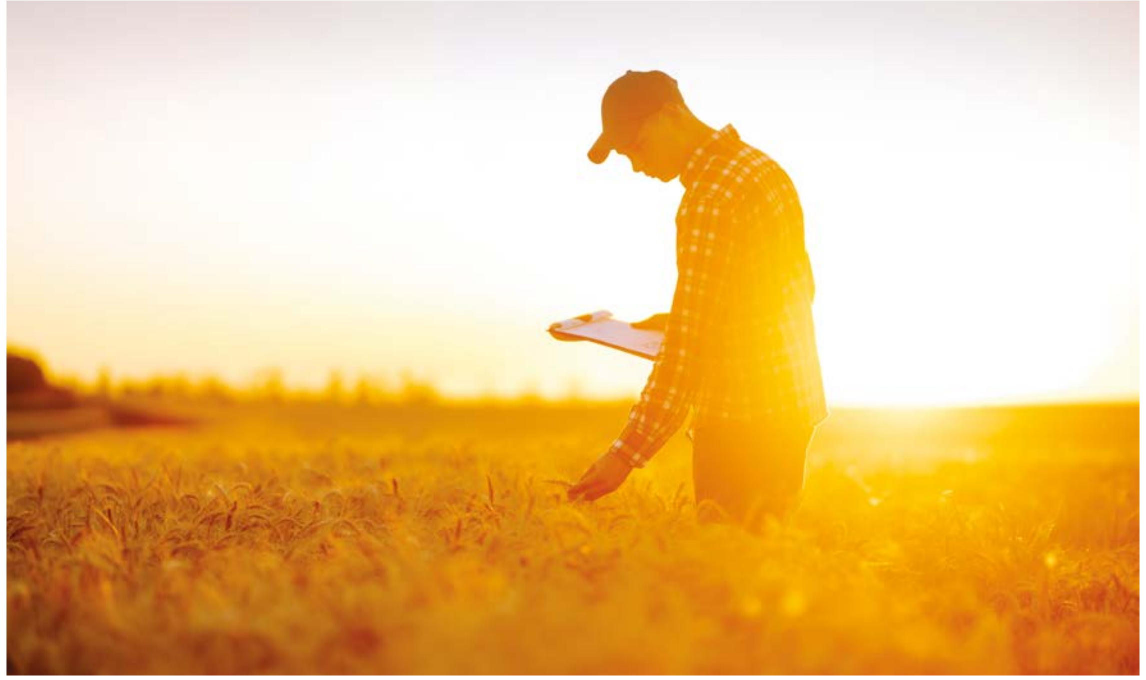
Designing a sub-seasonal heat stress forecast system

The CariCOF's current definition of heatwaves (i.e., a period of at least two consecutive days with daytime maximum temperatures being among the top 10% of historical measurements) currently incorporates three of the defining characteristics but does not incorporate sustained heat. Sustained heat could be incorporated by considering daily minimum temperatures. In addition, the CariCOF's definition does not consider humidity. This definition was primarily a practical compromise, based on data limitations in the region, although it was recognised that it is humid heat, as opposed to dry heat, that poses a threat in the region.

Under the Caribbean component of the ClimSA Programme, a consultancy aims to assist with the design of a sub-seasonal heat stress forecast system based on the following steps:

a) Refine the definition of extreme heat

Humidity data is unavailable and/or unusable for much of the region. Instead, minimum temperatures could be included (i) as a reasonable proxy for humidity, and (ii) to incorporate the sustained heat component of WMO's heatwave definition.



More refined definitions of extreme heat will be proposed and used as the basis for new sub-seasonal forecasts and to upgrade the existing seasonal forecasts.

b) Facilitating the calculation of sub-seasonal and seasonal forecasts of extreme heat

The automatic calculation of weather-spell predictands from daily input data will be implemented into the Climate Predictability Tool (CPT), which is used throughout the region for operational forecasts. These weather spells will enable the definition of a heatwave, considering cumulative heat.

c) Assessment of the sub-seasonal predictability of extreme heat

An assessment of the skill of week-2 and weeks 3+4 extreme heat forecasts will be performed based on operational global models from the US National Oceanic and Atmospheric Administration (NOAA) and the European Centre for Medium-Range Weather Forecasts (ECMWF). While NOAA's model had previously been used for inputs into CPT for rainfall extreme forecasts, the ECMWF's model, of which the operational global climate model is renowned for being one of the most skilful sub-seasonal forecast models, has recently started making such forecasts freely available. To take advantage of this development, a multi-model ensemble system will be implemented.

d) Training

Training to generate and interpret these new forecasts will be conducted for meteorologists and climatologists at a series of pre-CariCOF training workshops during 2025, and for health practitioners, meteorologists and other stakeholders at a multi-stakeholder workshop in 2025.

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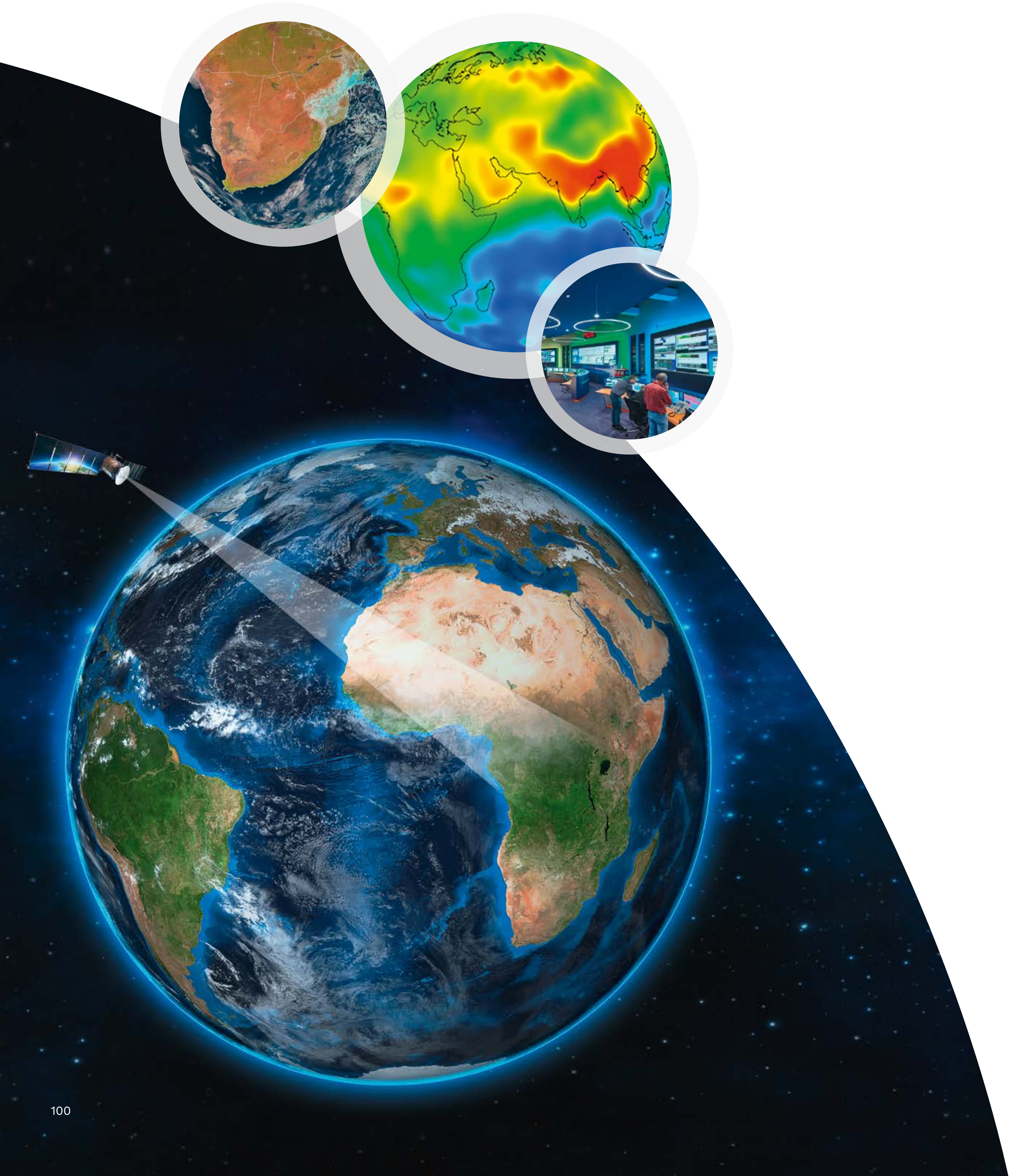


ClimSA
INTRA-ACP CLIMATE SERVICES AND RELATED APPLICATIONS PROGRAMME

CHAPTER 3.3 Ensuring Long-term Climate Monitoring from Space: a Global and Innovative Effort

Hervé TREBOSSEN and Vincent GABAGLIO

European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

3.3.1 Introduction

In the face of accelerating climate change, the need for consistent, long-term climate monitoring has never been more urgent. Space-based observations play a crucial role in tracking atmospheric, oceanic, and terrestrial changes over time.

Satellites provide a global perspective, enabling us to collect data that are essential for understanding climate variability and trends. However, exploiting this potential requires dedicated international efforts for recalibrating and reprocessing data, extracting climate records, and making them available to downstream applications and scientists.

A collaborative global effort has emerged to ensure continuity in climate observations, harnessing advanced technologies and innovations to improve the accuracy and reliability of the data. This effort is at the heart of EUMETSAT's mission, ensuring that its data services evolve with scientific and technological advances.

The continuous evolution of satellite technologies, instruments and processing techniques, as well as the development of new climate relevant products, is driven by international bodies, satellite operators, and research institutions, working together to ensure that long-term climate monitoring from space remains robust and sustainable.

3.3.2 A Global Effort

This global effort to ensure long-term climate monitoring from space is a coordinated initiative led by international organisations, satellite operators, and research institutions. It has materialised through the Strategy Towards an Architecture for Climate Monitoring from Space[23]. Key players include the Coordination Group for Meteorological Satellites (CGMS), the World Meteorological Organization (WMO), the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and others. These entities collaborate to ensure that satellite data for climate monitoring remains continuous, accurate, and accessible.

23 https://cgms-info.org/publication/strategy-towards-an-architecture-for-climate-monitoring-from-space/

International bodies, such as the WMO and CGMS, provide critical leadership in establishing global standards, coordinating data sharing, and promoting collaboration across national and regional satellite programs. For instance, CGMS ensures that satellite missions are planned and operated in such a way that they complement each other, offering long-term, harmonised datasets that are vital for monitoring climate trends and changes over decades.

Satellite operators within CEOS (Coordination Group on Earth observation satellite) including organisations like EUMETSAT, NOAA (National Oceanic and Atmospheric Administration), and the National Aeronautics and Space Administration (NASA), manage the technical aspects of climate-monitoring missions. They ensure that the satellites are equipped with sensors and instruments capable of collecting Essential Climate Variables (ECVs), which are key to understanding climate behaviour. Operators are also responsible for maintaining data continuity by launching successive generations of satellites, such as Meteosat Third Generation (MTG), EUMETSAT Polar System-Second Generation (EPS-SG) and Sentinel satellites under the European Union's Copernicus program.

Research institutions and scientists are integral to interpreting satellite data and converting raw measurements into actionable information. International organisations and initiative, such as the Copernicus Climate Change Service, and national meteorological agencies conduct scientific analyses and model the data to improve climate predictions and deepen the understanding of climate dynamics. These efforts ensure that decision-makers worldwide can access reliable information to guide climate policies.

Sustainability and Robustness

The global nature of the effort requires coordinated, long-term planning. Satellite missions are often designed to overlap, ensuring that there are no gaps in data coverage when older satellites reach the end of their operational lifespans. Moreover, programmes like GCOS (Global Climate Observing System) and ESA's Climate Change Initiative work to define the critical climate variables that need to be monitored and ensure their collection through sustained satellite observations.

This global framework ensures that space-based climate monitoring is both robust and sustainable through its capability to generate high-quality, continuous data. It is designed to operate over the long term, providing the necessary resources to understand and address the climate crisis effectively.

3.3.3 The Role of the CGMS in Climate Monitoring

The Coordination Group for Meteorological Satellites (CGMS) is composed of several key international satellite operators and organisations and plays a pivotal role in coordinating global satellite missions, ensuring harmonisation and cooperation among space agencies. CGMS provides a platform for data exchange and technological advancements, helping build a comprehensive global climate monitoring system. This collaborative approach is essential for the sustained generation of essential climate variables (ECVs) critical to understanding climate patterns and trends.

A key contribution of CGMS is its role in defining ECVs, which are critical parameters contributing to the characterisation of Earth's climate. These variables, established under the Global Climate Observing System (GCOS), provide the scientific basis for climate research, policymaking, and the implementation of adaptation and mitigation strategies. CGMS helps ensure the continuity and long-term availability of satellite data necessary for monitoring ECVs, including atmospheric temperature, greenhouse gas concentrations, sea level rise, and ice cover.

3.3.4 Contribution to the Elaboration of Essential Climate Variables (ECVs)

Essential Climate Variables (ECVs) are at the heart of climate monitoring efforts, providing the key metrics that allow scientists to assess changes in the Earth's climate system. Space-based observations are crucial for tracking many of these variables, especially those that require global and long-term datasets. CGMS plays a critical role in supporting the global community by ensuring that satellite missions provide the necessary measurements of these variables. Furthermore, these datasets are critical for climate model validation, trend analysis, and supporting international climate agreements like the Paris Agreement.

Through its partnerships, including with Copernicus, EUMETSAT delivers sustained, high-quality data for ECV production. Its satellites such as Metop and Meteosat provide critical datasets that help monitor the Earth's climate, supporting international efforts like those of the Global Climate Observing System (GCOS) to ensure data continuity and reliability.

Long-Term Data Records. EUMETSAT satellites have been providing over 40 years of climate data, contributing to the GCOS Climate Monitoring Architecture. This long-term archive ensures continuity and reliability in climate data, helping to build climate models and forecasts.

Box 5. EUMETSAT's contribution to the ClimSA Programme

EUMETSAT makes available its 40-plus years' worth of satellite observations over Africa to the ClimSA Programme to support the climate information services value chain. EUMETSAT's wealth of satellite data, including real-time weather observations and historical climate records, plays a critical role in enhancing the ClimSA Programme's ability to monitor and analyse weather patterns, climate variability, and long-term environmental changes across Africa.

EUMETSAT also supports the African Union Commission and the specialised centres of the Regional Economic Communities in procuring the necessary equipment to access and use the satellite data: the Preparation for Use of Meteosat in Africa (PUMA) 2025 workstations for weather forecast and early warning, and the ClimSA workstations, developed by the European Union's Joint Research Centre (JRC), for climatological analysis and services.

These two work-stations make use of massive satellite datasets to generate key products and services used for weather forecasting or climate monitoring applied for example to yield forecasting, such as Rapid Development Thunderstorm, Convective Rainfall Rate, Precipitation Estimation, Surface Solar Irradiance, Leaf Area Index, Evapotranspiration, Fraction of Absorbed Photosynthetic Active Radiation, etc,

In close partnership with four Training Centres in Africa, specialised in satellite meteorology, EUMETSAT also contributes to staff training of national meteorological services in using this equipment and providing weather, water and climate services to their communities.

3.3.5 The Future of Space-based Climate Monitoring

The new generations of satellites are designed to enhance the accuracy and scope of observations. Three key satellite programmes that will significantly contribute to climate monitoring in the coming years are the Meteosat Third Generation (MTG), the EUMETSAT Polar System-Second Generation (EPS-SG), and the European CO2 Monitoring mission (CO2M).

Meteosat Third Generation (MTG-I and MTG-S). The MTG programme comprises two types of satellites, MTG-I (Imager) and MTG-S (Sounder), together this system will provide critical data for climate monitoring for the next 20 years. The first MTG-I satellite has been launched in 2022. The MTG-I will offer soon high-resolution imaging of weather systems, atmospheric moisture and temperature changes, improving the monitoring of short-term climate phenomena such as storms and heatwaves. Meanwhile, MTG-S, with its Infrared Sounder, will allow for continuous measurement of the atmosphere's vertical profile, which is essential for detecting longer-term climate changes, especially in terms of temperature and humidity patterns.

EUMETSAT Polar System-Second Generation (EPS-SG) or METOP-SG. The EPS-SG is designed to provide next-generation polar-orbiting satellite data. Scheduled for launch in 2025, the first EPS-SG satellite will ensure the continuity of climate observations from polar orbits, particularly in monitoring ECVs such as sea surface temperature, sea ice and cloud cover. The suite of instruments aboard EPS-SG satellites will enhance the accuracy and frequency of data collection, providing more detailed insights into the climate system and improving climate models.

European CO_2 Monitoring mission (CO2M). One of the most significant new missions in terms of long-term climate monitoring is the European CO_2 monitoring mission (CO2M). As part of the European Union's Copernicus program, CO2M is designed to track global CO_2 emissions with unprecedented precision. This satellite will measure anthropogenic CO_2 emissions from space, providing critical data for monitoring greenhouse gases and helping to assess the effectiveness of global carbon mitigation efforts. CO2M's contribution will be indispensable in understanding the global carbon cycle and informing policies aimed at reducing emissions.

3.3.6 EUMETSAT's Innovation in Climate Monitoring

Innovation is at the heart of EUMETSAT's mission, ensuring that its data services evolve with scientific and technological advances. Through initiatives like Destination Earth and its involvement in the European Weather Cloud, EUMETSAT is fostering digital transformation, enabling faster and more efficient data processing and dissemination. The agency is also exploring the potential of Artificial Intelligence (AI) and machine learning to enhance data utilisation and provide users with new insights into climate dynamics. The continuous evolution of algorithms and the development of new products based on satellite observations ensure that EUMETSAT remains at the forefront of satellite meteorology. These innovations guarantee that the climate datasets generated will meet the highest standards of accuracy and precision, providing decision-makers with the reliable information they need to address climate change effectively.

3.3.7 Conclusions

Ensuring long-term climate monitoring from space is a collective effort that requires continuous innovation and international collaboration. Initiative like CGMS play a central role in facilitating these collaborations and ensuring the flow of critical climate data. With the development of advanced satellites like MTG, EPS-SG, and CO2M, the future of space-based climate observation will better contribute to the global effort to understand and mitigate the effects of climate change. ClimSA Station retrieves most of satellite datasets from the EUMETCast dissemination system, and Copernicus C3S Data Store. In the coming decades, these advancements will ensure that we can continue to monitor the Earth's climate, respond to new challenges, and support policies aimed at protecting our planet for future generations.

SECTION

4 TAILORING CLIMATE RESEARCH, MODELLING AND PREDICTION

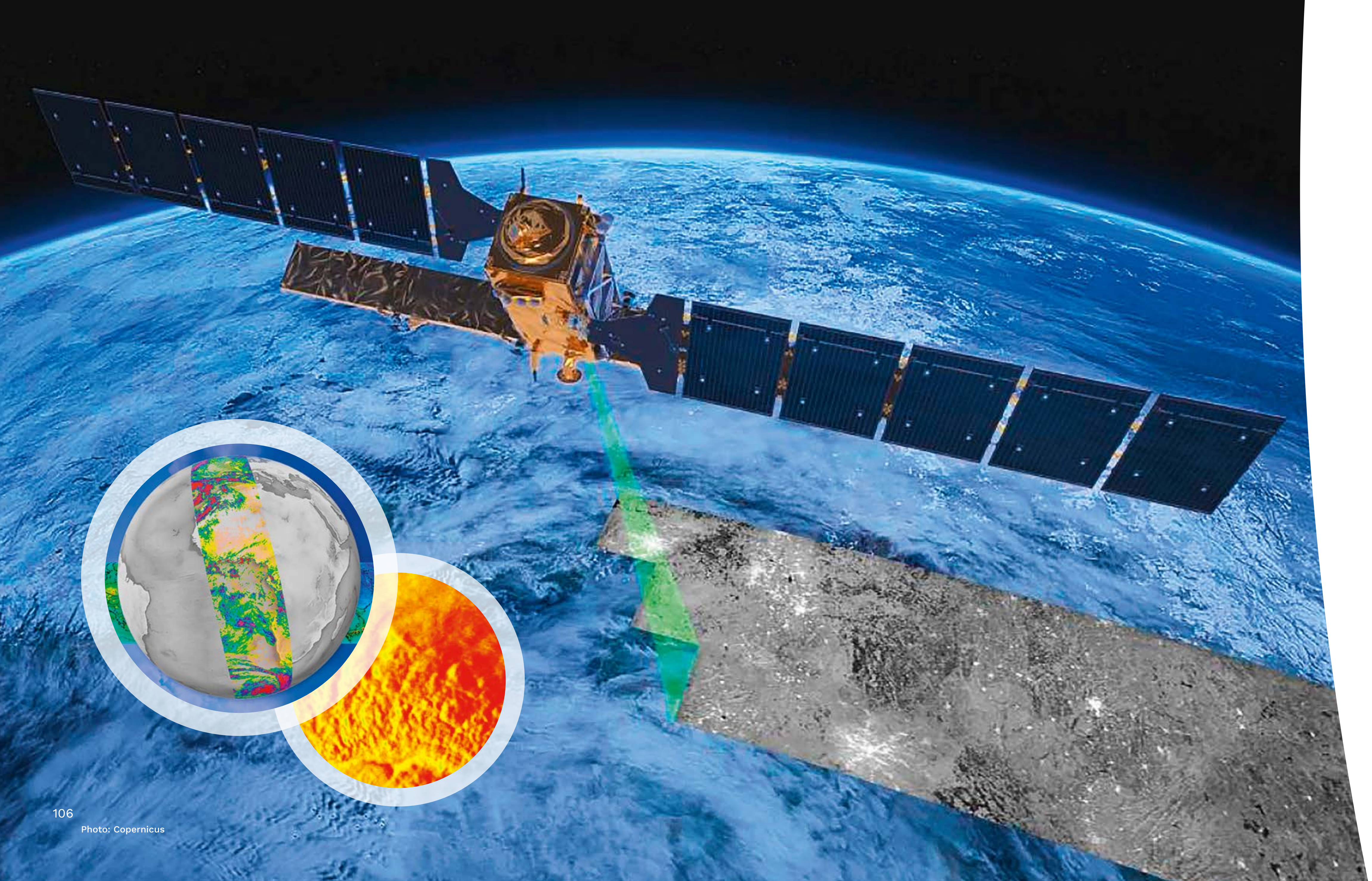


Photo: Copernicus

This section investigates how research, modelling and prediction advance the science needed for improved climate services that meet user needs.

The first chapter presents upgraded climate projections and their spatial distribution for Africa in the near future (2041-2060); by alerting policy makers against the impending future climate disasters, this information is likely to become increasingly important as African nations make efforts to respond to the growing effects of climate change over the coming decades.

The second chapter examines the role of climate change in enhancing the 2015/16 El Niño and its implications for Southern Africa; it explores how lessons from such recent El Niño events and attribution studies can inform current forecasting practices, improve resilience, and contribute to international loss-and-damage discussions, particularly for ACP countries that are disproportionately affected by climate variability and change.

CHAPTER 4.1 Upgrading Climate Projections and their Spatial Distribution for Africa in the Near Future (2041-2060)

Kamoru Abiodun LAWAL

African Centre of Meteorological Applications for Development (ACMAD)

4.1.1 Introduction

African countries are vulnerable to the consequences of climate change such as desertification, increasing frequency and intensity of droughts, floods, water stress and scarcity, food insecurity, and the incidence of disease. These adverse impacts are major challenges to the socio-economic development of the continent. Upgraded science-based climate projections and their spatial distribution, are therefore critical for African countries to address climate risks in a timely fashion and adapt to climate change.

The purpose of this work is to showcase the spatial climatological responses to changes in 2m-maximum-air-temperature (i.e. surface temperature) and precipitation in the near-future (i.e. 2041–2060) over the African continent. By alerting policy makers against the impending future climate disasters, this information is likely to become increasingly important as African nations make efforts to respond to the growing effects of climate change over the coming decades.

It is pertinent to note that this work is in fulfilment of one of the numerous deliverables of the activities of the Global Framework for Climate Services (GFCS) Intra ACP Climate Services and Related Application (ClimSA) Programme funded by the European Union (EU) through the African Union Commission (AUC). In view of this, the GFCS-ClimSA and other emerging UN/WMO-funded projects are contributing to better weather, water, climate change and services in Africa. These projects are supporting sustainable development by combating climate change through strengthening weather, water and climate service value chains. To strengthen service value chain, these projects provide technical assistance, financial assistance, infrastructure and capacity building.

The African Centre of Meteorological Applications for Development (ACMAD)'s role, in line with the project's missions, is to build the capacity of national and regional centres to provide weather, water, climate change and services to meet regional and country needs, supports the African Union (AU) and Regional Economic Communities (REC) as major players in climate, disaster and sustainable development policy dialogue through weather, water, climate change information and statements for policy making. Furthermore, ACMAD's mission is to provide continental weather and climate (change) watch information and act as the center of excellence on the applications of meteorology for sustainable development in Africa.

Table 3. List of climate models used for future climate scenario and observation analyses.

Dataset	Full name	Resolution	Period
Climate models used for future scenario analyses			
bcc-csm1-1-m	Beijing Climate Center Climate System Model version 1.1	1.12° x 1.13°	1861-2099
CCSM4	Community Climate System Model version 4	85km x 85km	1861-2099
CNRM-CM5	National Center for Meteorological Research-Coupled Model Intercomparison Project phase 5	50km x 50km	1861-2099
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation Model	1.9° x 1.9°	1861-2099
FGOALS-g2	Flexible Global Ocean-Atmosphere-Land System Model-Grid point version 2	1° x 1°	1861-2099
GFDL-CM3	Geophysical Fluid Dynamics Laboratory-Climate Model version 3	100km x 100km	1861-2099
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory-Earth System Model	100km x 100km	1861-2099
HadGEM2-ES	Hadley Center Global Environment Model version 2-Earth System	1.875° x 1.25°	1861-2099
IPSL-CM5A-LR	Institute Pierre Simon Laplace – Climate Model version 5 -Low Resolution	1.25° x 2.5°	1861-2099
IPSL-CM5A-MR	Institute Pierre Simon Laplace – Climate Model version 5 -Low Resolution- Medium Resolution	1.25° x 2.5°	1861-2099
MIROC5	Model for Interdisciplinary Research on Climate version 5	85km x 85km	1861-2099
MIROC-ESM-CHEM	Model for Interdisciplinary Research on Climate-Earth System Model-	85km x 85km	1861-2099
MPI-ESM-LR	Max Planck Institute for Meteorology-Earth System Model-Low Resolution	103km x 103km	1861-2099
MRI-CGCM3	Meteorological Research Institute	2.25° x 1.125°	1861-2099
NorESM1-M	Norwegian Earth System Model	2° x 2°	1861-2099
Observation dataset			
ECMWF Reanalysis V5-Land	Era5-Land is a reanalysis dataset that is providing a hourly high resolution information of surface variables over several years at approximately 9km horizontal grid. It covers the period from 1950 up to 2-3 months before the time of access (https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5-land).	9km x 9km	1950-2021

4.1.2 Data and Methods

The ERA5-Land daily reanalysis (1950-2020) dataset from the European Centre for Medium-Range Weather Forecasts[24] (ECMWF) is utilised as the observation (Table 3). The climatological reference period used here is 1991-2020. Table 3 also shows the fifteen (15) climate models, out of the large ensembles of the simulated climate models, from the Climate Model Intercomparison Project 5[25] (CMIP5; 1861-2091) that were utilised as the simulations for the near-future climate. These carefully selected simulations, listed on Table 3, feature models whose performance evaluations have been carried out over Africa and were deemed reliable (Almazroui et al., 2020; Dosio et al., 2021). Daily observation and simulation datasets were compressed to monthly and then to annual datasets. To ensure uniformity and facilitate analysis, all datasets were re-gridded to match the horizontal resolution of the observation (reanalysis: 9km x 9km) before they were analysed.

For easier comparison of observation to the near-future climate scenarios, some predefined climatological zones, normally used in the analyses of spatial climatological maps, were deployed. The operational climatological zones are presented as tabularised in Table 4. African climatological (i.e. arithmetic mean) maps of 2m-maximum-air-temperature and precipitation were produced for both the observation and the simulated near-future climate scenarios. Each climatology is evaluated on grid-point by grid-point basis. Basic descriptive statistics were calculated and mapped for verification.[26]

Bias correction was carried out using the quantile delta mapping (QDM) techniques (Fang et al., 2015; Casanueva et al., 2020). A quantile mapping methodology was utilised to adjust for the difference in scales between observations and model outputs. QDM-corrected ensemble means, which were utilised in this work, have been shown to have the best performance (Li and Li, 2023).

Future climate projections were forced with 4 (four) Representative Concentration Pathways (RCPs) - RCP2.6, RCP4.5, RCP6.0, and RCP8 (Moss et al., 2010; Taylor et al., 2012; van Vuuren et al., 2011 and 2013; van Vuuren and Carter, 2014). They represent the greenhouse gas (GHG) concentration trajectories of how the future climate may change with respect to a range of variables. These variables include socio-economic, technological, energy and land use changes. They also include changes in emissions of GHGs and atmospheric air pollutants. RCPs are used as input for climate model simulations as a basis for assessment of possible climate change impacts, mitigation options and associated costs (van Vuuren et al., 2011). These four were adopted by the Intergovernmental Panel on Climate Change (IPCC) and used for climate modelling and research as they describe different climate change scenarios, all of which are considered possible depending on the amount of GHG emitted in the years to come. Details about their developments can be found in van Vuuren et al. (2011).

24 https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5-land (accessed 7 Aug. 2024).
25 https://crd-data-donnees-rdc.ec.gc.ca/CCCMA/products/CLIMDEX/CMIP5/ (accessed 7 Aug. 2024).
26 https://web.csag.uct.ac.za/~lawal/Newfiles/ACMAD/Climate_Change_Analyses/Observations/Verifications/ (accessed 7 Aug. 2024).

4.1.3 Findings and Results

Near-future simulations of 2m-maximum-air-temperature over Africa

Visual comparisons of the spatial distributions of the observed long-term climatological zones[27] for surface maximum temperature over Africa (hereafter known as OLTC-temp) to panels in Figure 40, that depicts the same but for the near-future, show four major features as higher RCPs are encountered:

1. **The adornment of the continent by tropical zone (25-28°C) is noticed to be decreasing in landmass occupation.**
2. **The equatorial zone (28-31°C) is encroaching on the North African coasts and becoming absent on the West African coasts.**
3. **The warm zone (31-34°C) is rapidly expanding southward and becoming more dominant in the central parts of Africa.**
4. **The arid-hot zone (>34°C) is noticeably expanding in all directions.**

The near consensus is that temperatures are increasing as higher RCPs are encountered (Figure 41), implying that surface maximum temperatures are likely to rise in the near-future, relative to the present-day climatology. Spatial correlations of panels in Figure 40 with OLTC-temp (observation) range between 0.571 to 0.652. This implies it is likely there will be structural / spatial deviation in the near-future climatology of surface temperature. In practice this may entail some readjustments in the landmasses occupied by the zones with reference to the present-day observations, with presently cooler areas likely to become warmer.

In the near-future, landmasses occupied by each climatological zones of surface maximum temperature over Africa are likely to experience structural readjustments relative to space / areas they are currently occupying (Figure 42). The RCP8.5 scenario indicates highest possible landmass gain and or loss in all temperature zones; and vice-versa for the RCP2.6 scenario. Moderate and lower temperature zones, i.e., equatorial (28-31°C), tropical (25-28°C), cool (22-25°C) and temperate (<22°C) zones, are likely to lose territories in the range of about 2% to 8% of their current landmasses. On the contrary, higher temperature zones – the warm (31-34°C) and arid-hot (>34°C) zones – are likely to gain more territories in the range of 1% – 6% and 8% – 15%, respectively, of their present landmasses in the near-future. The implication is that probably some places that will experience sharp increase in temperature but remain within their climatological zones; while some places will completely migrate to the next hotter climatological zone (Figure 43). Overall, these projections confirm that presently cooler areas may become warmer due to expansion in the landmasses occupied by warm climatic zones.

27 https://web.csag.uct.ac.za/~lawal/Newfiles/ACMAD/Climate_Change_Analyses/Observations/Temperature_Analyses/Spatial_Analyses/Africa_AveTempMax_1950-2020_New.gif (accessed 7 Aug. 2024).

Table 4. List of maximum temperature and precipitation climatological zones currently adopted for operational use at the African Centre of Meteorological Application for Development (ACMAD).

Maximum Temperature		Precipitation	
Zones	Annual Average	Zones	Annual Accumulation Average
Temperate	<22° C	Desert	1-100mm
Cool	22-25° C	Arid	100-400mm
Tropical	25-28° C	Semi-Arid	400-600mm
Equatorial	28-31° C	Sub-Humid	600-1200mm
Warm	31-34° C	Moist Sub-Humid	1200-1500mm
Arid-Hot	>34° C	Humid	>1500mm

Figure 40. The projected near-future 2m-maximum-air-temperature climatology zones for all scenarios: upper left - RCP2.6; lower left - RCP4.5; upper right - RCP6.0, and lower right - RCP8.5.

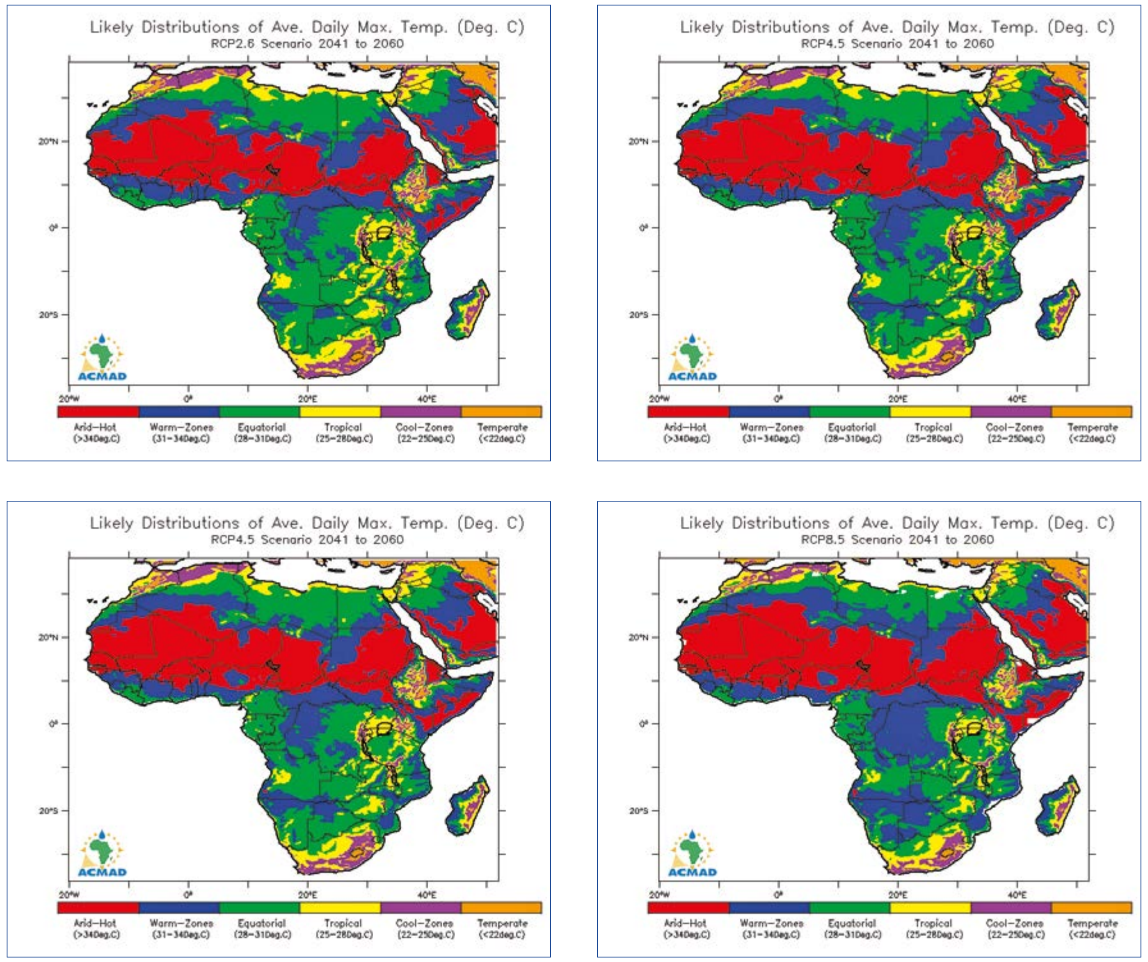


Figure 41. The projected near-future deviations of 2m-maximum-air-temperature from the 1991-2020 climatological period, under different scenarios: upper left - RCP2.6; lower left - RCP4.5; upper right - RCP6.0, and lower right - RCP8.5.

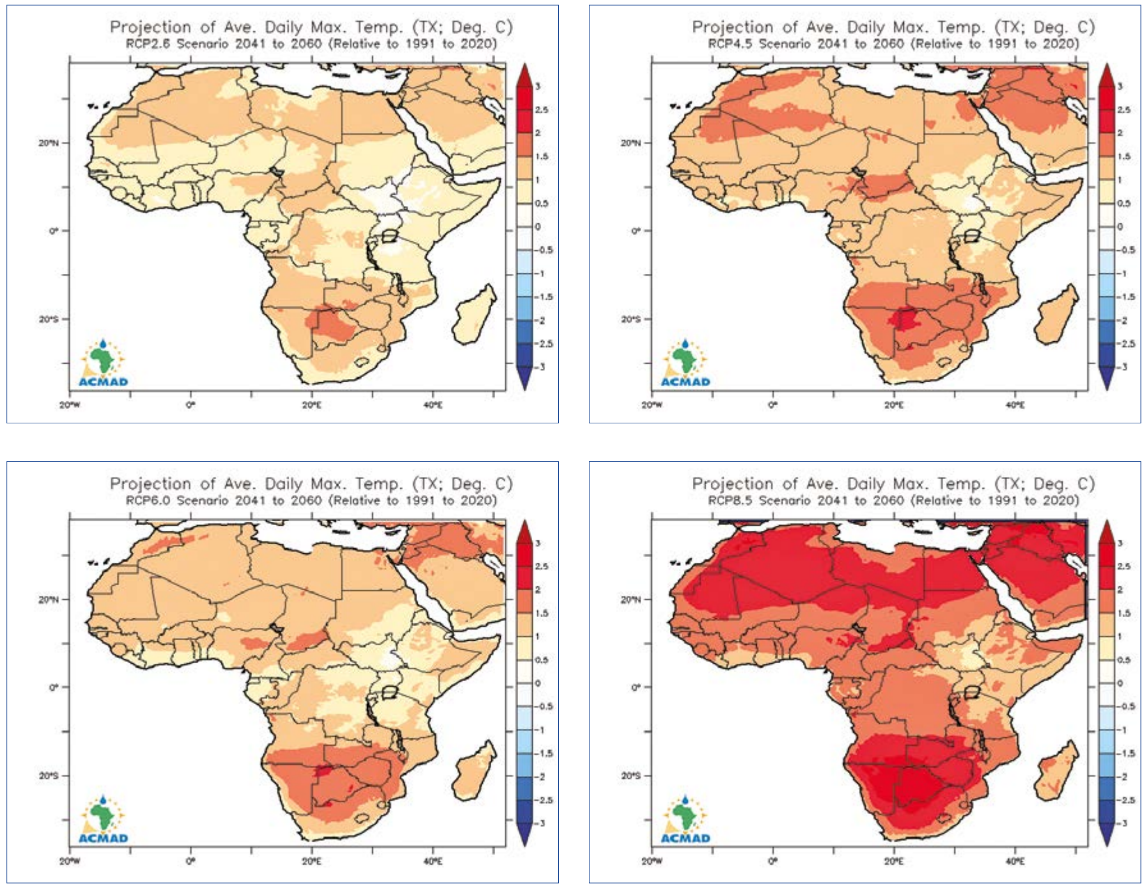
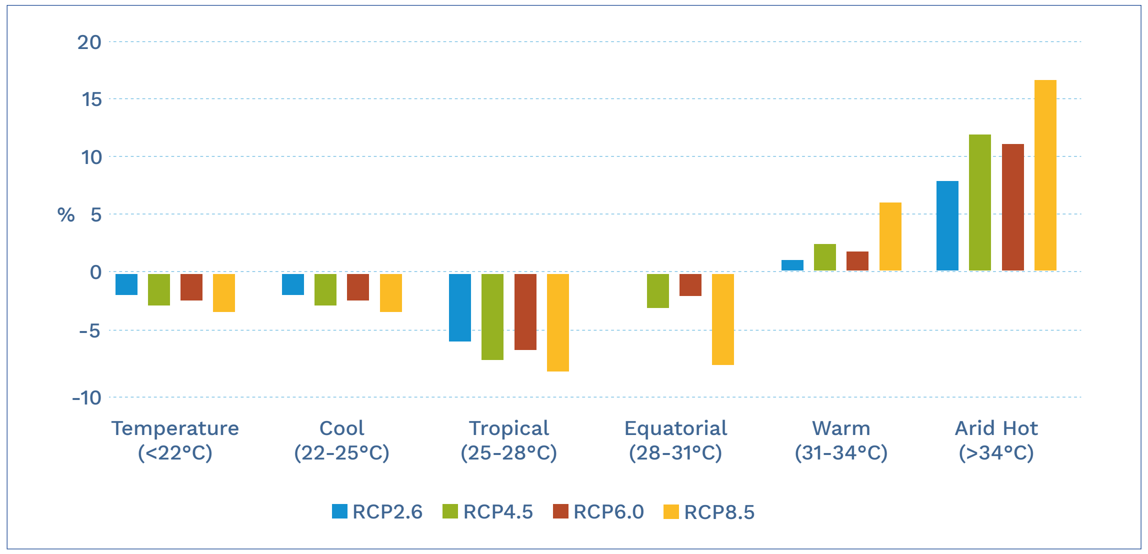


Figure 42. Near-future projections of African landmass occupied, in %, by each climatological zones of 2m-maximum-air-temperature over Africa. Departures are relative to 1991-2020 climatological period for all scenarios.



Near-future simulations of precipitation over Africa

Visual analysis of panels in Figure 44, showing the likely spatial distribution of zones for the near-future average annual total precipitation (when precipitation = > 1mm), compared to the observation[28] (hereafter known as OLTC-preci), do not reveal any noticeable feature. This is because statistical associations between the panels in Figure 45 and the OLTC-preci (observation) are very high. Their spatial correlation, ranging between 0.84 and 0.96, suggests they may be spatially or structurally similar or connected in terms of locations and values. As a result, visually and or statistically significant readjustments in terms of landmass occupations by the climatological zones, may not occur in the future.

Across all the 4 RCP scenarios, annual total precipitation is likely to be slightly on the decline over Southern Africa and Madagascar in the near-future (Figure 46), relative to the observed climatology. The entire coastlines of the northern Africa are projected to have rainfall deficits with the sole exception of the central coastal parts of Libya, across all scenarios.

Figure 43. The projected near-future likely areas for the intensification of 2m-maximum-air-temperature within a climatological zone or complete migration to warmer climatological zone, for all scenarios: upper left - RCP2.6; lower left - RCP4.5; upper right - RCP6.0, and lower right - RCP8.5

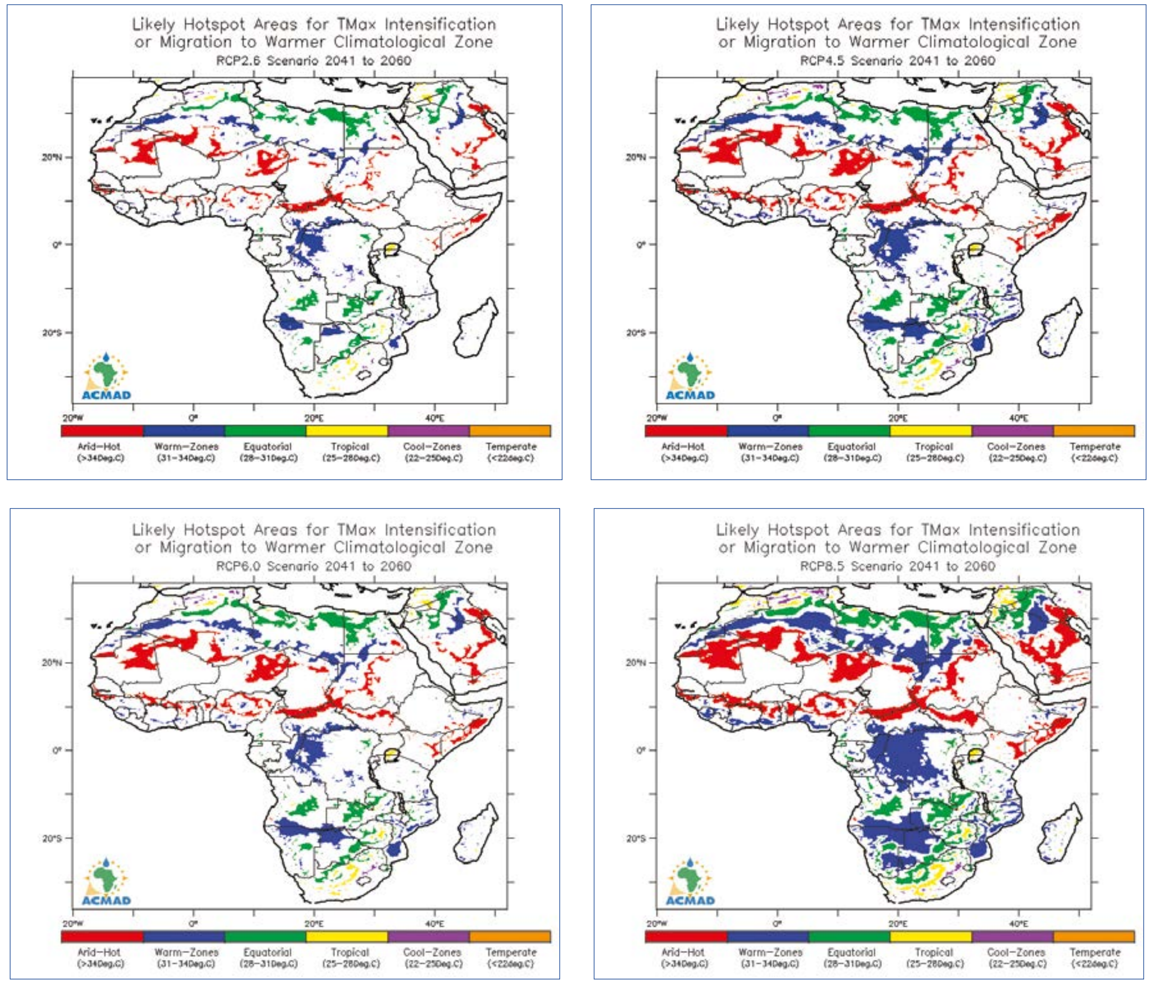
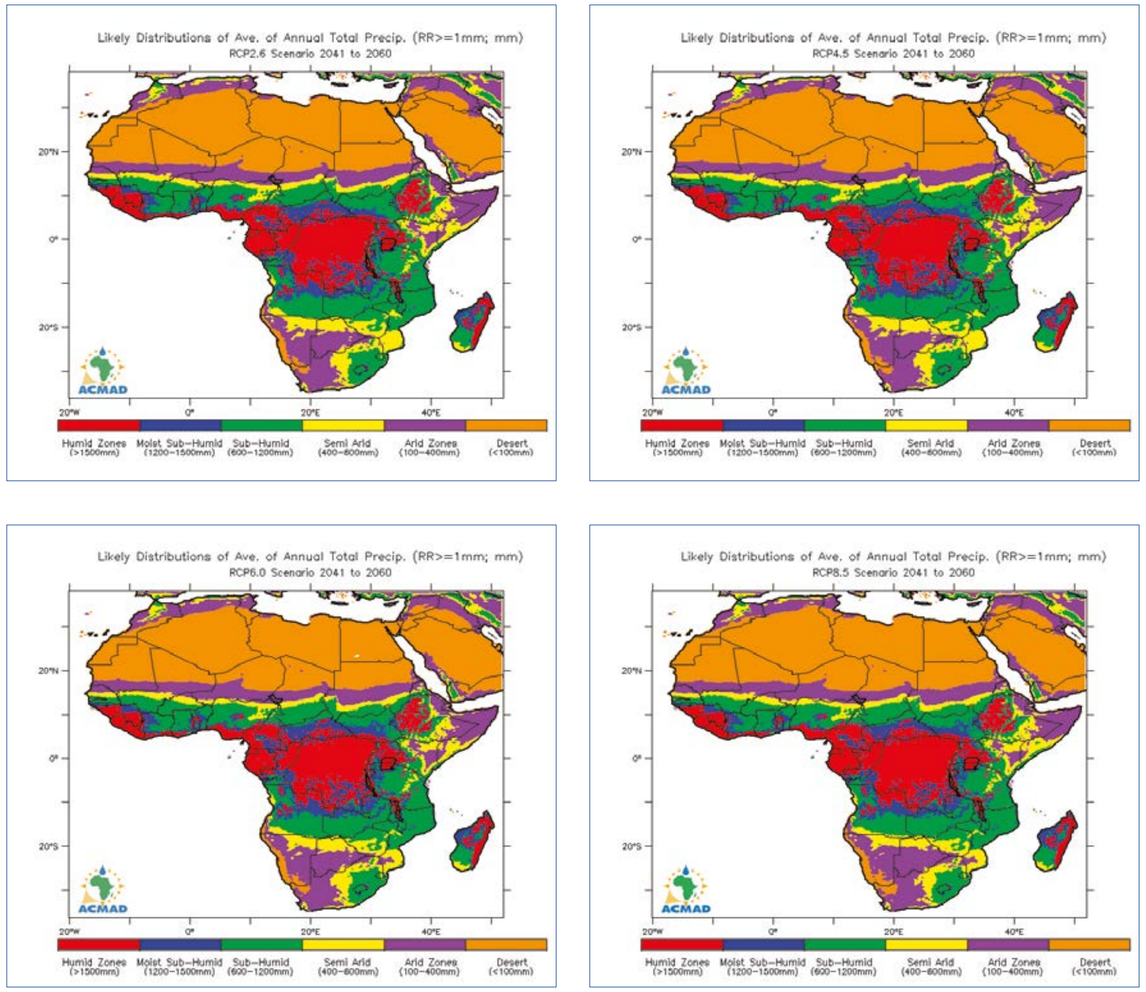


Figure 44. Same as in Figure 40, but for precipitation, relative to 1991-2020 climatological period for all scenarios: upper left - RCP2.6; lower left - RCP4.5; upper right - RCP6.0, and lower right - RCP8.5.



The pockets of deficits existing within the surplus zones in RCP2.6 scenario may however extend further south, according to RCP 4.5 scenario over Algeria and western Libya. These projections, either negative or positive, are not more or less than +/-10% of the OLTC-preci.

The projected landmass gains or losses by all precipitation climatological zones are however minute in nature (Figure 47). They range between -2% and 1% of the African landmass, with the exception of the humid zone (>1500mm) that is projected to expand, across all scenarios, by about 3% of the African landmass. This implies that the projected near-future rainfall in Africa, may likely be driven more by inter-annual / temporal variations, probably in conjunction with climate drivers that are dynamic in nature, rather than by spatial variations. The variability of the rainfall, in terms of frequency, intensity and duration, may be potent enough to induce drought and flood events because their strength will strongly depend on the magnitude of their anomalies.

28 https://web.csag.uct.ac.za/~lawal/Newfiles/ACMAD/Climate_Change_Analyses/Observations/Precipitation_Analyses/Spatial_Analyses/Africa_AnnualTotalPrecip_1950-2020_New.gif (accessed 7 Aug. 2024).

Figure 45. Same as in Figure 41, but for deviations, in %, of the average annual total precipitation from the 1991-2020 climatological period, under different scenarios: upper left - RCP2.6; lower left - RCP4.5; upper right - RCP6.0, and lower right - RCP8.5.

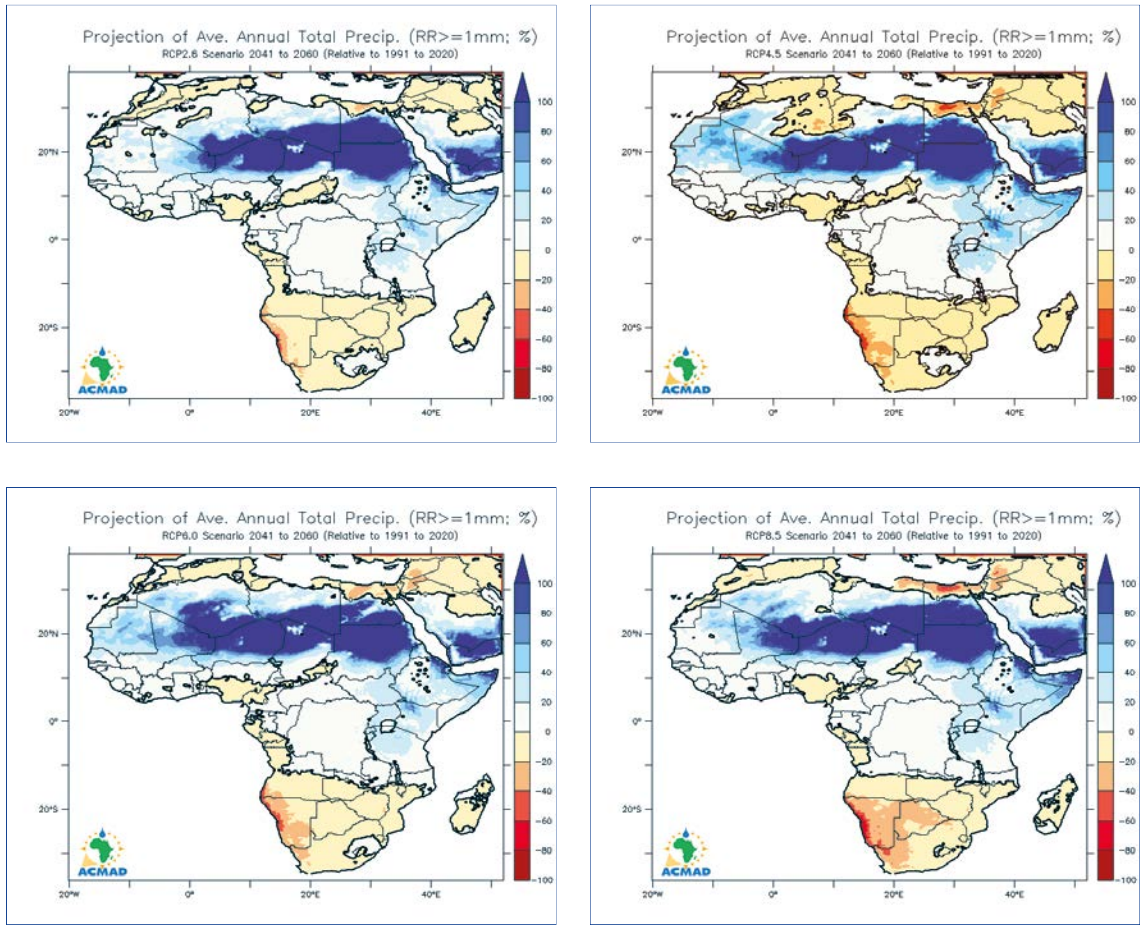
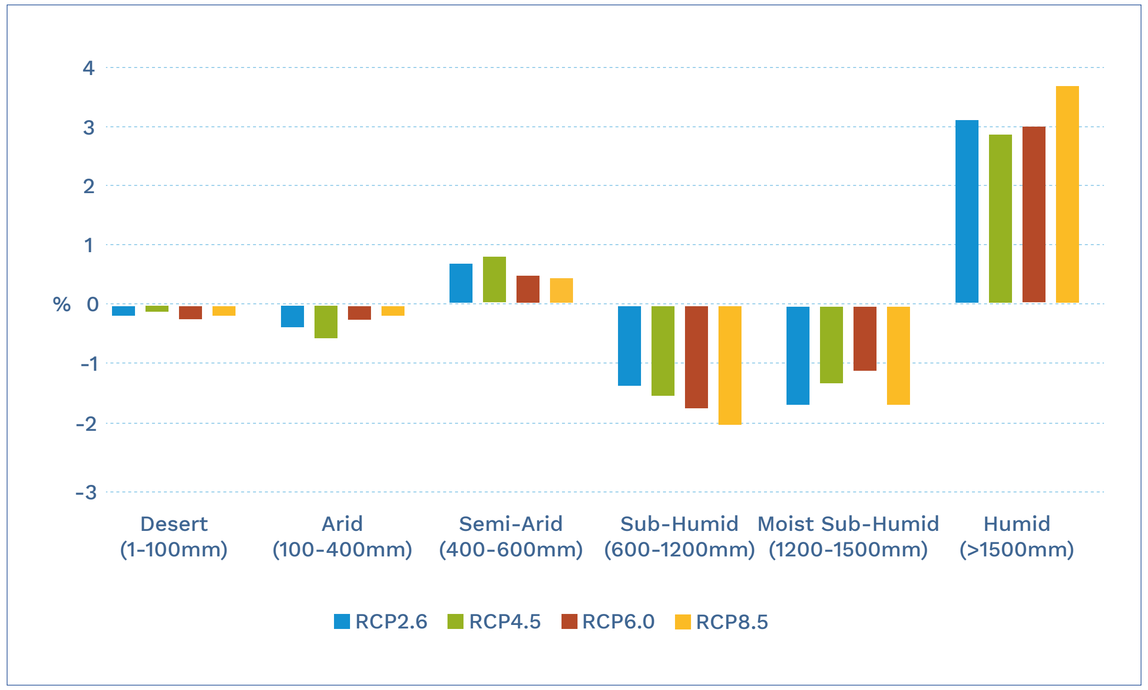


Figure 46. Same as in Figure 42, but for the climatological zones of average annual total rainfall over Africa. Departures are relative to 1991-2020 climatological period for all scenarios.



4.1.4 Conclusions

This work has been able to showcase the analyses of spatial climatological responses as a result of climate change projections for the near-future over the African continent. It critically gives attention to the spatial behaviour and the climatological responses of the surface air temperature and precipitation to the imminent changes in our climate. These are done with the aim of using the findings to prevent adverse climate effects.

The findings may likely be among the signals for early warning alerts over Africa because there are high possibilities of associated hazards and some unpleasant impacts over Africa. The impacts may cut across some social and economic spheres of lives such as health sectors (Klutse et al., 2014); agriculture, vis-à-vis droughts and water stress through evapotranspiration (Waha et al., 2013); malnutrition and food security (Alfani et al., 2015); possible disappearance of mass of ice on top of Mount Kilimanjaro[29]; imminent shrinking in sizes and possible reduction in the oxygen-carrying capacity of water in African lakes with serious implications on the population of fish in the lakes[30]; etc. In spite of the continent's rainfall projections showing no clear signal and or direction other than the significantly likely inter-annual variations, precipitation extremes on inter-annual and spatial scales may likely result in environmental, societal, agricultural and economical damages (Paeth et al., 2010) and losses of lives in Africa.

Nevertheless, socio-economic activities in Africa will continue to strongly depend on rainfall patterns over the continent. Therefore, any effort to sustainably increase agricultural production, reduce poverty, enhance food security and livelihoods in Africa must account for irregularity in the continent's seasonal rainfalls.

The information presented in this work will become important over the coming decades as African nations are making efforts to respond to the growing effects of climate change. It is therefore hoped that the outcome of this work will, undoubtedly, alert cities, the teeming populations and the policy makers against the impending future climate disasters.

Acknowledgments

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29 *https://earthobservatory.nasa.gov/images/79641/kilimanjaros-shrinking-ice-fields (accessed 17 Aug. 2024).*
30 *https://environment.ec.europa.eu/news/decreasing-levels-oxygen-deep-lake-water-linked-longer-warm-seasons-2023-06-08_en (accessed 17 Aug. 2024).*

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CHAPTER 4.2 Leveraging El Niño Forecasts and Attribution to Improve Predictions and Mitigate Impacts in ACP Regions, with a Focus on Southern Africa

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4.2.1 Introduction

The impact of climate change on extreme weather events has become a topic of interest, particularly in ACP regions where the consequences of extreme events are severe. The 2015/16 El Niño, one of the strongest on record, brought catastrophic droughts and agricultural failures to Southern Africa, underscoring the need to understand the role of human-induced climate change in amplifying such events. As evidence mounts linking anthropogenic warming to more intense El Niño impacts, the importance of integrating this knowledge into climate forecasting and disaster preparedness becomes more critical.

This paper examines the role of climate change in enhancing the 2015/16 El Niño and its implications for Southern Africa. It explores how lessons from recent El Niño events and attribution studies can inform current forecasting practices, improve resilience, and contribute to international loss-and-damage discussions, particularly for ACP countries that are disproportionately affected by climate variability and change.

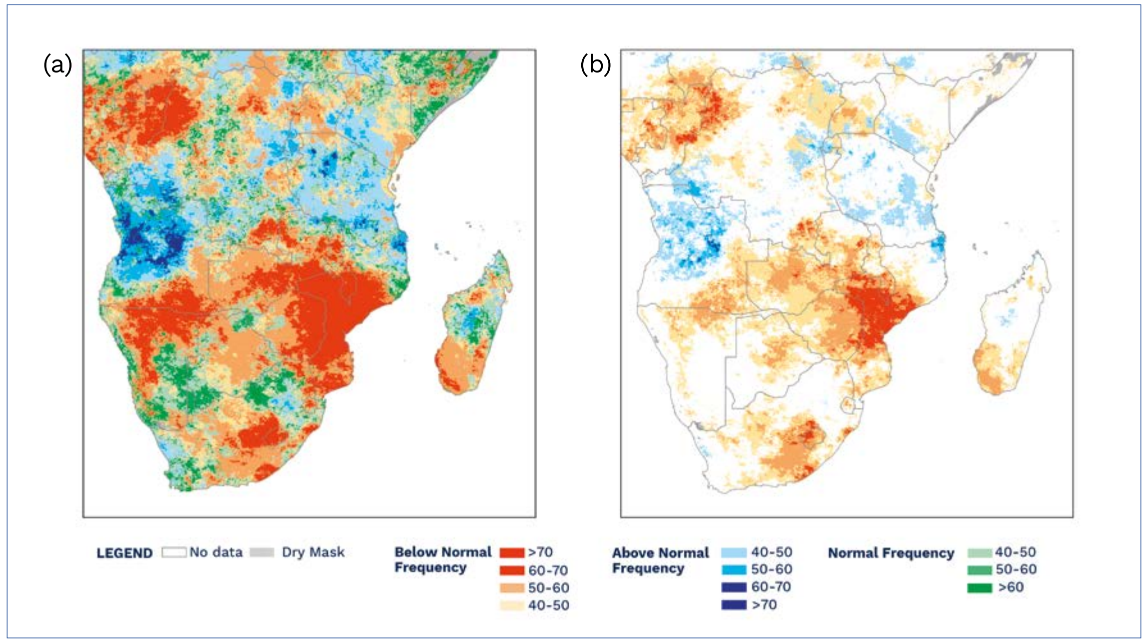
4.2.2 Attribution of the 2015/16 El Niño Event

Numerous studies have analysed recent extreme climate events and concluded that climate change was linked to many of those extreme events (Herring et al., 2018). In Southern Africa, following the strong 2015/16 El Niño that resulted in catastrophic consequences, Funk et al. (2018) published a climate attribution study linking the Anthropogenic Enhancement of the 2015/16 El Niño event to the resultant drought and poor harvests in Southern Africa. Funk et al. (2018) used a large ensemble of climate change change simulations to show that human-induced warming in the equatorial east Pacific has already substantially increased El Niño Southern Oscillation (ENSO)-related Pacific sea surface temperatures and precipitation, such that recent El Niño events have sea surface temperatures that are greater by about +0.8C. This warming was associated with substantial increases and decreases in East Pacific and Southern African precipitation respectively. Further analysis linked these precipitation reductions to decreases in Southern African crop production.

4.2.3 El Niño Impacts in Southern Africa

Historically, El Niño has been strongly associated with below normal rainfall in Southern Africa. Moderate to strong El Niño events typically result in January-to-March rainfall totals in the lowest tercile (less than or equal to the 33rd percentile) over 70% of the time in many parts of Southern Africa, and within the lowest 20th percentile at least half the time (Figure 47). Moderate El Niño's are defined based on an Oceanic Niño Index (ONI) of between +1.0 and +1.4, while strong El Niño events have an ONI of 1.5 or greater.

Figure 47. (a) Frequency of below, normal and above normal rainfall totals for January-March during moderate to strong El Niño events, as defined by ONI of >= 1.0. (b) Frequency of January-to-March rainfall totals below the 20th percentile or above the 80th percentile.



4.2.4 Use of ENSO and Seasonal Forecasts in Early Warning

Food security early warning agencies such as the Famine Early Warning Systems Network (FEWS NET) leverage this strong relationship between ENSO and seasonal rainfall in southern and eastern Africa and other ACP regions, to assess potential climate impacts on food security and provide improved early warning on food insecurity. FEWS NET uses a suite of methods, from climatological analysis, climate modes (including ENSO) and seasonal forecasts to develop agroclimatology assumptions that are used as inputs for food security projections covering the next six to eight months (Magadzire et al., 2017). FEWS NET typically assesses and considers several seasonal forecasts, including regional climate forecasts such as the Southern African Regional Climate Outlook Forum (SARCOF), and dynamical multi-model ensemble forecasts such as the North American Multi-Model Ensemble (NMME) (Kirtman et al., 2014). Using available information on the skill and performance of the various available forecasts, and a convergence of evidence approach, FEWS NET scientists review and refine assumptions on likely outcomes of various food-security related agrometeorological parameters such as onset of rains, seasonal rainfall totals and temperature, based on their expected impacts on end of season crop yields. Statistical analysis outlining characteristic impacts of climate modes, particularly ENSO, provide additional weight in understanding and assessing the forecasts and reviewing food security assumptions.

Through the Southern Africa Development Community's (SADC) Agrometeorological Update report, which is produced in collaboration with FEWS NET and SARCOF, the ENSO forecasts are also used to generate advisory and recommendations to take in the agriculture and food security sectors in light of the forecast. This report and advisory is received and utilised by a wide range of national, regional and international organisations.

4.2.5 How the 2023/2024 El Niño Guided Anticipatory Actions

Given the strong association between moderate-to-strong El Niño events and reduced rainfall in Southern Africa, as well as the growing body of evidence for the association between climate change and stronger El Niño impacts, many agencies now closely monitor the development of El Niño and take decisions and actions based on the ENSO status. In June of 2023, the National Oceanic and Atmospheric Administration (NOAA) and other climate institutions released forecasts calling for a moderate to strong El Niño likely by late 2023 (https://www.weather.gov/news/230706-ElNino). In July 2023, the Climate Hazards Center (Funk et al., 2023) issued a forecast identifying concerns about outcomes in Southern Africa, highlighting the link between past moderate-to-strong El Niño and low rainfall, and noting concerns in view of the forecast of a strong El Niño. Updates in September and October 2023 further highlighted an increase in the expected strength of the 2023/24 El Niño.

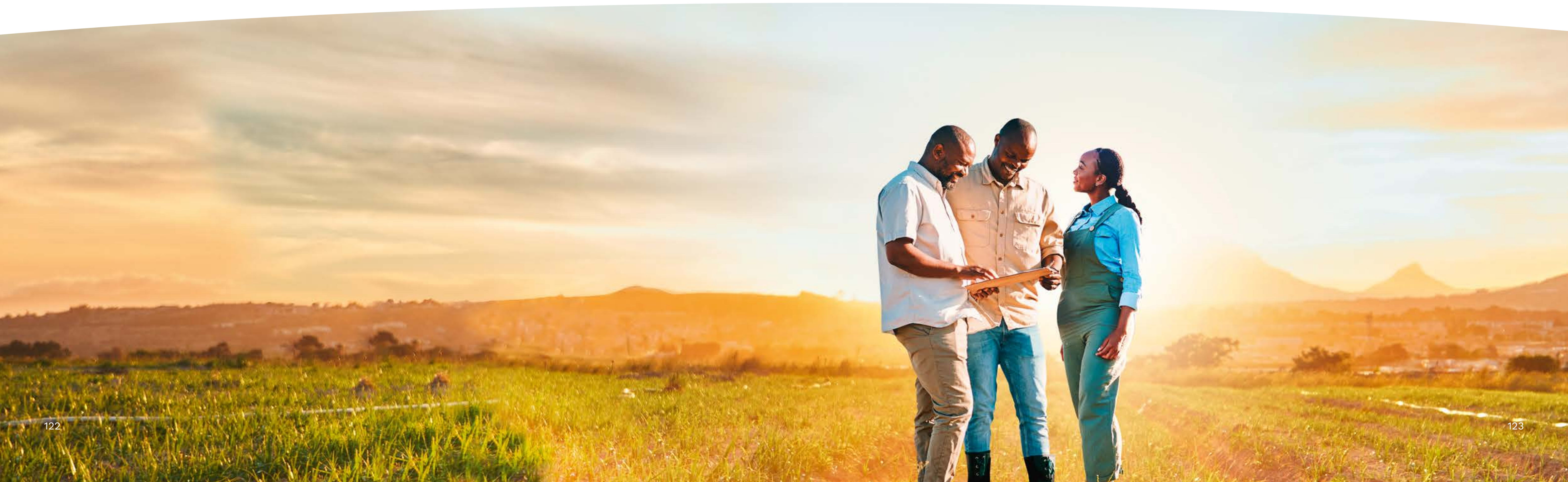
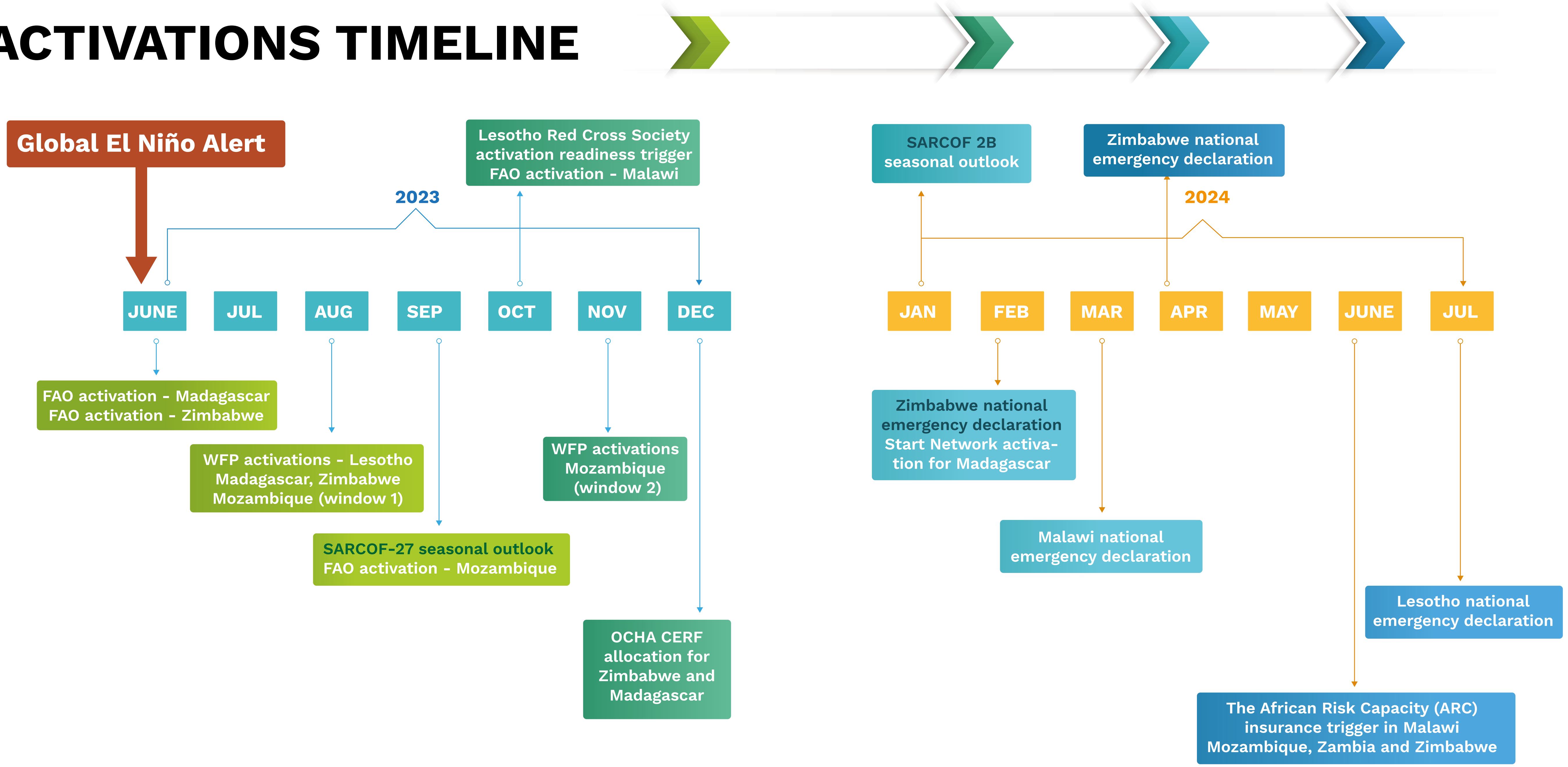


Figure 48. Timeline of activations related to drought and El Niño events from June 2023 to July 2024 in Southern Africa.

ACTIVATIONS TIMELINE



Source: RAAWG - (Huhn et al., 2024).

Governments in Southern Africa and humanitarian institutions have taken note of the dangers posed by moderate to strong El Niño events, and in 2023 took anticipatory actions to mitigate the risks due to the impending El Niño. Based on the 2023 El Niño forecasts, the Zimbabwe Government took measures to mitigate potential drought impacts on agriculture during the 2023/24 growing season. These interventions included encouraging the planting of drought-tolerant crops, rehabilitating irrigation systems, and promoting water harvesting and water conservation techniques, as well as establishing and strengthening post-harvest management procedures (Mugiyo et al., 2023).

The 2023 El Niño forecast also triggered record-level anticipatory actions by humanitarian agencies across Southern Africa between June 2023 and July 2024 (Figure 48). The actions, by United Nations (UN) agencies such as the Food and Agriculture Organisation(FAO), the World Food Programme (WFP), the Office for the Coordination of Humanitarian Affairs (OCHA) and the Start Network, targeted multiple sectors such as food security, agriculture, water, sanitation and hygiene (WASH), nutrition, health, disaster risk reduction (DRR) and early warning. The actions included the pre-positioning of supplies, the activation of contingency plans, and the coordinated efforts to mitigate the potential impacts of anticipated droughts and food insecurity. The Southern Africa Regional Anticipatory Action Working Group (RAAWG) reported that more than 35 implementing organisations indicated distributing approximately USD 33.5 million across seven (7) countries (Zimbabwe, Madagascar, Mozambique, Lesotho, Malawi, Eswatini and Zambia) reaching up to 2.07 million people (Huhn et al., 2024).

A mapping exercise by the Southern Africa Regional Anticipatory Action Working Group (RAAWG) on the Anticipatory Action activations for 2023/24 (Huhn et al., 2024) indicated that FAO, WFP, OCHA, and the Start Network led significant anticipatory actions across Southern Africa, targeting drought and cyclone impacts in 2023 and 2024. FAO focused on Food Security and Livelihoods (FSL), supporting 45,000 people in the Androy and Anosy regions of Madagascar with $1.4 million, 3,190 households in Chikwawa, Neno, and Balaka districts of Malawi with $500,000, 20,000 people in Gaza province, Mozambique with $500,000, and 15,000 people in Buhera, Chipinge, and Bikita districts in Zimbabwe with $1.2 million. WFP provided food, cash, and nutrition support to 132,640 people in the Ampanihy, Betioky, and Tsihombe districts of Madagascar with $3.46 million, 228,000 people in Tete, Gaza, and Sofala provinces of Mozambique with $1.15 million, and 160,000 people in Hwange, Gwanda, and Chiredzi districts of Zimbabwe with $5 million, focusing on drought-tolerant inputs, water provision and climate information. OCHA, through the UN Central Emergency Response Fund (CERF), and in partnership with other UN agencies, reached over 273,000 people in the Ampanihy, Betioky, and Tsihombe districts of Madagascar and 262,000 people in Manicaland and Masvingo provinces of Zimbabwe, allocating around $700,000 to sectors like FSL, health, protection, nutrition and WASH. The Start Network and International Non-Governmental Organisations like Oxfam and Welthungerhilfe supported tens of thousands of people in Madagascar, Zimbabwe, Malawi, and Mozambique, with actions ranging from cash transfers to early warning systems, supported by millions of dollars in donor funding.

In contrast, a report by the Anticipation Hub (2023) noted anticipatory action activations mainly by the International Federation of Red Cross and Red Crescent Societies (IFRC), Start Network, WFP, and FAO, covered a broader range of natural hazards, including floods and cyclones across Southern Africa especially in Mozambique, Madagascar, and Zimbabwe. It was estimated that total funding of approximately USD 4.22 million reached over 375,056 people in terms of FSL humanitarian action, cash transfers, nutrition, shelter, and early warning systems. This significant increase in funding, coverage, number of implementing partners as well as sectors in 2023/24, compared to the 2022/23, reflects the critical role of timely triggers such as the El Niño forecast which provided agencies with longer lead time and actionable early warning information to trigger their at scale. This proactive approach highlights the growing recognition of the importance of ENSO forecasts in disaster preparedness and response, and how the predictability presented by El Niño is being utilised for mitigating disaster.

4.2.6 El Niño can Strengthen Forecasts

The well-established connection between El Niño and Southern Africa droughts presents an opportunity for Southern Africa regional and national forecasts to improve the accuracy and precision of their seasonal forecasts. The Southern Africa Regional Climate Outlook Forum (SARCOF) issued their 2023/2024 forecast in October 2023, projecting a 35% chance for below normal rainfall in the Oct-to-Dec 2023 period, while the forecast projected a 25% chance of below normal rainfall for the Dec 2023 to February 2024 period. Basing the forecast on historical ENSO analysis and a near-certain forecast for a strong El Niño event would have put the chances of below normal rainfall forecast projected a 25% chance of below normal rainfall for the Dec 2023 to February 2024 period. Basing the forecast on historical ENSO analysis and a near-certain forecast for a strong El Niño event would have put the chances of below normal rainfall at over 70% for January-to-March 2024 in many parts of the region (Figure 47). Similarly, the SARCOF 2015/2016 forecast also had a 35% chance of below normal rainfall in most parts of Southern Africa, against a > 70% chance for an El Niño forecast. This highlights the opportunity for improved forecast accuracy through integration of ENSO dynamics into regional forecasts, thereby enhancing climate resilience and preparedness. Climate mode-based regression analyses such as those undertaken by Funk et al. (2023) are additional inputs that can be used to further improve forecasting processes in selected ACP regions, particularly those that are strongly and predictably influenced by climate models like ENSO, including southern Africa.

4.2.7 Using El Niño Attribution for Loss and Damage

The link between climate attribution and loss-and-damage issues has become increasingly pertinent as the impacts of climate change continue to intensify. The ability to attribute specific extreme weather events, such as the 2015/16 El Niño, to anthropogenic factors strengthens the case for loss-and-damage compensation in international climate negotiations. Attribution studies such as Southern Africa's El Niño induced droughts highlighted by studies such as Funk et al. (2018), and more broadly noted by Herring et al. (2018) provide useful evidence. Countries in the ACP regions are disproportionately affected by climate change (Levy & Patz, 2015), and could leverage such attribution studies to advocate for financial support and other forms of assistance to address the adverse effects of climate-related disasters. This connection between attribution and loss and damage is crucial for ensuring that vulnerable communities receive the support they need.

4.2.8 Conclusions

The analysis of recent extreme climate events, particularly the 2015/16 El Niño, has underscored the significant influence of anthropogenic factors on the severity of El Niño impacts. As demonstrated by the attribution studies, human-induced climate change has exacerbated the impacts of El Niño in Southern Africa, leading to severe droughts and substantial agricultural losses. The 2023/24 El Niño forecasts, which prompted widespread anticipatory actions across the region, highlight the advantages that can be gained by utilising ENSO forecasts in decision making, and the potential gains that can be obtained from robust integration of ENSO information into seasonal forecasts. By doing so, regional and national institutions can enhance the accuracy of their predictions, better prepare for potential disasters, and ultimately help to improve the resilience of vulnerable communities. In addition, the growing recognition of the link between climate change and extreme weather events strengthens the case for loss-and-damage compensation in international climate negotiations, offering a vital pathway for ACP countries to secure the support they need in the face of an increasingly volatile climate.

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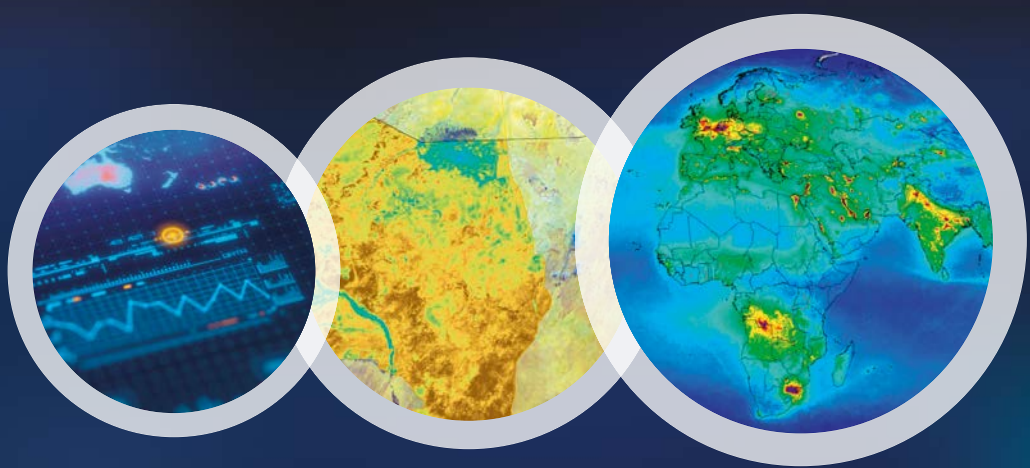
SECTION

5 ENHANCING CAPACITY DEVELOPMENT



The section aims to review how capacity development supports the systematic development of the institutions, infrastructure and human resources needed for effective climate services.

The first chapter hinges on the need to invest in improved Decision Support Systems (DSSs) for Agricultural Policy development; by integrating advanced technologies, enhancing data management, focusing on user-centric design, incorporating scenario analysis and aligning with policy frameworks, stakeholders can significantly enhance the effectiveness and impact of agricultural policies.

The second chapter presents a new Socio-Economic Benefit (SEB) tool for the assessment of climate services in the OACPS regions; the model's methodology, based on the input-output system dynamic, is able to compute the damage effects of various scenarios, and when adapted and calibrated to represent a specific country, it becomes a critical element in a DSS supporting the actions and decisions to be taken by decision makers.

The final chapter in the section examines policy and practice implications for enhancing climate services targeting the agriculture sector, by assessing key advances since the establishment of the Global Framework for Climate Services (GFCS) in 2012, which laid the foundation for a more systematic and coordinated approach to climate services worldwide; the contribution also looks ahead at how the development of more user-centric, inclusive and participatory climate services could enhance opportunities for further policy integration and financial support, both from national and regional governments as well as the ternational climate finance instruments.

CHAPTER 5.1 Improvement of Decision Support Systems for Agricultural Policy Development

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5.1.1 Introduction

Climate Information Services (CIS) play a significant role in enhancing the resilience and productivity of various socio-economic sectors. The evidence underscores the importance of Climate Information Services in supporting sustainable development across various socio-economic sectors. The tangible benefits observed include: increased agricultural productivity, improved water management efficiency, enhanced disaster preparedness and response, better public health outcomes, optimised energy production, biodiversity conservation, and sustained economic growth. Overall, the integration of climate information into decision-making processes not only mitigates risks associated with climate change but also creates opportunities for advancement and sustainability in socio-economic sectors. One way to achieve this is through a Decision Support System (DSS).

5.1.2 What is a Decision Support System?

A Decision Support System is a computerised programme used to assist in making decisions, judgments and taking courses of action in an organisation or a business. A DSS processes massive amounts of data, compiling comprehensive information that can be used to solve problems and inform decision-making (Segal, 2024). By presenting several options for users to consider, these systems enable more informed decision-making, timely problem-solving and greater efficiency in operations, planning and management. Within the Regional Climate Centres (RCCs) of the Organisation of African, Caribbean and Pacific States (OACPS), the main DSS tools currently available are the regional and national climate outlook forum's products and services. In each region, the RCC organises a climate outlook forum at the onset of the rainy season to generate a seasonal climate forecast, which acts as an early warning system for the forthcoming agricultural season.

5.1.3 Regional Climate Outlook Forums

The DSS process starts with the Regional Climate Outlook Forum (RCOF), convened by the RCC to discuss the trends of the upcoming season. Climate scientists start by preparing the models to be used for forecasting future trends and assess the impact of predicted climate anomalies on various socio-economic sectors. In most of cases, the forecast is made by considering the oceanic and atmospheric factors that influence the climate across each geographical zone (Funk et al., 2023). Climate services are produced either by regional centre or national meteorological and hydrological services (NMHSs) (Hewitt and Stone, 2021). Chapter 1.1, and 3.1 of the current publication have provided insight of the process.[31,32]

The user community participating to the RCOF discusses and formulates the mitigation measures for each climate-sensitive sector. The potential implications of the consensus climate outlook are analysed and mitigation measures developed for each area of interest. Key recommendations are then drawn, emphasising prevention over cure through the recovery actions. The anticipated favourable (or unfavourable) rainfall performance for the season presents opportunities (or threats) to alleviate (or exacerbate) the suffering of the populations potentially affected.

On the side-lines of the ClimSA Forum held in Jamaica from 25 to 27 June 2024, a questionnaire was sent to all stakeholders prior to the Forum to collect views on the services produced and disseminated by the RCCs. The findings revealed that 67.9% of the stakeholders had attended RCOF sessions or other regional-level climate workshops. These forums significantly influenced professional decision-making, with 70% of participants reporting positive impacts on their strategic planning and operational activities. A notable 46.2% of respondents strongly agree that these workshops have positively impacted their professional Wdecisions, while 12.3% remained neutral.

These data underscore the critical role that climate workshops play in enhancing the capacity of professionals to make informed, climate-resilient decisions in their respective fields. This highlights the effectiveness of the RCOF as a tool in the decision-making process within the ACP regions. The RCOF's products are the main inputs for tactic and strategic decision making, leading to mainstream climate information into policy, strategies and programmes.

Despite the progress made in promoting climate smart agriculture (CSA), several gaps remain, particularly in the availability of timely and precise climate information to guide decision-making. The existing climate services in ACP regions often lack the granularity and predictive capabilities required to support farmers and agricultural planners effectively.

31 Chapter 1.1. Capitalising 25 years of operations of the Greater Horn of Africa Climate Outlook Forum (GHACOF). Prepared by Zachary Atheru. IGAD Climate Prediction and Applications Centre (ICPAC).
32 Chapter 3.1. Lessons for Agriculture and Food Security from the Southern African Regional Climate Outlook Forum (SARCOF). Prepared by Surekha Ramessur. Southern Africa Development Community (SADC).

5.1.4 Key Limitations

(i) Lack of location specific weather data: current weather forecasting systems in many ACP countries are limited in their spatial resolution, often covering large regions without providing actionable insights at the local level. This gap makes it difficult for farmers to make informed decisions about crop management, irrigation, and the timing of agricultural activities.

(ii) Inadequate seasonal forecasting: while general seasonal forecasts are available, they often do not provide the specificity needed for agricultural planning. Farmers and planners require more detailed, long-term forecasts that consider local climatic conditions and the potential impacts on specific crops and regions.

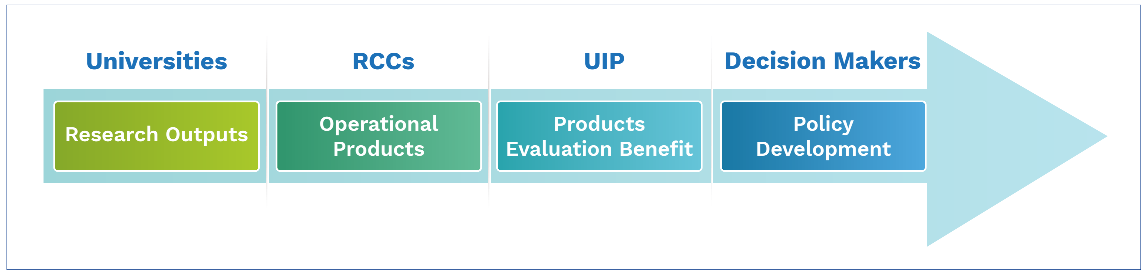
(iii) Limited tools for land and crop suitability analysis: climate change alters the suitability of land for various crops, yet current tools for assessing these changes are not widely available or integrated with local climate data. Farmers need more accessible, dynamic tools that can help them adapt their crop choices to shifting climate conditions.

(iv) Challenges in integrating climate data with agricultural practices: there is a need for seamless integration of climate data with practical agricultural decision-making. This includes forecasting the onset of rains, managing water resources efficiently, and identifying climate-resilient crops that can thrive in changing environmental conditions. The ClimSA Programme has planned to address these gaps through the new project on artificial intelligence for climate smart agriculture to be started in the last quarter of the year.

5.1.5 Mainstreaming Climate in Policy: Benefits and Challenges

This section outlines the benefits and challenges faced by ACP regions in mainstreaming climate into policy, at all levels of decision-making. This is particularly relevant in regions like Africa, the Caribbean and the Pacific, where climate change poses significant risks to development, livelihoods, and ecosystems. The results of the survey reviewed at the ClimSA forum held in Jamaica in 2024 (see above), indicate that 78% of countries integrate climate considerations into national development plans and 72% adjust agricultural policies to incorporate climate-smart practices.

Figure 49. Proposed process for policy development.



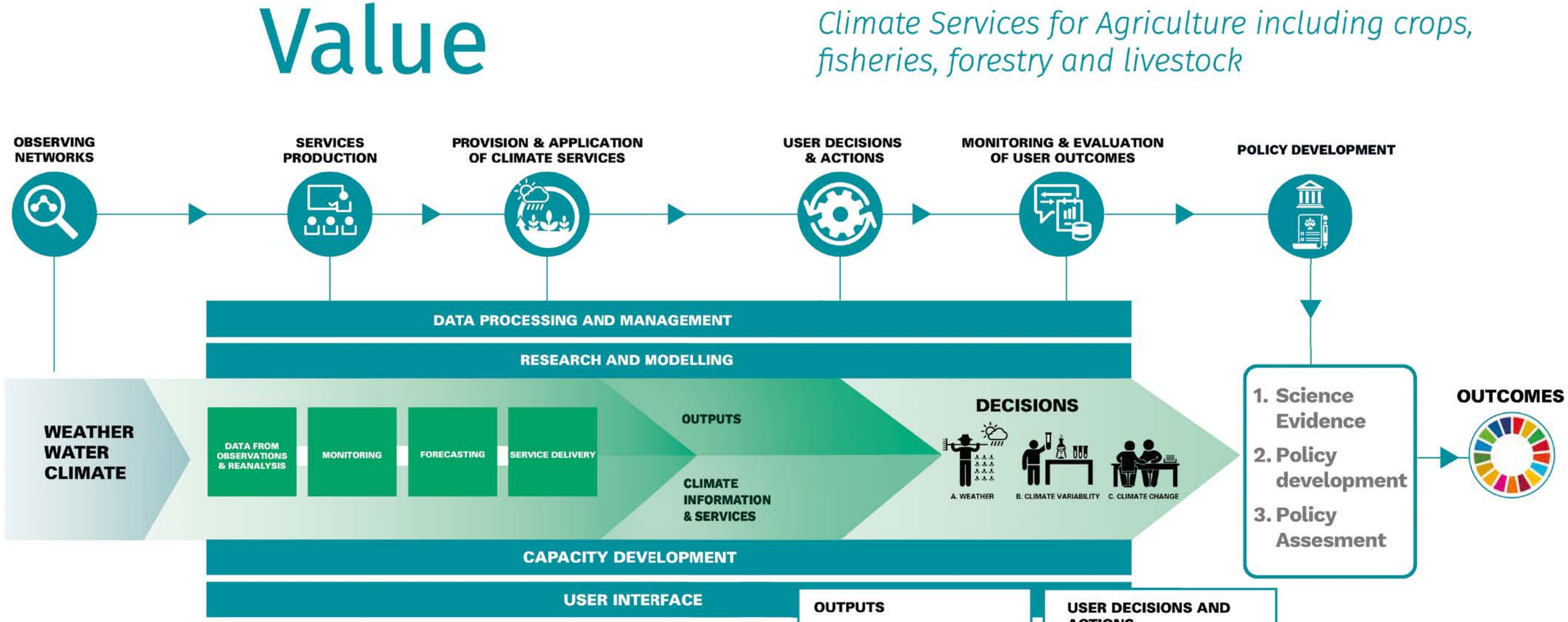
The ClimSA Programme has crafted its strategy for mainstreaming climate into policy by focusing on coordinating the capacity development of RCCs in the production, application, and evaluation of the impact of climate information and services for the sustainable socio-economic development of these regions.

The ClimSA approach to policy development is based on assessing the benefits of climate information and services for climate-sensitive socio-economic sectors, in order to inform policy development. The evaluation of users' outcomes will serve as a catalyst for policy and regulatory development. Each RCC is required to produce climate information (outputs of the action) through a co-production mechanism, ensuring the outputs are tailored to the specific needs of particular sectors.

Once the tailored climate services are designed and produced, the Programme must support the users in the application of climate information (through trainings and advisories) and participate in the evaluation of the user's outcomes under the User Interface Platform (UIP). Figure 49 provides a summary of the ClimSA proposed process for policy development, where the process starts with research's outputs that are transformed into operational products and services to be applied in sensitive sectors. Once the products and services have been used for improving productivity, there is a need to assess the benefits generated by the products. If the valuation of climate services is supported, then decision makers can develop policy to support the production sectors and secure their sustainable development.

Policy development should become part of the climate value chain, as proposed in Figure 50.

Figure 50. Enhanced climate service value chain extended to policy development, modified from WMO (2019) initial figure.



Climate services for improved adaptation outcomes hinge on a simple, yet comprehensive value chain. This value chain encompasses not only the production and delivery of climate services (the Climate Services Information System), but also stakeholder actions and outcomes, and involves the routine evaluation of associated socio-economic costs and benefits (WMO, WBG, GFDRR, USAID, 2015). Climate affects the agriculture sector in multiple ways, from farm-level production, processing, shipping and marketing. This report emphasizes services to farmers, who often represent some of the most vulnerable stakeholders in the sector.

OUTPUTS

A. Weather
- Days suitable for fieldwork
- Accumulated growing degree days for season
- Heat indices for livestock
- Fire Danger Ratings
- Pest/Disease Forecasts

B. Climate Variability
- Crop-yield forecasts
- Average dates of beginning and end of rainy season
- Average first and last frost dates
- Crop-Weather Calendar
- Drought Indices/Warnings

C. Climate Change
- Maps of changes in agroecological zoning
- Maps of changes in first/last frost dates
- Analyses on future crop impacts

USER DECISIONS AND ACTIONS
- When to plant and harvest
- When to irrigate
- When to apply fertilizers/ pesticides
- When to rotate/move live stock
- Investing in drought resilient crops and livestock
- Investing in more efficient irrigation systems

This framework is inspired by the WMO climate services value chain (WMO, 2019), where policy development is embedded in the value chain. The feedback is required for each benefit assessment and policy development to improve product quality and regulation. Policy development is thus based on scientific evidence. Modelling of climate-triggered policy development is the main tool for the science-policy interface platform. This is an area that needs more research for advancing climate mainstreaming in policy.

Mainstreaming climate into policy offers significant benefits for sustainable development, resilience and health in the ACP regions (Box 6). However, it also presents various challenges that need to be addressed through coordinated efforts, capacity building, and adequate funding (Box 7). Capacity building and the mobilisation of expertise are required to develop innovative solutions for building resilience. Agricultural systems in ACP regions are diverse due to varying climatic conditions, crop types and socio-economic structures and there is a skills gap among policymakers, farmers and local governments in effectively utilising DSS tools. By overcoming these challenges, the ACP regions can enhance their preparedness in facing the impacts of climate change and ensure a more sustainable future.

Box 6. Benefits of mainstreaming climate into policy in ACP regions.

Enhanced Resilience

- Adaptation strategies: Developing policies that integrate climate risks can lead to improved preparedness for climate impacts.
- Community engagement: Empowering local communities to take action enhances their resilience to climate-related shocks.

Economic Opportunities

- Green economy: Transitioning to a green economy can create jobs in renewable energy, sustainable agriculture and eco-tourism.
- Funding and investment: Mainstreaming climate action can attract international funding and investment focused on sustainability.

Improved Health Outcomes

- Air quality: Policies aimed at reducing emissions can improve air quality and public health.
- Food security: Climate-informed agricultural policies can improve food security and nutrition.

Sustainable Development

- Integrated development: Aligning climate action with development policies can lead to more sustainable outcomes.
- Biodiversity conservation: Protecting ecosystems through climate policies can promote biodiversity and enhance natural resource management.

Box 7. Challenges to mainstreaming climate into policy in ACP regions.

Institutional Barriers

- Lack of coordination: Fragmented policies across sectors can hinder effective climate action.
- Insufficient capacity: Limited technical and human resources can impede the implementation of climate policies.
- Vulnerability to climate change: ACP regions are highly vulnerable to climate change, and policies often fail to account for these risks adequately.

Funding Limitations

- Limited financial resources: Many countries face challenges in securing necessary funding for climate initiatives.
- Dependence on external aid: Relying on international funds can lead to uncertainties in policy implementation.

Socioeconomic Constraints

- Poverty and inequality: High levels of poverty can limit communities' ability to adapt to climate change.
- Cultural factors: Traditional practices may conflict with modern climate strategies, leading to resistance.
- Lack of cooperation: Poor coordination between different governmental bodies, international organisations, and private sectors results in fragmented decision-making.
- Unclear long-term impacts: Policies are often implemented without fully understanding their long-term socio-economic and environmental impacts.
- Limited access to services: Many farmers in ACP regions lack access to financial services and market information, limiting their ability to invest in sustainable practices.

Data Scarcity & Lack of Infrastructure

- Lack of reliable data: Insufficient climate data can hinder effective policy-making and evaluation.
- Research gaps: A lack of localised research on climate impacts can limit the understanding necessary for informed decision-making.
- Inadequate infrastructure: Rural areas in ACP regions may have limited access to traditional IT infrastructure.
- Outdated data: ACP regions often suffer from poor-quality, outdated or fragmented data on agriculture, weather patterns and economic factors.

5.1.6 Improvement of Decision Support Systems for Agricultural Policy Development

This section introduces the effort required to improve the DSS in the RCCs' contribution to sustainable development. Decision Support Systems play a crucial role in shaping agricultural policies by providing data-driven insights and enabling informed decision-making. Integrating sustainable farming practices with adaptive strategies that increase agricultural productivity and resilience to climate change, requires the development of a specific DSS.

This tool is essential to address the increasing challenges due to the growing impacts of climate change, including erratic weather patterns, prolonged droughts and unpredictable rainfall. Currently, the climate services in ACP regions often lack the granularity and interoperability required to support an integrated DSS for farmers and agricultural planners.

Enhanced data analysis would lead to better-informed policy decisions, while streamlined processes would improve efficiency by reducing time and resource wasted in policy development (Samuel et al., 2022). Policies developed through improved DSSs would thus promote more sustainable agricultural practices. Several strategies can be employed to improve DSSs, positioning RCCs as indispensable contributors to agricultural planning (Box 8).

Box 8. Key elements to improve DSSs for agricultural policy development in ACP regions.

Integration of Advanced Technologies

- Artificial Intelligence (AI): AI-driven forecasting tools could provide improved actionable insights, optimising agricultural productivity and building resilience to climate variability.
- Remote Sensing: Combining satellite imagery, drone technology and the Internet of Things (IoT) with real-time data on crop health and land use, has the potential to revolutionise climate-smart agriculture.
- Blockchain technology: Blockchain improves traceability in the agricultural supply chain, allowing farmers to connect directly with markets and increase profitability. Data sharing between farmers, researchers and policymakers also helps better resource allocation and incentive programmes rewarding farmers for more sustainable practices.

Data Management Enhancements

- Data Quality Improvement: Regularly update and validate data sources to ensure accuracy.
- Interoperability: Enable seamless data sharing between various agricultural stakeholders and systems.
- Big data analytics: Leverage big data technologies to process and analyse vast amounts of agricultural data.

User-Centric Design

- Stakeholder Engagement: Involve farmers, policymakers, and agronomists in the design process to ensure that the system meets their needs.
- Training and Support: Provide training sessions for users to effectively utilise the DSS tools.

Scenario Analysis and Simulation

- Scenario's development: The development of simulation models to assess the impact of different policy options on agricultural output and sustainability is a priority in an unpredictable and uncertain future.
- Risk Assessment Tools: DSS needs to incorporate tools to evaluate potential risks associated with various agricultural practices and policies.

Policy Framework Alignment

- User outcomes' evaluation: The benefit of climate services must be assessed to inspire confidence in informed decisions.
- Compute the Cost of Loss and Damage: The SEB tool is an example of a powerful tool to address this need. The outputs will inform any action for sustainable development.
- Alignment with Sustainable Development Goals (SDGs): The DSS should support policies aligned with SDGs, particularly those related to agriculture and food security and climate change.
- Feedback Mechanisms: RCCs need to associate decision makers through the UIP for continuous feedback on policy effectiveness and necessary adjustments.
- Policy development: Once the previous steps are completed, formulate new policies or regulations on scientific evidence will become straightforward. This model ensures RCCs are included in budget allocation decisions.

5.1.7 Conclusions

Improving Decision Support Systems for agricultural policy development is essential for fostering a resilient and sustainable agricultural sector. By integrating advanced technologies, enhancing data management, focusing on user-centric design, incorporating scenario analysis and aligning with policy frameworks, stakeholders can significantly enhance the effectiveness and impact of agricultural policies. Utilising hyperlocal weather forecasting, AI-driven seasonal climate predictions and climate-driven land and crop suitability assessments will provide farmers and agricultural planners with the actionable insights they need to optimise agricultural productivity and build resilience against climate variability.

Currently, RCCs outlook products to develop effective DSSs for agriculture and food security. The outlook statement either represents a good opportunity to maximise agricultural production, particularly for areas that normally receive good rainfall and where the forecast indicates normal to above-normal rainfall, or it poses a potential threat to yield. However, end-users should be cautioned that there are always three possible outcomes i.e. normal, below-normal or above, and contingencies should be in place for the less likely scenarios.

From a crop production perspective, farmers can comprehensively utilise the forecast by committing a larger portion of their cropland to medium to late maturing, high performance varieties. However, some percentage of the cropland should still be allo cated to early maturing and drought-tolerant crops and varieties as a contingency measure against the possibility of below-average rainfall. Developing an integrated climate outlook with an agriculture model in an automated way is the improvement RCCs are expecting to set up for mainstreaming climate into policy development.

Enhanced Decision Support Systems foster collaboration among stakeholders by providing a common framework for discussions. This collective approach ensures that all voices are heard in the policy development process, leading to more comprehensive strategies that benefit everyone involved in agriculture. In short, investing in improved DSS is crucial for crafting effective agricultural policies that promote resilience, productivity and sustainability in an ever-evolving landscape.

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CHAPTER 5.2 A Socio-Economic Benefit (SEB) Tool for the Assessment of Climate Services in the OACPS regions

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5.2.1 Introduction

The member countries of the Organisation of African, Caribbean, and Pacific States (OACPS) are more vulnerable to physical climate risks than many other countries because they lack the resources for large-scale adaptation, abatement and mitigation. Dependence on climate-sensitive resources means that the primary sectors are likely to be most affected. Climate-related impacts on health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming, with significant economic damages already detected in climate-exposed sectors such as agriculture, forestry, fishery, energy, and tourism (IPCC, 2023).

A survey undertaken by the Intra-ACP Climate Services and related Applications (ClimSA) Programme in 2021, revealed that an estimated 70% of OACPS Regional Climate Centres (RCCs) and National Meteorological and Hydrological Services (NMHSs) were unable to provide products which could be directly applied to climate-informed decision-making and policy development (ClimSA, 2021). Strengthening the capacity to analyse climate information services through the development of a socio-economic benefit (SEB) assessment tool was identified as a priority intervention area for all countries in ACP regions.

Starting in 2022, the ClimSA Programme has contributed to the development of a SEB assessment framework based on an integrated Cost Benefit Analysis (CBA) methodology, where social, economic and environmental impacts – as well as policy outcomes - are considered. The CBA considers three main analytical components: investment, avoided costs and added benefits (WMO, 2019).

The overall objective of the SEB tool is to guide actionable climate-informed decision-making to increase climate services development and application in climate-sensitive sectors. Adapting the tool to specific countries will lead to investment decisions that consider alternative options based on multi-criteria analysis.

Results presented here focus on the model's outputs for Burkina Faso, one of five pilot OACPS countries where template models have been developed. The paper summarises information on the socio-economic benefits of using climate services at different scales and functional categories. It presents the results of uncalibrated outputs of the ClimSA SEB tool in assessing the socio-economic impacts of climate change and the use of climate services as adaptation measures to mitigate negative impacts and build resilience.

5.2.2 Development of Methodology

A variety of methods to quantify the value of climate services exist, although many forecasting models tend to yield reasonable results only over a narrow band within the range of typical past behaviour and may have difficulties in coping with unprecedented scenarios which fall outside this narrow range.

The ClimSA SEB tool has been based on Vensim, a visual modelling tool that allows to conceptualize, document, simulate, analyse, and optimise models of dynamic systems. Vensim provides a simple and flexible way of building simulation models from causal loop or stock and flow diagrams[33].

Model template

The OACPS SEB tool country template has adopted the technique of using economic input-output tables to capture the realistic normal interdependence of sectors of an economy, coupled with system dynamics techniques for developing and testing robust simulation models. The system dynamics methodology uses first principles to derive nonlinear effects for non-linear deviations from normal conditions (Figure 51).

Figure 51. The main steps of SEB tool development.

33 https://vensim.com/ (accessed 20 January 2025).

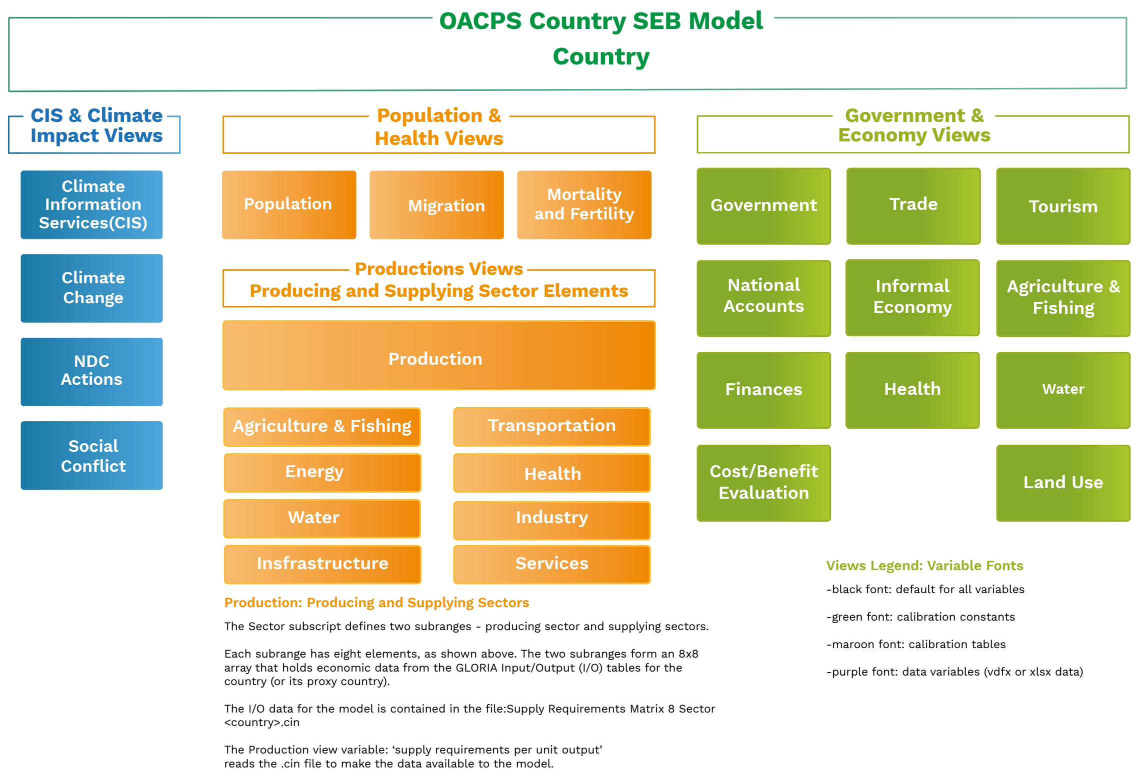
The template model contains multiple Views to support the calculation of SEB, namely (i) Climate Information System (CIS) and climate impact, (ii) Population and Health, (iii) Production and (iv) Government and Economy (Figure 52).

The timeframe used is from year 1990 to year 2100. The model identifies eight main sectors. The eight main sectors aggregate the economic data from the 97 sub-sectors included in the input/output (IO) tables used in the model. All sectors of the economy are sensitive to climate change, but the sensitivity varies according to the type of sector. Time-series IO data indicates the supply/production interaction between each pair of sectors. While Population is not a production sector, it is included as a variable in the Production model structure due to its critical importance in determining economic performance and overall socio-economic benefit.

The input-output approach deals with the interconnectivity of each sector and comes out with an integrated production sector, integrating into the model of the full input-output structure of the economy (Figure 53).

The structure of the producing sectors has been extended to calculate the value added by each producing sector to a country's Gross Domestic Product (GDP) through (i) supplying intermediate inputs to support the production by producing sectors, (ii) providing investments in fixed capital in all sectors, and (iii) satisfying consumption demands from households and government. The new explicit priorities were important for achieving the full range of potential economic responses to climate change and climate information systems (Figure 54).

Figure 52. Model structure showing the eight main economic sectors included.



Identification and assessment of impacts

This stage concerns the identification and assessment of impacts. It aims to answer the question: what are the impacts of the ‘no climate effect’ scenario compared with those of the ‘climate effect’ scenario? The impacts of climate change on human health, the environment, the economy, society and other areas are defined as the differences between these two scenarios. If more than one response is likely under the ‘no climate effect’ scenario, the differences between the impacts of each response and the ‘climate effect’ scenario must be identified and analysed. This step is carried out in four generic stages:

Identification of impacts

The potential impacts of climate effects on the economy and society are identified based on baseline and climate change scenarios. The end purpose of the OACPS SEB template country model, is to assess the damages from climate change and the benefits of remedial actions, such as Climate Information Systems (CIS).

The costs and benefits are best quantified by looking at the differences in GDP and population caused by the changes due to climate change and/or improvement initiatives. To make that difference immediately apparent, the model was effectively expanded, to perform three scenarios for each simulation. The SEB tool has integrated the Intergovernmental Panel on Climate Change (IPCC)’s Shared Socioeconomic Pathways (SSPs) scenarios developed to model possible future climate impacts. SSPs from the IPCC Sixth Assessment Report are used in the model to incorporate three SSP scenarios: SSP1-1.9, SSP1-2.6, and SSP2-4.5. SSP1-2.6 is the default scenario (Figure 55).

The Vensim Run Manager feature allows any of the three to be selected, and for more scenarios to be added. The scenario used under the National Determined Contribution (NDC) climate temperature change, will remain less than 2°C in 2100 in accordance with the Paris Agreement targets. Normal Climate values from 1990 to 2020 are from any IPCC scenario (all the same from 1990 to 2020) and then constant for model time to 2100. The temperature has been increased from 1980 up 2020 with a rate of 1.25°C, assuming to remain constant up to the end of the century. This is baseline scenario, called the Normal Climate, it shows what would have happened had climate change not happened.

The “Normal Climate” scenario is defined by holding constant both temperature and sea level at the values from a specified time, designated the “normal climate reference year”. The second scenario, the “Warming Climate”, shows what has and will happen to the country under conditions of increasing temperature and rising sea level. The scenario considers going beyond 2°C but no reaching 3°C. The third scenario called “the NDC climate action” refers to the balance between the normal and warming climate, that the country can finance through the NDC climate action. The scenario follows the Paris Agreement target of 1.5°C, i.e. no reaching or remaining below 2°C.

The potential impact of Climate Information Systems (CIS) on the production systems is illustrated in Figure 56. CIS intervenes on the avoided cost of losses and damages. It impacts the production sectors through the fraction of vulnerable infrastructure protected by CIS, the effect of CIS on agriculture productivity, water availability, energy supply, transmission and distribution, on transport, construction, and health prevention (by reducing mortality and morbidity), etc.

Figure 53. Complete integration of the input-output tables into the model production sectors. Variables in red are full arrays from the input-output table, showing the interdependence of the sectors. Variables in black determine the internal workings of each sector.

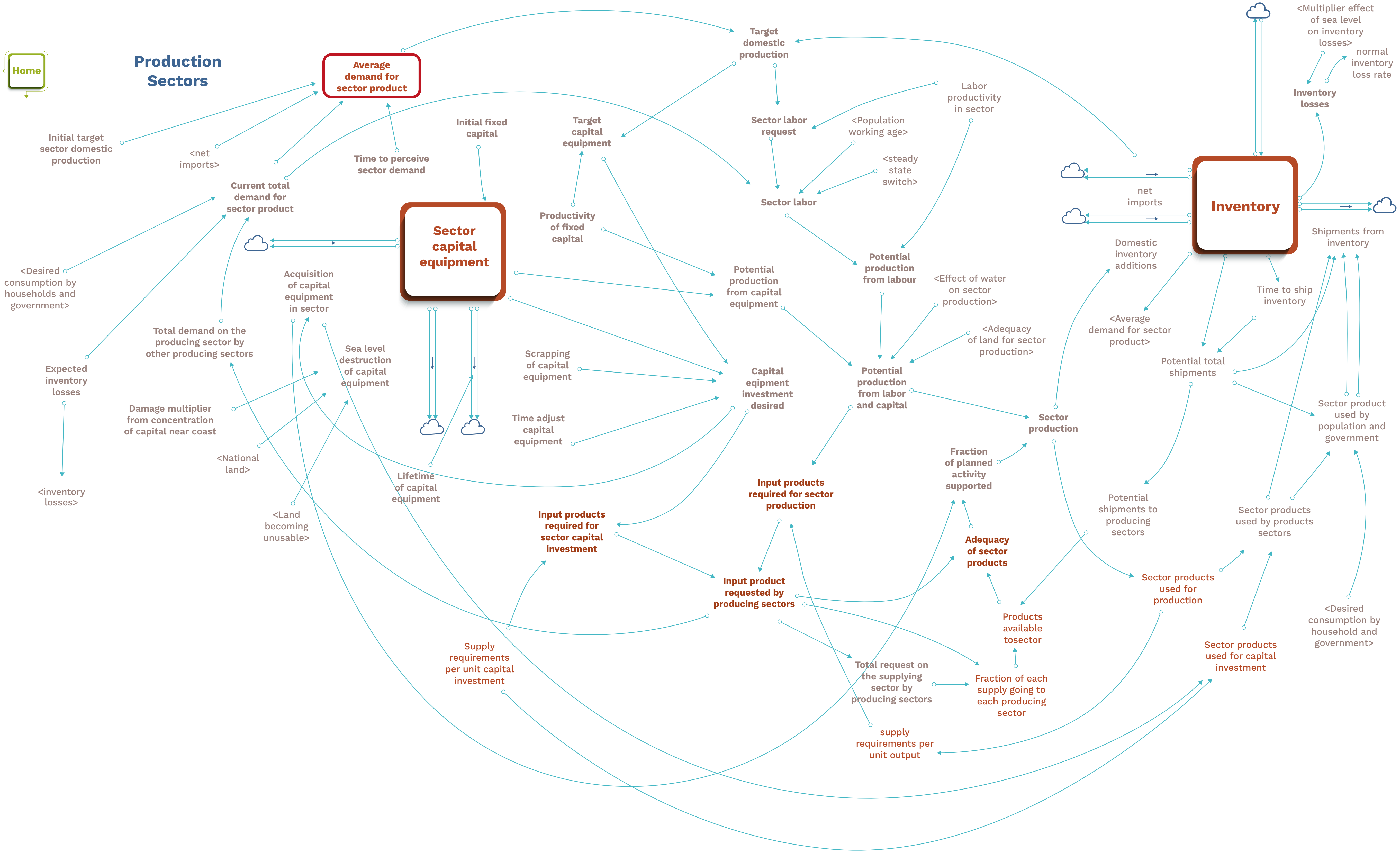
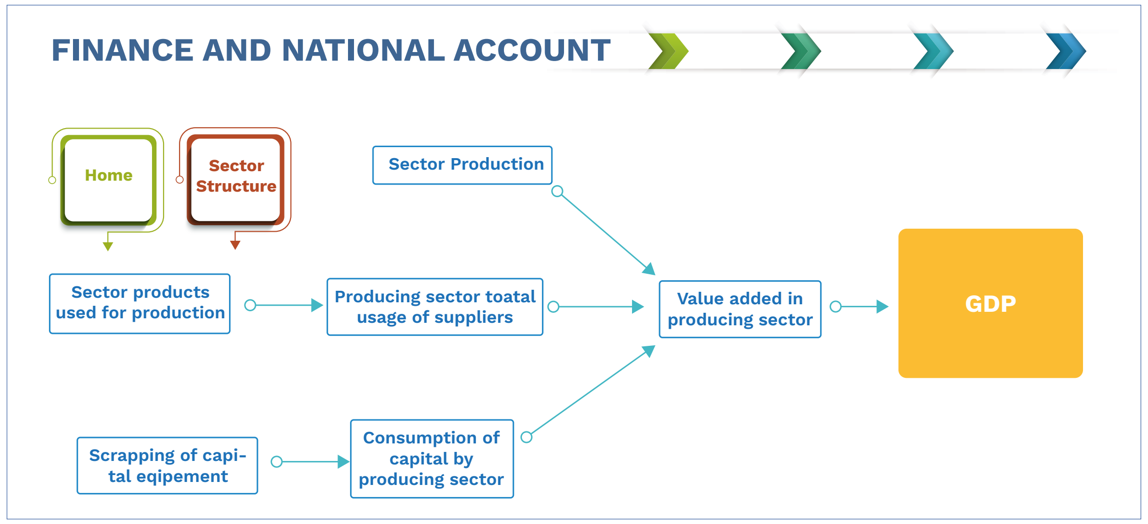


Figure 54. Connection between the input-output structure and GDP.



The application of climate services to the sensitive socio-economic sectors will result in the fluctuation of GDP. The impacts were drawn through the relationship between climate and the economic system. The assumption made is that each sector has a constant factor of climate impact on the economy. The model provides the generic value available in the literature and will need to be calibrated if local data are available. The model managed to incorporate the impact of CIS on the economy according to WMO's climate services check list level and categories, which classifies climate services in four categories: Basic, Essential, Comprehensive and Advanced.

Cost/Benefit Analysis

The methodological framework to calculate value-added measures throughout the production value chain is based on the theory of input-output approach and the macroeconomic framework provided by the System of National Accounts (SNA, 2008). The tool calculates a set of indicators that represent the socioeconomic performance of the value chain (Figure 57).

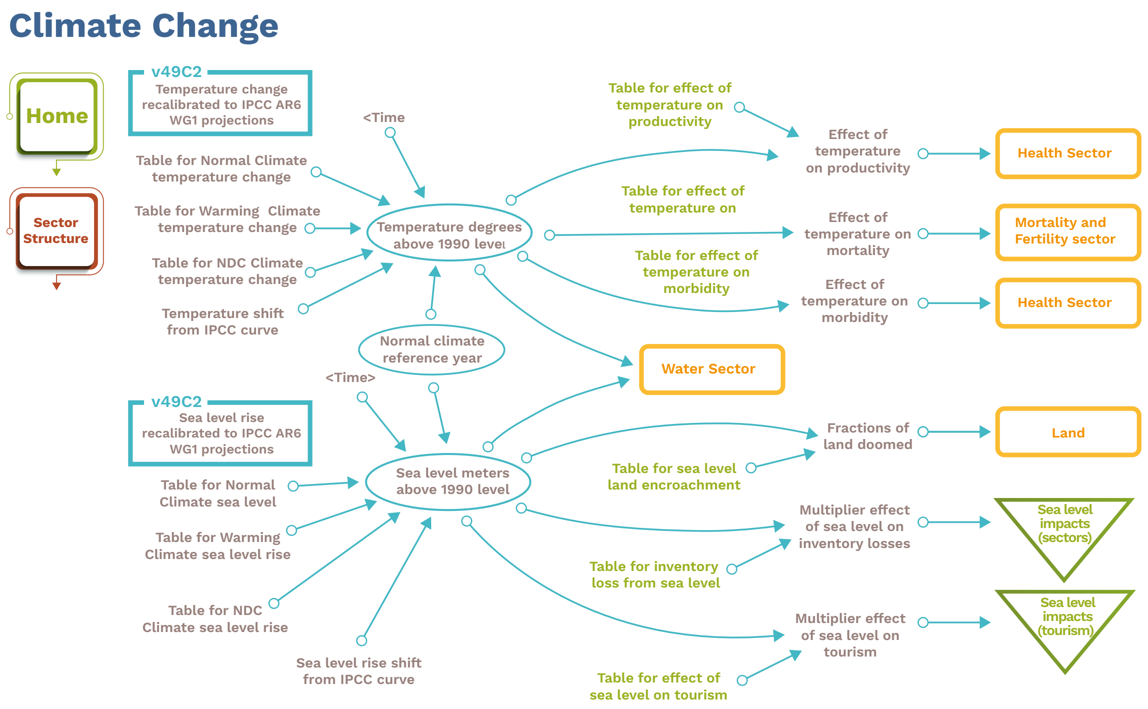
It first distinguishes between the production account and the income account. The production account determines the value added of the production process. The income account determines how this value added is distributed among the actors participating in the production process through the supply of production factors such as land, labour, capital, etc.

In addition to the socio-economic performance calculation described above, the economic performance increases resulting from spending on adaptation and abatement projects is included. This performance is also included in the CIS value chain, but since these projects are aspirational and contingent on funding, they are added after the main production process value-add calculation for visibility and transparency.

The result is a user-controllable interface in which the user may rapidly explore various scenarios and immediately see the associated costs and benefits by adjustment of sliders and lookup tables. Scenarios may include different degrees of climate change, different adaptive policies (such as Climate Information Systems), and different assumptions about the underlying structure of the ecology and economy of the country.

The result is a user-controllable interface in which the user may rapidly explore various scenarios and immediately see the associated costs and benefits by adjustment of sliders and lookup tables. Scenarios may include different degrees of climate change, different adaptive policies (such as Climate Information Systems), and different assumptions about the underlying structure of the ecology and economy of the country.

Figure 55. Calculation of temperature and sea level impacts, for three scenarios: "Normal Climate", "Warming Climate", and "NDC climate action" to enable rapid quantification of costs and benefits.



Calibration and validation of constants and model parameters

Once all the factors are featured in the model, the user needs to calibrate the constants and model parameters according to local datasets. Calibrating involves adjusting a variable in the model optimally by modifying certain constants, following a standardised sequence of key steps (Figure 58).

On completion of the calibration, the model can be used for predictions and informed decision-making on how to improve system performance and use the tool in strategic planning.

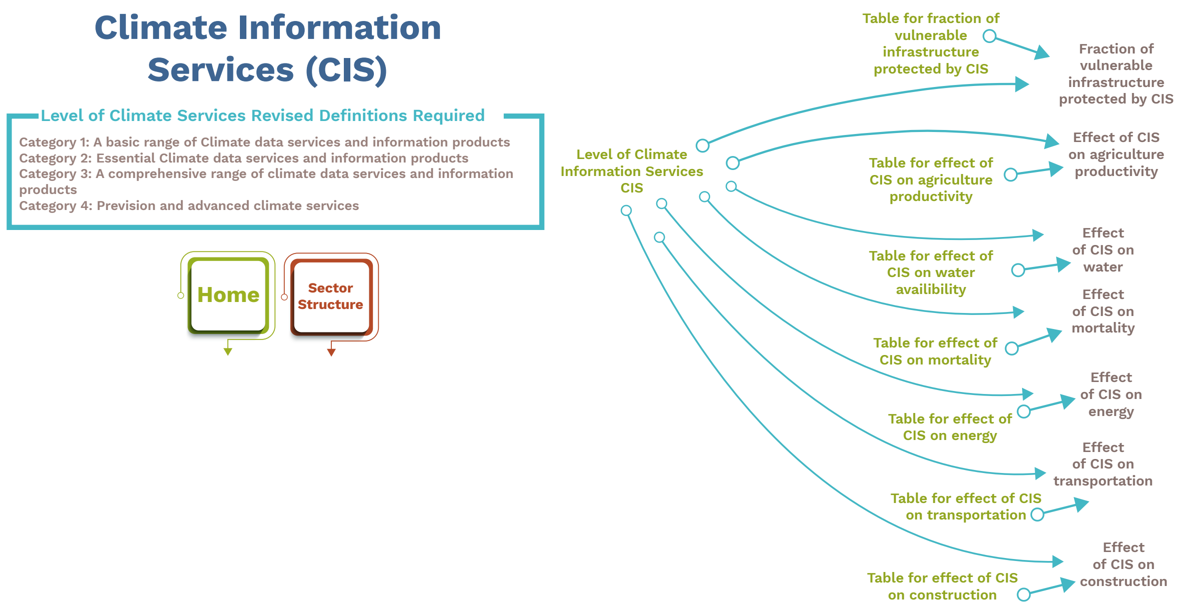
Data set used in the SEB tool

Four types of datasets were used as inputs in the model: population, labour force, GDP, and input-output tables. The data model was used to perform additional manipulations on the raw data, like aggregating them and creating new variables that are derived from the raw data. The outputs from the data model can then be read into the OACPS Template Model.

Population Data

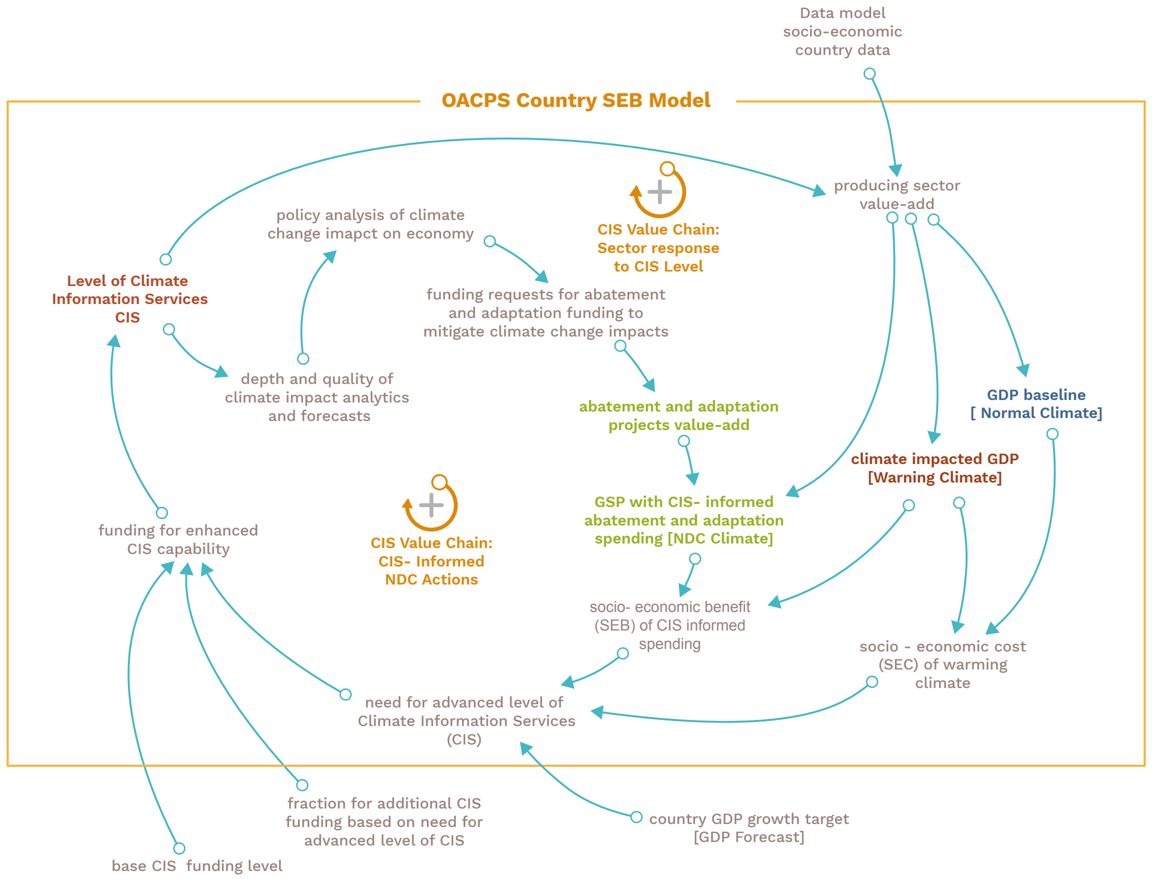
The United Nations World Population Prospects Programme was identified as the best source of population data.[34] The variables that are relevant to the model include the total population by age, the number of births, the number of deaths by age, and the net number of migrants. The data include historical values and three scenarios for future projections.

Figure 56. The benefits of Climate Information Services.



34 https://population.un.org/wpp/ (accessed 10 February 2025).

Figure 57. Representation of the two aspects of the CIS value chain.



Data are available for all OACPS countries, although not all variables are available for the smallest countries. A spreadsheet tool was created for each type of population data that allows users to extract and format appropriately the data for their country of interest. Users can then import the spreadsheet data to the data model.

Labour Force Data

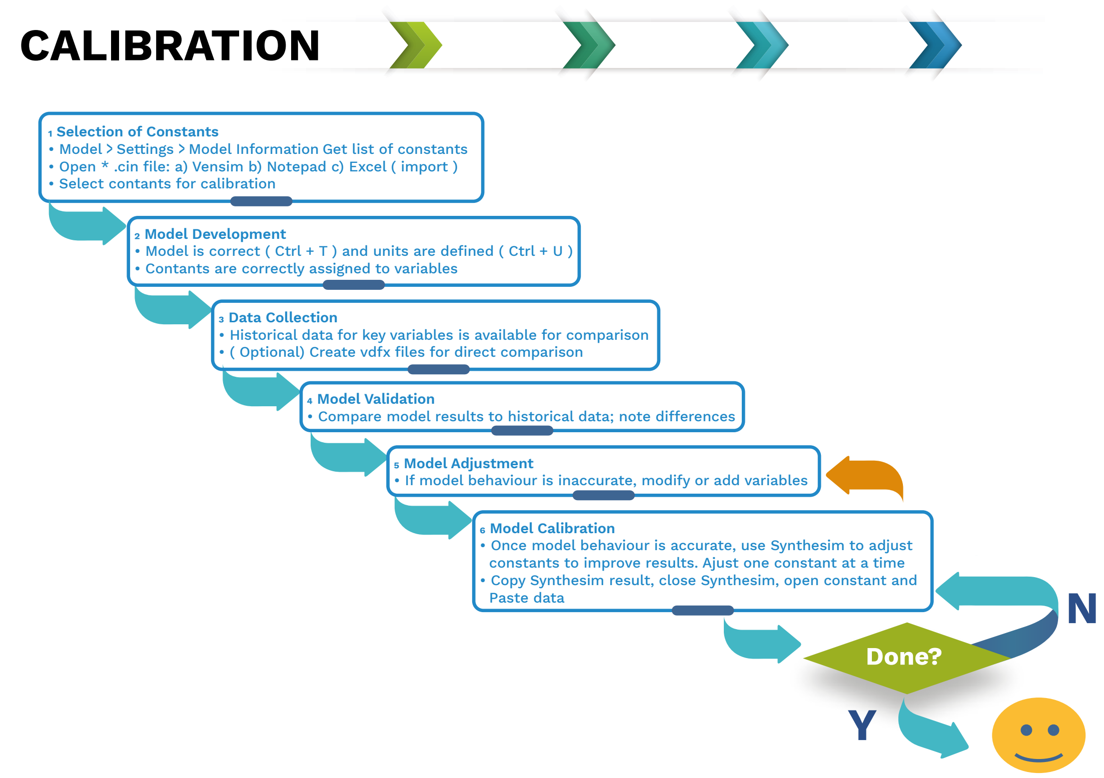
The World Bank's World Development Indicators database was identified as the best source of labour force data.[35] The variables that are relevant to the model are the total labour force and its percentage breakdown into agriculture, industry, and services. Running the data model calculates the number of workers in agriculture, industry and services.

Input-Output Table Data

The Global Resource Input Output Assessment (GLORIA) database was identified as the best source of input-output tables.[36]

35 https://databank.worldbank.org/source/world-development-indicators# (accessed 5 February 2025).
36 https://ielab.info/resources/datasets (accessed 5 February 2025).

Figure 58. Calibration and validation of constants and model parameters.



The GLORIA data quantify the monetary values of the inputs and outputs among each constituent part of an economy. This allows to quantify the dependencies among the sectors and final consumers. The GLORIA database covers 47 of the 79 OACPS countries. The spreadsheet tool calculates an input-output table every five years from 1990 through 2015, plus 2019. An example of an input-output table for the eight-sector OACPS Template Model is shown below.

The input-output table spreadsheet provides two types of data for the OACPS Template Model. The spreadsheet calculates text that can be copied into a constants input (.cin) file that the Template Model can read to obtain data. The spreadsheet is also read by the data model to calculate additional variables for use in the Template Model.

Gross Domestic Product Data

The United Nations System of National Accounts was identified as the best source of GDP data.[37] The GDP data serve two purposes. One is to calculate a deflator to convert the values in the GLORIA input-output tables from current US dollars to constant US dollars. The other purpose is to scale the input-output table values for a proxy country to a country that doesn't have GLORIA data. If a country of interest does not have an input-output table in GLORIA, users can enter the name of their own country and the name of the GLORIA country they choose as their proxy. Users can then import the data to the data model. The data model scales up the values in the input-output table for the proxy country to equal the GDP of the country of interest.

37 https://unstats.un.org/unsd/snaama/downloads (accessed 5 February 2025).

Table 5. Example of GLORIA Input-Output Table.

Values stated in Thousands of Current US Dollars	Agriculture	Energy	Water	Infrastructure	Transportation	Health	Industry	Services	Household	Government	GROSS TAXED Capital Formation	Exports	Imports
Agriculture	314	85	5	699	196	2,578	46,564	11,026	39,446	197	2,227	6,830	-29,412
Energy	212	2,744	190	977	946	187	6,331	5,922	10,117	35	406	1,061	-5,567
Water	8	40	8	52	106	22	406	737	3,221	140	1	41	-140
Infrastructure	341	92	22	5	109	79	218	2,079	234	18	21,961	0	-1,261
Transportation	1,210	2,062	563	903	662	527	7,802	11,663	17,203	94	5,796	4,958	-14,026
Health	26	3	0	5	28	0	134	93	11,047	3,672	-163	47	-196
Industry	4,359	2,076	439	6,969	5,784	4,591	43,116	36,982	45,583	793	34,735	124,588	-101,823
Services	3,982	2,615	696	4,129	2,192	1,870	26,136	22,209	141,900	67,968	35,057	29,167	-71,788
Net taxes on products	10,070	3,106	1,545	891	6,354	891	6,727	16,562	0	0	0	0	0
Compensation of employees	10,962	2,789	484	5,955	12,301	2,425	34,493	80,596					
Taxes on production	1,065	275	12	83	296	25	1,087	2,977					
Subsidies on production	8	6	0	0	0	0	20	1					
Net operating surplus	35,619	5,265	436	1,617	6,138	791	22,055	42,823					
Net mixed income	7,059	1,354	157	1,166	2,833	538	8,416	23,111					
Consumption of fixed capital	5,518	1,051	85	446	1,471	175	4,689	9,352					
Total Value Added	60,231	10,740	1,174	9,267	23,040	3,953	70,759	158,860					
Sector Output	80,754	23,561	4,642	23,897	39,416	14,697	208,192	266,132					
Total Final Demand									268,750	72,917	100,021	166,692	-224,211

Quality control of datasets

Data from various sources were compared to get an idea of how much accuracy might be attributed to such data. Significant differences in the magnitude of some economic activities were found among four reputable sources, namely the United Nations, GLORIA, National Statistical Institute, and EXIOBASE 189.

At the level of total value added (the major component of GDP), the four sources were consistent within roughly 10% of each other. However, at the individual sector level, even when the economy is aggregated into 11 sectors, the sources sometimes disagreed by as much as a factor of 4. These comparisons were useful for setting expectations for the eventual adaptation of the Template Model to individual countries, realising that economic data must be acknowledged as approximate.

5.2.3 Results of SEB Assessment

The purpose of the model, which is to assess climate-caused economic and social damage, predicts which sectors will be most damaged by loss of some of their fixed capital to environmental damage. The software panel displays the climate impact on GDP, as well as the contribution of key production sectors, such as agriculture, water resources, transport, health, infrastructure, etc.

Results presented here focus on climate impact on GDP and particularly the agricultural sector, based on the model's outputs for Burkina Faso. This is one of five pilot OACPS countries where template models have been developed to show the impacts of climate information and climate change impacts on the main socio-economic sectors. The results are presented in the three scenarios as explained above.

Climate impacts on GDP

The input-output system dynamic model was initially run with the data collected from the global dataset to reproduce the trend of GDP, and compared with the real dataset, either from the same source or from the national institution, to identify the bias.

The impact of climate on GDP was estimated at two levels. First, the relationship identified in the literature between GDP and temperature change and sea level rise was integrated to define the impact of climate change. Further parameters were then introduced, namely the fraction of vulnerable infrastructures protected by the climate information services, the effects of climate information services in sensitive sectors such as agriculture, water resource management, energy production and transport.

Results are presented under three scenarios. Across all model variants, the effect of climate change and variability on GDP is largely significant. A significant negative effect was found with temperature and sea level increases associated with a permanent loss of economic output in hot regions. This loss is significant: a 1°C temperature increase in a region with an annual mean temperature of 25°C reduces the region's GDP by about 3.5%. By adjusting the slider of the panel of climate service level up to four, the model again showed the impact of investing in CIS. Upgrading the category to level four of the WMO's climate services checklist could buffer the negative impacts of climate on sensitive sectors and offset the potential negative impacts on socio-economic production.

The impacts of climate change on Burkina Faso's economy are illustrated in Figures 59 and 60. The year 2020 was considered as the baseline for projections up to year 2100.

The physical climate risk is expected to worsen over the course of the century, even under the best-case scenario of the global emissions pathway (RCP4.5). Current information on the magnitude of the costs and economic consequences for Burkina Faso suggests that they could be significant. Damage to assets and productivity losses due to physical climate impacts are expected to have a net negative macroeconomic impact of 6.5% of GDP in 2040, rising to 11% of GDP loss in 2100. However, with the use of climate information services, the country could increase productivity by 3.7% of GDP in 2040 under the NDC climate action. This result showed that the model has identified the impact of CIS to avoid losses can go up to 60% (i.e. the rate of gain from CIS (3.7%) against the loss rate of 6.5%).

In 2100, the loss of GDP could reach 11%. This result is in line with the World Bank's analysis, which found that improving climate services could lead to a 10% reduction in disaster losses in low-income countries such as Burkina Faso. Matthias Kalkuhl and Leonie Wenz (2020) had found that a global mean surface temperature increase of around 3.5°C by the end of the century would reduce global output by 7-14% in 2100, with even higher losses in tropical and poor regions.

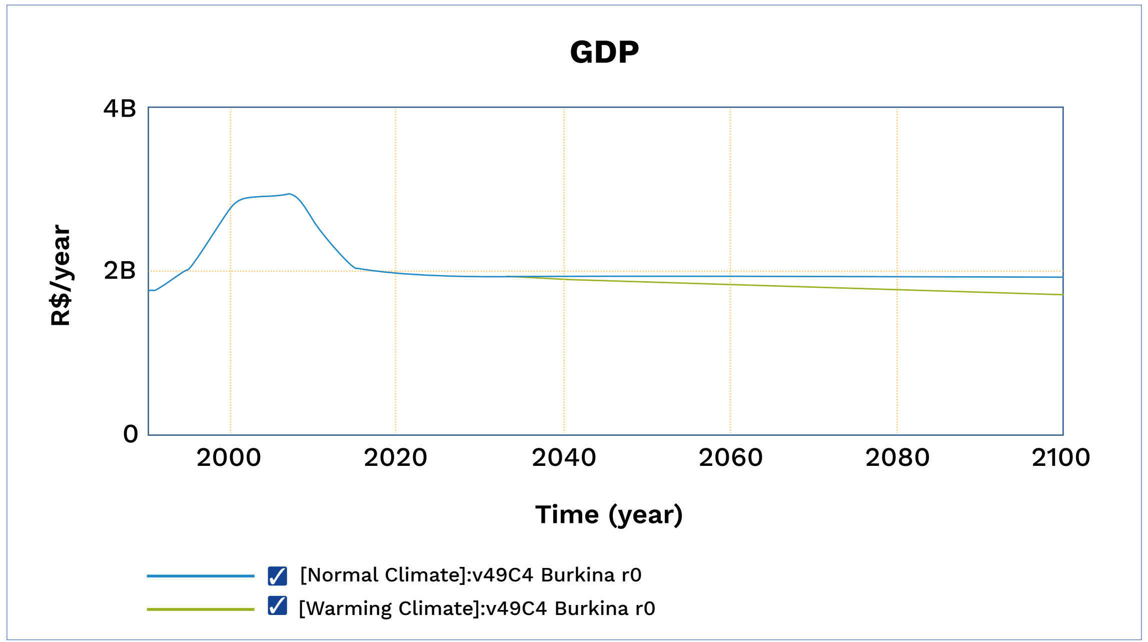
Effect of climate variability and change on agriculture production

The agriculture sector is among the main contributors to the national GDP. The results of the model show that agriculture production will be most affected by climate change, for it depends on natural resources and will be more directly exposed. The sector will lose up to 50% of its productivity on average (ranging from 34% to 80%). Figures 61 and 62 illustrate how agriculture production will respond to climate change according to the model. The red curve indicates the decline in production due to a warming climate. The green curve represents the potential improvement in agricultural production with the application of climate services of level one (basis climate services). The blue curve projects agricultural production under normal climate conditions (no adverse phenomena).

Resilience and mitigation measures will have a large influence on the magnitude of impacts. The average of the modelled simulations suggests that the impact of increased use of climate information services (CIS) would result in a 5.9% reduction in GDP losses in 2060. This productivity improvement is due to the role of climate information in agriculture. The model results show that CIS can increase productivity from 35% to 70% between 2040 and 2080.

In the village of Tenado in Burkina Faso, the CREWS Programme carried out a socio-economic evaluation. The results show that the annual gain for a farmer using agro-meteorological advice during 2019 and 2020 crop seasons had received a respective profit of FCFA 216,150 and FCFA 175,400 in 2019 and 2020, for a pilot farmer, against respectively FCFA 64,800 and FCFA 66,000 in 2019 and in 2020 for a control farmer. This shows an increase of almost 3 times more for using climate information services compared with a control farmer not using the climate information (CREWS, 2020). Yields increased by almost 30% during the agricultural season.

Figure 59. The impact of climate change on GDP for Burkina Faso.



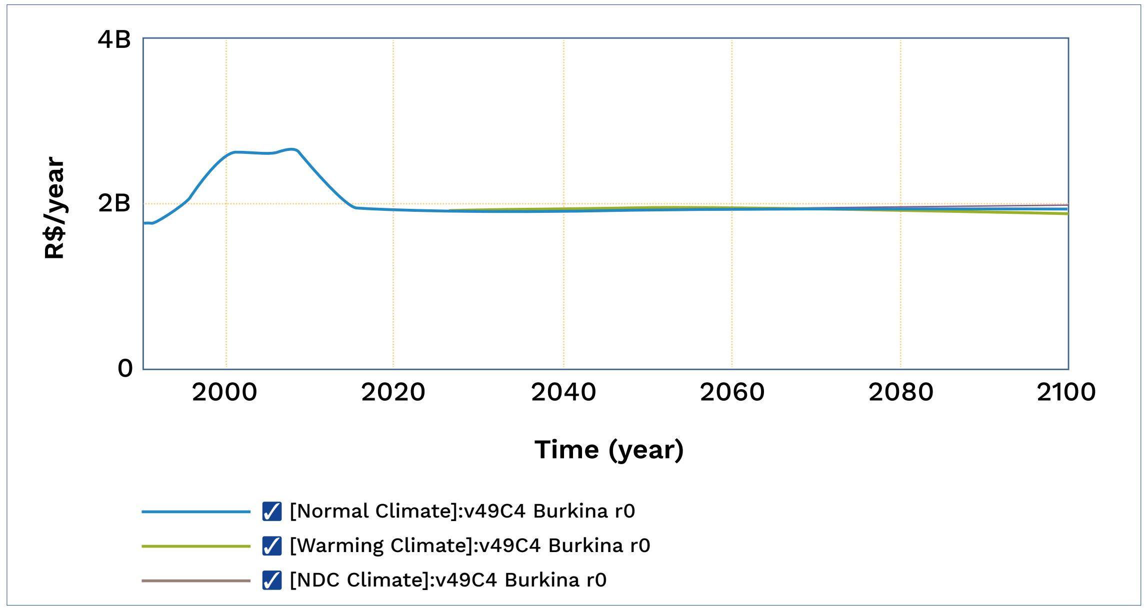
Portele et al. (2021)[38] had demonstrated that seasonal forecast-based action for droughts achieves potential economic savings up to 70% of those from optimal early action. Although the results are localised to a specific area, and if all other things being equal, these results confirm the order of magnitude of the impacts that can be expected at the national level. The SEB model outputs indicate an improvement in agricultural production of between 35% and 70% at the national level.

Burkina Faso's adaptation response could have a major impact on the long-term economic impacts arising from climate physical risks. Decisions of present and future governments on adaptation policies and the support of functioning financial and insurance markets will affect the size of these impacts and how and when they might occur. Climate change poses several macroeconomic risks as demonstrated by many authors (Mongelli et al., 2022. Bylund and Jonsson, 2020) quoted by New-Zealand (2023). The SEB tool outputs bring insight to policy makers for adopting regulation and strategies to avoid loss and damage on long-term planning as most existing studies point to longer-term GDP losses (Batten and al., 2020; Bylund and Jonsson, 2020; Salinger and Porteous, 2014, and Burke et al., 2018).

On the supply side, gradual changes in a country's climate (such as warming and changes in regional climates) could lead to changes in land use and the mix of commodities produced, while increased climatic variability between seasons and years is likely to lead to greater volatility in production from year to year and could lead to long-term increases in food costs. In addition, an increase in the frequency and severity of acute weather events could lead to a series of negative supply shocks that could temporarily suppress production and increase prices.

The model showed that multiple factors influence the scale and timing of impacts.

Figure 60. Effect of investing in CIS for upgrading up to the category level four.



38 https://www.nature.com/articles/s41598-021-89564-y (accessed 5 February 2025).

These factors tend to be complex and are referred to in the framework as sources of variability. The way that impacts compound upon and interact with each other is an additional source of variability as they often do not occur in isolation. The SEB framework further classified sources of variability as "amplifiers or multipliers" or "abatement or moderators". Multipliers are factors that can worsen or heighten impacts. Moderators can dilute or reduce the overall impact. For example, previous adaptation actions and broader resilience factors (such as the use of climate information services, diversification and availability of insurance) could dampen the potential impacts of climate risks on the economy and public finances.

The model supports the above by showing the "suppression effect" of the benefits. If the temperature rises at an unexpected rate, where current mitigation and adaptation measures become irrelevant, the previous investment in CIS will not pay off in the production systems. Figure 63 illustrates the effect of rising temperature, which hinders the gain of CIS on productivity, even though the country benefits with level four of advanced climate services, the suppression of the gain generated by CIS is pronounced. This situation implies that there is a need to combine both mitigation (GHG reduction) and adaptation policies to maintain the benefit of CIS, otherwise the effect of CIS will be cancelled out.

The above statement also applies to other economic factors that may inhibit the effect of CIS on productivity. In other words, to see the effects of CIS, other economic factors such as the availability of trade currency and its restriction on imports, the capital productivity multiplier (amplifier), the multiplier for desired imports and consumption must be effective and meet the requirements of the production system. The lesson to be learnt is that monitoring of the climate system is a key factor to be considered in the same line as updating policies on mitigation and adaptation, as well as investments in CIS to adapt to the current needs of user requirements. Henceforth, research and innovation must be and remain a priority in the uncertainty of future climate conditions.

Figure 61. Impact of basis level (one) of CIS on agriculture production.

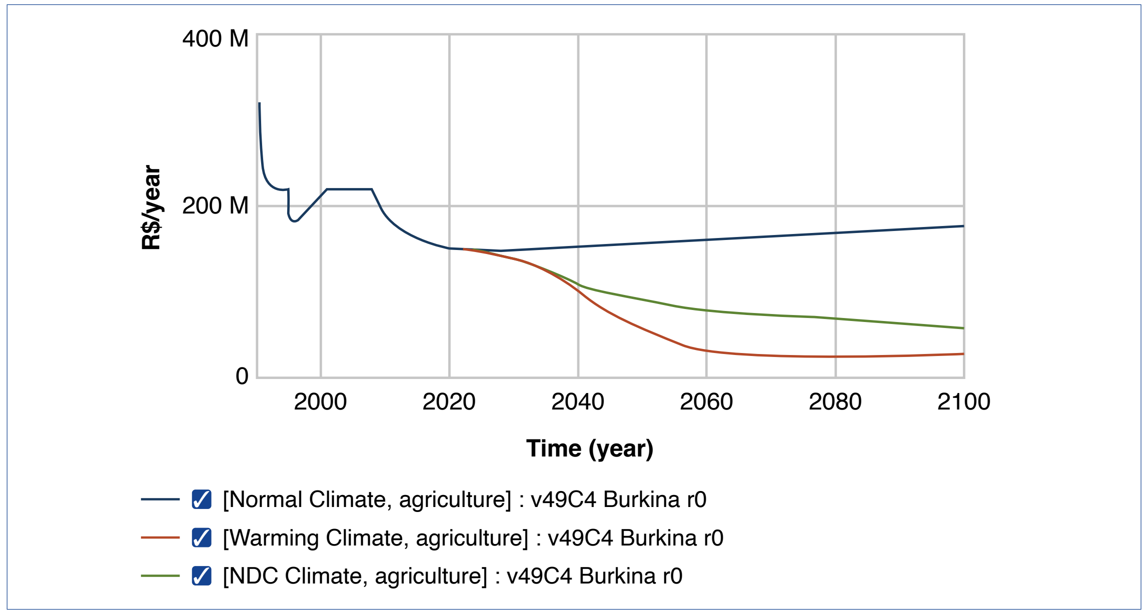
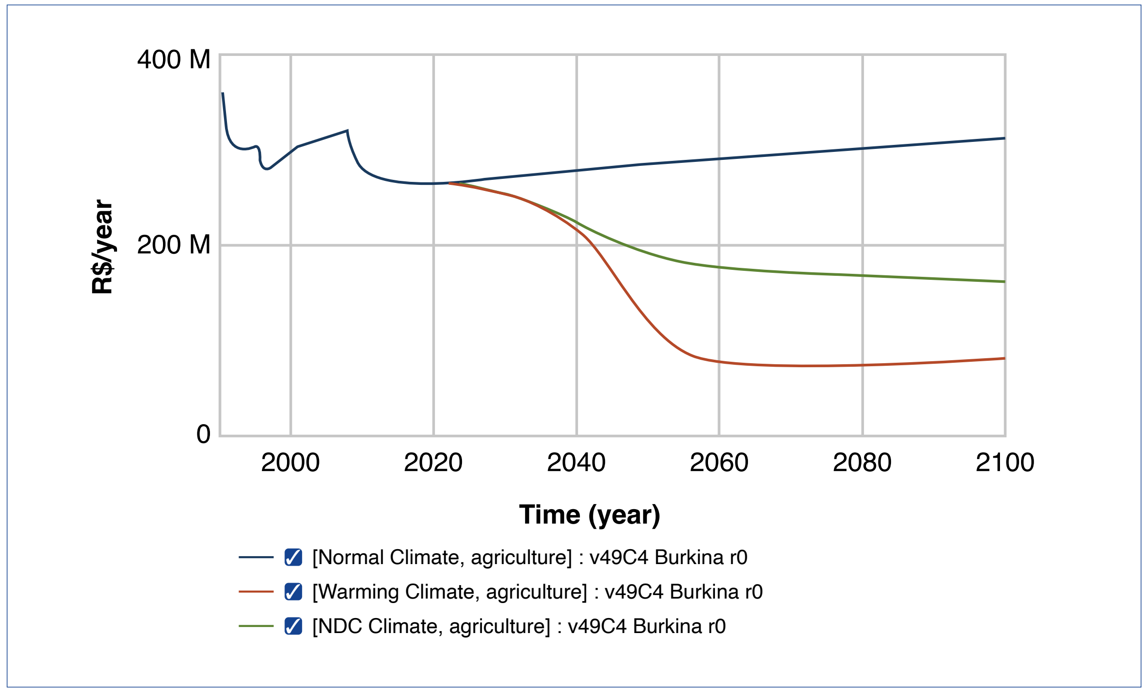


Figure 62. Impact of advanced level (four) of CIS on agriculture production. In red production in warming climate with basis climate information (level One), in green improvement of agriculture production with climate services application of level four (advanced climate services), and in blue agriculture production with no climate change (normal climate).



5.2.4 Conclusions

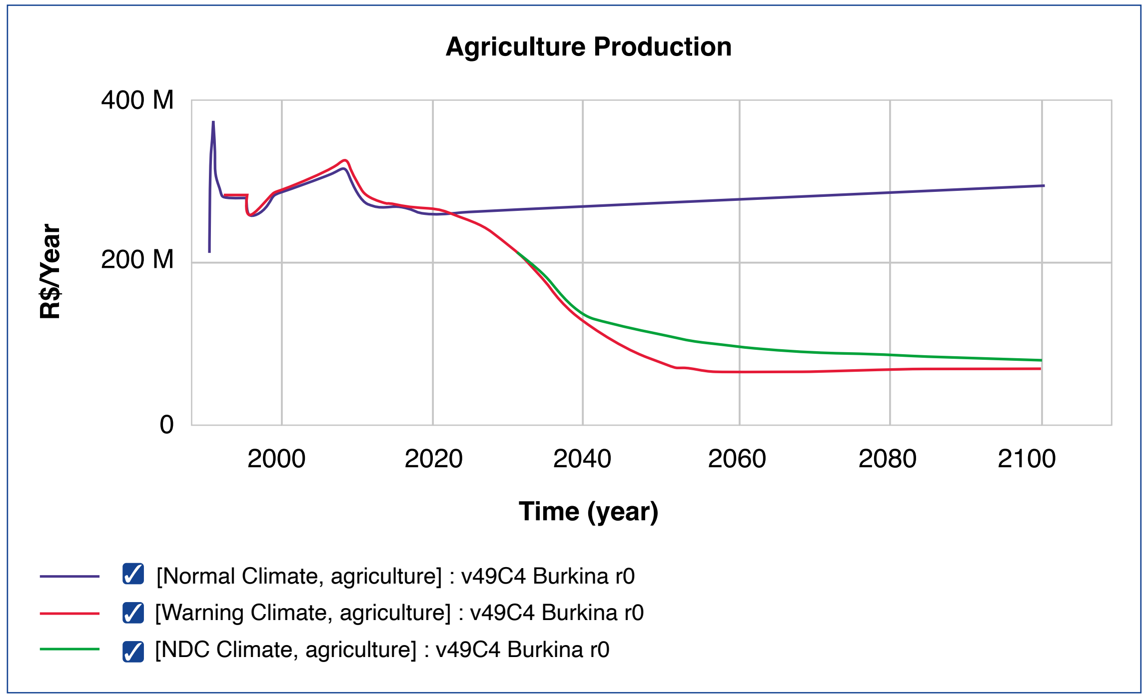
The ClimSA SEB model provides a framework to look at the socio-economic effects of any climate change scenario affecting the resources of the economy (people, land, stocks of fixed capital, inventories of goods, etc.). The model's methodology, based on the input-output system dynamic, is able to compute the damage effects of various scenarios, with and without various investments and interventions (including improved CIS levels), thereby showing the benefits of various actions and decisions to be taken by decision makers.

When the template model is adapted and calibrated to represent a specific country it becomes a critical element in a decision support system (DSS). The model's outputs demonstrate the long-term effects of climate change including the impact of temperature increase and sea level rise, and the effect of different levels and categories of climate information services on GDP. The outputs on the magnitude and economic consequences for Burkina Faso suggested that the costs could be significant. Damage to assets and productivity losses due to physical climate impacts are expected to have a net negative macroeconomic impact of 6.5% of GDP in 2040, rising to 11% of GDP loss in 2100. With the use of climate information services, the country could increase productivity by 3.7% of GDP in 2040 under the NDC climate action. The model predicts that the impact of CIS to avoid losses may rise up to 60% (i.e. the 3.7% rate of gain from CIS against the loss rate of 6.5%).

The model's outputs also illustrate the "suppression effect" of potential benefits. Under a worst-case scenario the suppression of the gain generated by CIS is pronounced, highlighting the need to combine both mitigation (GHG reduction) and adaptation policies to maintain the benefit of CIS, which would otherwise be cancelled out. To achieve the projected effects of CIS, other economic factors - such as the availability of trade currency and its restriction on imports, the capital productivity amplifier, the multiplier for desired imports and consumption - must be effective and meet the requirements of the production system.

An important lesson to be learnt is that monitoring of the climate system is a key factor to be considered in the same line as updating policies on mitigation and adaptation, as well as investments in CIS to adapt to the current needs of user requirements. Therefore, research and innovation must be and remain a priority in the uncertainty of future climate conditions. The SEB model has proved to be an effective tool to support decisions and negotiations concerning climate effects on OACPS' economic production and sustainable development.

Figure 63. Effect of temperature increase buffering the impact of CIS. The green line falling closer to red line demonstrates the "suppression-effect" of the temperature increase over the current effort of mitigation and adaptation.



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CHAPTER 5.3 Policy and Practice Implications for Enhancing Climate Services for the Agriculture Sector

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5.3.1 Introduction

The agriculture sector is undoubtedly one of the most vulnerable sectors to climate variability and change. This is particularly true in those developing countries and Small Island Developing States (SIDS) in Africa, the Caribbean and the Pacific that rely highly on rainfed agriculture for food security and economic development. As a result, agriculture features prominently in the National Adaptation Plans (NAPs) of many developing countries, both in terms of vulnerability to climate change (impacts on crop yields, pasture availability, livestock productivity, post-harvest losses) as well as prioritisation of adaptation actions.[39] Agriculture also features prominently in the Nationally Determined Contributions (NDCs),[40] firstly as a major Greenhouse Gas (GHG) emitter and secondly as an area for obtaining co-benefits that contribute to both the mitigation and resilience goals of the Paris Agreement as well as various food security and climate change targets of the Sustainable Development Goals (SDGs). In the broader United Nations Framework Convention on Climate Change (UNFCCC), agriculture is addressed through the Koronivia Joint Work Programme on Agriculture[41, 42] and its successor the Sharm el-Sheikh joint work on implementation of climate action on agriculture and food security[43] The focus being on enhancing climate action in the agriculture and food security sector, while recognising that climate solutions must be 1) informed by a mix of scientific and local knowledge; 2) context specific and locally relevant; and 3) inclusive and participatory processes involving farmers, pastoralists, indigenous peoples, local and vulnerable communities, women and youth. Although climate services are not specifically mentioned in these points, they do have a key role to play in climate action for the agriculture sector. To support this, the National Meteorological and Hydrological Services (NMHSs) across the world often have divisions dedicated for climate services in the agriculture sector.

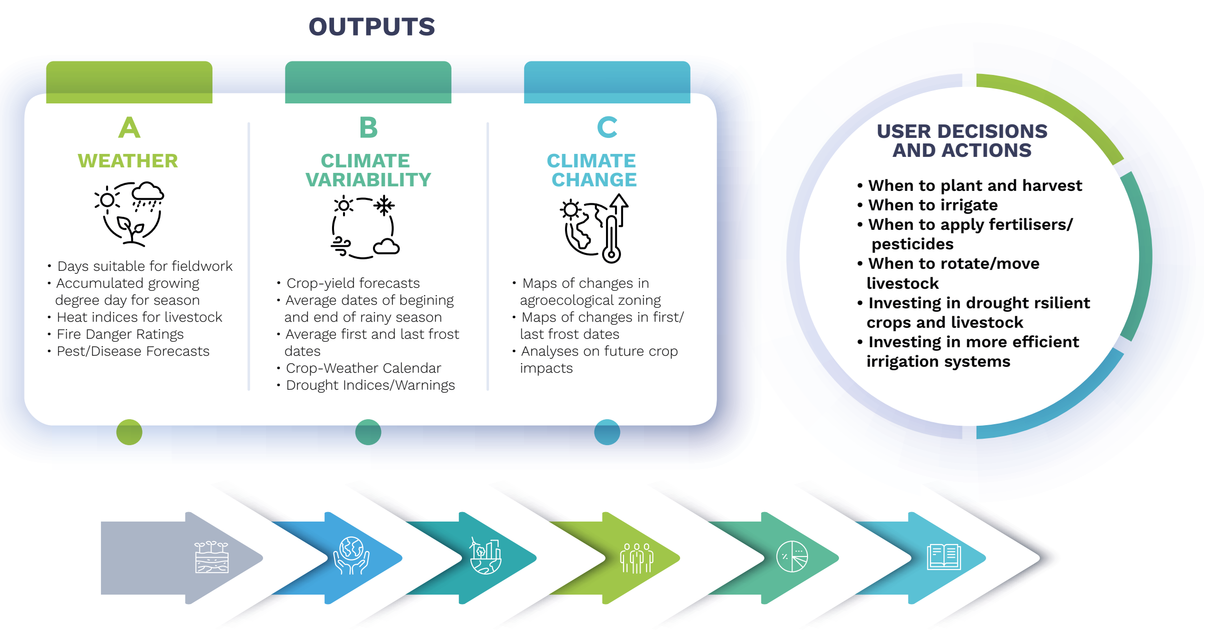
39 https://openknowledge.fao.org/server/api/core/bitstreams/71972844-74fd-4a68-bf77-7528b0317e3a/content (accessed 09 July 2024).
40 https://openknowledge.fao.org/server/api/core/bitstreams/5a0b9782-3c0f-402f-a0f5-e781c6a3b599/content (accessed 09 July 2024).
41 https://unfccc.int/sites/default/files/resource/docs/2017/cop23/eng/11a01.pdf (accessed 09 July 2024).
42 https://www.fao.org/koronivia/en/ (accessed 09 July 2024).
43 https://unfccc.int/sites/default/files/resource/cp2022_10a01_adv.pdf#page=16 (accessed 09 July 2024).

Looking back, the establishment of the Global Framework for Climate Services[44] (GFCS) in 2012, laid the foundation for a more systematic and coordinated approach to climate services worldwide (Hewitt et al., 2012). This included identification of priority sectors, of which agriculture and food security was one. Over a decade later, climate services have evolved greatly, particularly from being provider-driven services to more user-centric, inclusive and participatory services that bring users, intermediaries and climate service providers together in what is called coproduction (Carter et al., 2019; Vincent et al., 2018).

5.3.2 The Users and Uses of Climate Services in Agriculture

In this transition to a user-centred approach, fundamental questions that must be answered when dealing with climate services in the agriculture sector are: who the users are; what are their needs; and how can those needs be best served. In agriculture, there are various users, including policy makers in government dealing with implications of climate change on the sector, agricultural planning departments who often plan on mid-term basis (typically 5 years), food security planners from government and non-governmental organisations who need to understand the year-to-year or season-to-season status of food production and the impacts on food security, agricultural enterprises like seed producers or agrodealers, agricultural finance agencies, extension agents who are intermediaries of climate information, and farmers themselves (including pastoralists).

Figure 64. User decisions in agriculture (WMO, 2019).



44 https://wmo.int/site/global-framework-climate-services-gfcs (accessed 18 July 2024).

At the farmer or local community level, understanding the user landscape in relation to, for example, gender and marginalised groups, should be a key component of the mapping of different users of climate services.

As part of the user landscape mapping, an understanding is needed of the type of decision to be taken by different stakeholders and that can be informed by climate services (WMO, 2019) Figure 63 provides a snapshot of the types of decisions that are made in relation to agriculture and the type of climate information that can support them.

Even within a single farming community, the needs for climate services cannot be assumed nor simply extrapolated from one group or location to another. For example, in rural sub-Saharan Africa, men and women have different social roles in farming systems (Jost et al., 2016) implying different needs of information (in terms of content, timing of delivery, format and channels of delivery) as well as different abilities to act on that information (Tall et al., 2014; Carr et al., 2016; (Tall et al., 2014; Carr et al., 2016; Gumucio et al., 2020). While various methods can be used to identify user needs, inclusivity through involvement of women, the most vulnerable and marginalised who would not normally have access to such information or processes, or have specific information needs, must always be considered.

5.3.3 Different Communication Channels

The choice of communication channel can have a great effect on access to the climate information and whether it is used or not. While digital technologies offer new opportunities to ensure that information reaches farmers and other actors in the agriculture sector (FAO, 2021), in many smallholder farming communities, local radio remains the preferred means for receiving climate information (Bacci et al., 2023). There are multiple other communication channels including print media, messaging apps, social media, institutional websites, SMS, written agrometeorological bulletins, e-mail lists, bulletin boards and more. Often it is not a matter of choosing the "best" communication channel, but rather identifying a range of suitable communication channels that can ensure that various user and stakeholder groups, can access and make use of information that is relevant for their agricultural decision-making needs. Developing, with users and intermediaries, written and agreed upon communication plans that can be used and updated from season to season can be a useful process for NMHS to institutionalise the various agrometeorological communications channels. In various locations, IGAD Climate Prediction and Applications Centre (ICPAC) has successfully supported NMHSs to engage local media through what is coined a Seasonal Media Action Plan (SMAP[45]) that documents the roles and responsibilities of different media organisations and individuals in communication of climate information. Key aspects to consider when identifying different climate services communication channels are: i) local language; ii) capacities of users and intermediaries to understand the information; iii) access and preference of users to certain communication channels and technologies; iv) and inclusivity of different user groups.

45 https://www.icpac.net/news/enhancing-media-and-meteorological-agency-engagement-in-eastern-africa/

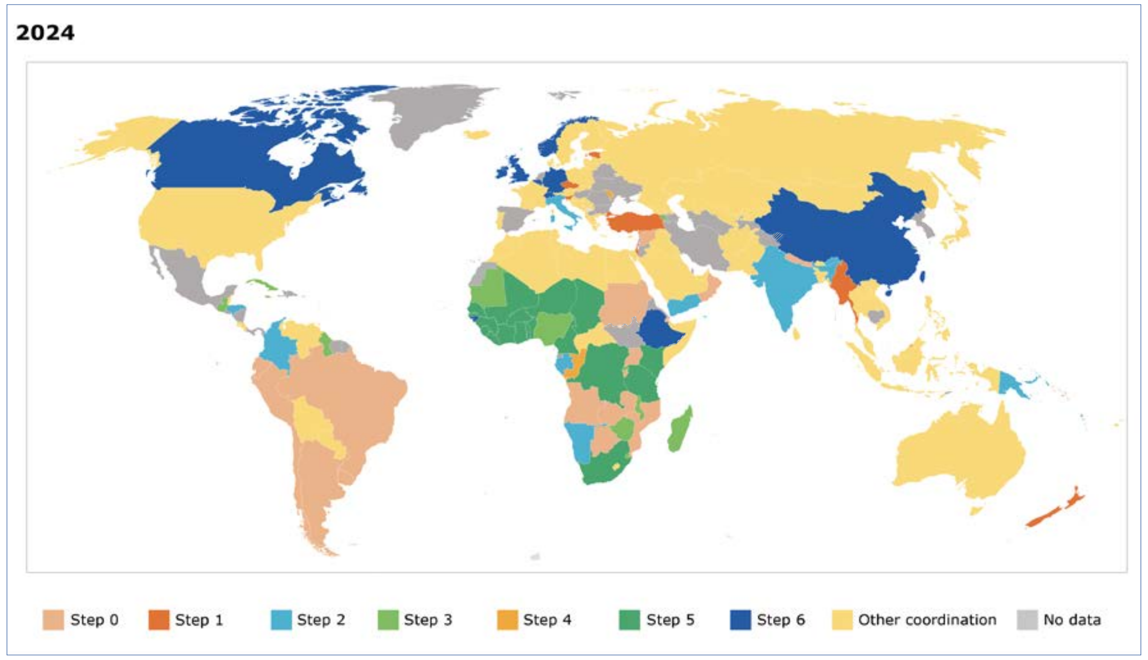
5.3.4 The Importance of Involving Users from Co-design to Co-evaluation

While data and tools to produce tailored climate information are no doubt crucial, a key aspect of the delivery of climate services for the agriculture sector in developing countries has been a shift to inclusive and participatory process for their coproduction. In East Africa, ICPAC has supported implementation of Participatory Scenario Planning (PSP[46]) (CARE, 2018) to collaboratively design and deliver seasonal user-centred climate information services in communities in Uganda and Kenya. In the Caribbean[47], Participatory Integrated Climate Services for Agriculture (PICSA) (Dorward et al., 2015) has been used to help farmers understand historical climate and the implications of seasonal forecasts in their decision making. Other methods of coproduction exist, including Roving Seminars on Weather, Climate and Agriculture[48] that have been largely used in West Africa (Stigter, 2016 ; Tarchiani, 2019); Local technical agroclimatic committees (LTACs) / Mesas Técnicas Agroclimáticas (MTAs) used largely in South America; and Groupes du travail pluridisciplinaire (GTPs) used in West Africa. The approach chosen should be based on the local needs and context, with the principle of being participatory and inclusive always remaining.

At regional level the users and stakeholders are primarily engaged through the Regional Climate Outlook Fora (RCOFs), with some having sectoral working groups for sectors like agriculture. At national level, countries have engaged users through their respective National Climate Outlook Fora (NCOFs). The National Frameworks for Climate Services, that exist in various countries across Africa, the Pacific and the Caribbean (Figure 65), are often the coordination, governance, and collaboration mechanism within which user engagement on sectoral climate services is framed.

46 https://careclimatechange.org/practical-guide-to-participatory-scenario-planning-seasonal-climate-information-for-resilient-decision-making/
47 https://www.climsa.org/media/news/participatory-integrated-climate-services-agriculture (accessed 10 July 2024).
48 https://community.wmo.int/en/roving-seminars-weather-and-climate-farmers (accessed 10 July 2024).

Figure 65. The status of National Frameworks for Climate Services (NFCS) across the world.



For the co-evaluation of climate services, these regional and national platforms and frameworks also offer opportunities for users to provide feedback on the services they receive, enabling the NMHSs to further tailor and improve products informed by, and respond to evolving user needs and challenges. Developing appropriate evaluation logic models that incorporate aspects of climate services use, distribution, uptake and impact (Vogel et al., 2017) and involving users in the evaluation of climate services is a key aspect for demonstrating value and enhancing investment in agrometeorological services (Tarchiani and Bacci, 2024). Yet WMO surveys to NMHSs have found that the monitoring and evaluation of the benefits and impacts of climate services remains consistently weak (WMO, 2019). There are various examples of the benefits of climate services in the agriculture sector. For example, ICPACs socio-economic benefit analysis of climate services in the agriculture sector in Kenya and Uganda[49] showed that household food security and resilience, were higher among users of climate services. In projects in Burkina Faso, evaluations showed that climate services resulted in 40% reductions in agricultural production costs (reduced seed loss and reduced use of fertiliser) and a 41% increase in income for farmers (Tarchiani, 2021) with similar experiences in pilot sites under the ClimSA Programme.

49 https://www.icpac.net/documents/871/ClimSA_socio-economic_policy_brief_Final_version_QwcQzz7.pdf

5.3.5 The Scale up and Sustainability of Agrometeorological Services

A common theme for the delivery of climate services in the agriculture sector is sustainability. The agrometeorological divisions of the NMHS are often understaffed and their capacities stretched, government extension often inadequately resourced, and generally there is a limited availability of financial resources for the broader national to local level delivery of agrometeorological services[50]. Collaboration and synergies among climate services projects and programmes offers one opportunity for sustainability, while enhancing the overarching governance and institutional aspects of climate services delivery, through for example National Frameworks for Climate Services (NFCS), provide another. Public-private partnerships could also be an option, as demonstrated in Ghana[51] through the partnership between a private company ESOKO, the Ghana Meteorological Agency (GMet), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (Partey et al., 2019). A key aspect to enhance sustainability and increase funding will be the demonstration and quantification of the social and economic benefits of climate services.

5.3.6 Recommendations

Recommendations that emerge from the experiences documented in this paper on the application of climate services for the agriculture sector can be split into policy recommendations and practice recommendations.

Policy Recommendations

- **Continue to invest in the capacity building of NMHS**, including data, tools, processes and competencies to produce tailored climate information for the agriculture sector.

- **Ensure funding not only for climate services production but also on the means for their communication and coproduction**, including through the capacity building of extension agents and other intermediaries who are the link between the NMHSs and the farmers themselves.

- **Demonstrate and quantify the socio-economic benefits (SEB) of climate services for the agriculture sector** and integrate SEB aspects in climate service programmes from beginning to end.

Practice Recommendations

- **Co-production of agrometeorological services from regional to sub-national levels must be supported as a key enabler** for enhanced understanding, uptake and effectiveness of climate services in the agriculture sector.

50 https://focus-africaproject.eu/wp-content/uploads/2024/06/FOCUS-Africa-Policy-Brief.pdf (accessed 09 July 2024).
51 https://www.cgiar.org/news-events/news/a-ccafs-informed-public-private-partnership-reaches-300000-farmers-with-climate-information/

- **It is imperative to understand the user and broader stakeholder landscape**, including their differing needs and challenges in relation to climate services for agriculture.

- **Identifying a range of communication pathways and channels** is often necessary, followed by tailoring these to the specific context.

- **Continue to build capacity of climate services producers, intermediaries, and end-users** to understand the information and make best use of it.

- **Solicit feedback and conduct regular monitoring and evaluation** of the socio-economic benefits of the information provided.

5.3.7 Conclusions

Coproduction remains a key enabler for the design, communication and uptake of climate services in the agriculture sector and can be done at different levels using different methodologies, some that have been used in the ClimSA Programme, like PSP or PICSA. Inclusivity in the approach to coproduction and user engagement is crucial, ensuring that women, youth, the elderly, and marginalised people are engaged and involved to ensure the information is relevant for them and their specific needs and challenges. For this, understanding the user and broader stakeholder landscape and their needs and capacities is crucial. Appropriate packaging and communication of agrometeorological information taking consideration of a range of available communication methods is important, with opportunities to engage and capacity build local media and extension in the process. The capacity building of the agrometeorological divisions of NMHSs is a key need, noting that for the effective communication and uptake of climate services, the capacities of intermediaries and farmers themselves must not be neglected. Partnership building, including public-private partnership between NMHSs and for example ICT service providers presents another opportunity for scale up and sustainability of agrometeorological services.

Looking ahead, the recognition of climate services as a key component for resilience and adaptation in the agriculture sector (and indeed other climate-sensitive sectors) is increasing, as reflected in their inclusion in various NAPs and NDCs. This recognition needs to be supported by enhanced understanding of the socio-economic benefits and the co-benefits of the use of climate services in the agriculture sector in terms of both adaptation and mitigation. This in turn could enhance opportunities for further policy integration and financial support, both from national and regional governments as well as the international climate finance instruments.

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