National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

Understanding, predicting and communicating high impact weather events across Africa

Linda Hirons

ECMWF Annual Seminar 2025 | Bonn, Germany | April 9th 2025

l.c.hirons@reading.ac.uk

Outline

- Where sub-seasonal forecast **skill** and forecast **use** overlap – a co-production approach
- **Skill** – examples of regime-dependent skill, drivers of predictability controlling East African rainfall variability.
- **Use** – examples of co-production from the Global Challenges Research Fund (GCRF) African Science for Weather Information and Forecasting Techniques (SWIFT) sub-seasonal forecasting testbed.
- Taking learning into new projects in Flood and Tropical Cyclone early warning **(ACACIA*)** and Renewable Energy decision-making **(POWER-Kenya*).**

***ACACIA - A**nticipatory **C**limate **A**daptation for **C**ommunities **i**n **A**frica
***POWER-Kenya - P**otential of sub-seasonal **O**perational **W**eather and climate information for building **E**nergy **R**esilience in Kenya

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

SKILFUL

- Sources of predictability
- Regime-dependence

Why? Where? When?

USEFUL

- Support decisions
- Build resilience

How?

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

SKILFUL

- **Sources of predictability**
- **Regime-dependence**

Why? Where? When?

Scientific understanding

Do we understand the **large-scale drivers** that influence African weather on **sub-seasonal** timescales?
[e.g., Madden Julian Oscillation (MJO), El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), land surface conditions, regional SST anomalies]

Do we understand the **link** between the large-scale driver and the **local weather**?
[e.g., through changes in horizontal & vertical wind shear, wind direction, moisture availability, vertical instability].

Modelling

Can models represent the **large-scale drivers**?
Can models also represent the **local response** to large-scale?

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Application

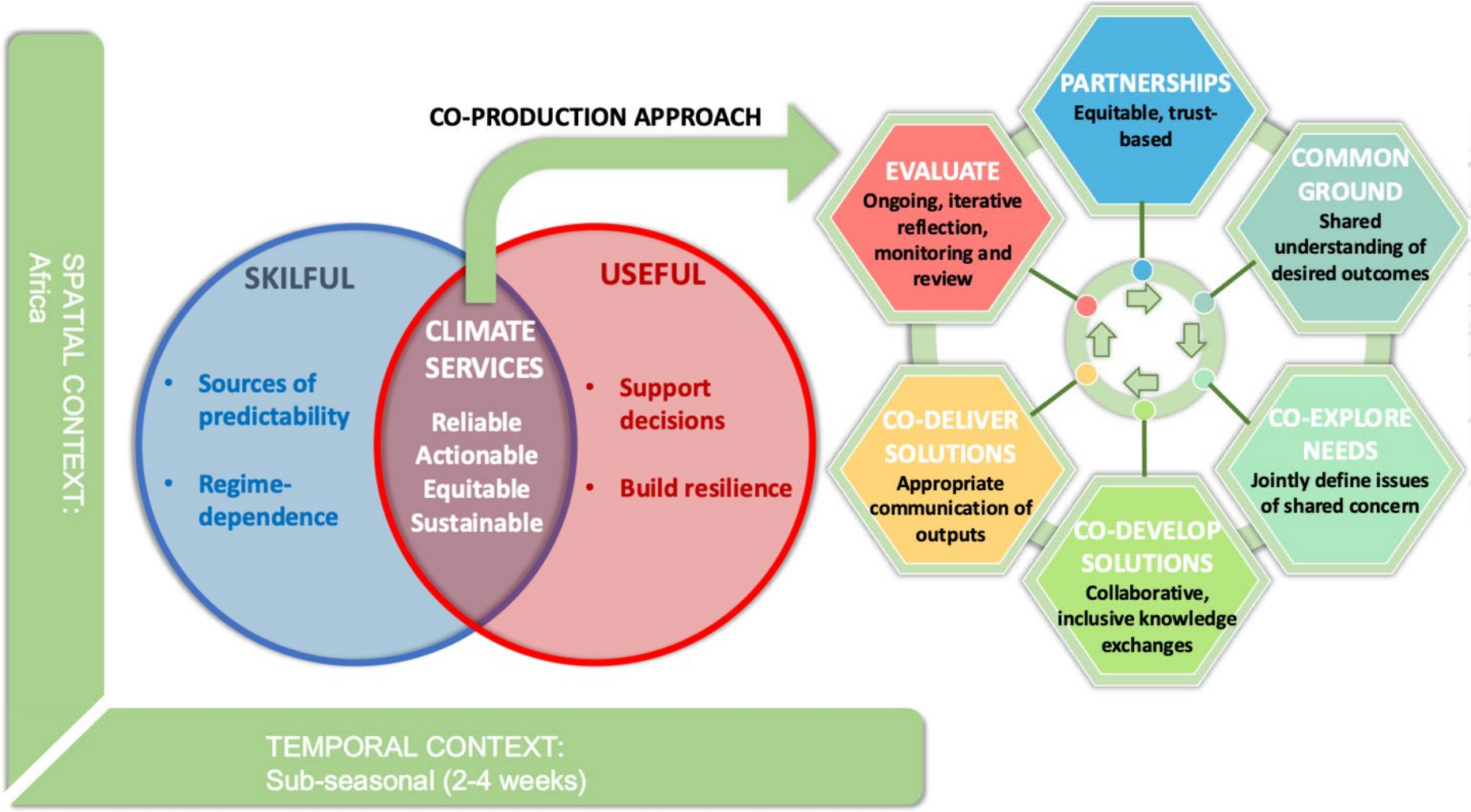
Can we make forecasts useful, useable and used?

fit for purpose

communication
accessibility

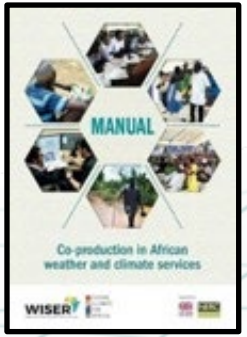
trust
legitimacy
agency

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL


SPATIAL CONTEXT:
Africa
CO-PRODUCTION APPROACH
SKILFUL
• Sources of predictability
• Regime-dependence
CLIMATE SERVICES
Reliable
Actionable
Equitable
Sustainable
USEFUL
• Support decisions
• Build resilience
PARTNERSHIPS
Equitable, trust-based
COMMON GROUND
Shared understanding of desired outcomes
CO-EXPLORE NEEDS
Jointly define issues of shared concern
CO-DEVELOP SOLUTIONS
Collaborative, inclusive knowledge exchanges
CO-DELIVER SOLUTIONS
Appropriate communication of outputs
EVALUATE
Ongoing, iterative reflection, monitoring and review
TEMPORAL CONTEXT:
Sub-seasonal (2-4 weeks)

A co-production approach

Future Climate For Africa (FCFA) Manual for Co-production in African weather and climate services (Carter et al. 2019).



Co-production: brings together different knowledge sources, experiences and working practices to jointly develop new knowledge for addressing societal problems of shared concern.

- *Weather context: transforms users' role from recipient of information to participant in knowledge generation process.*
- *Co-production approach: shifts the emphasis from a supply-driven forecast product to a demand-led process*

Ten principles for good co-production

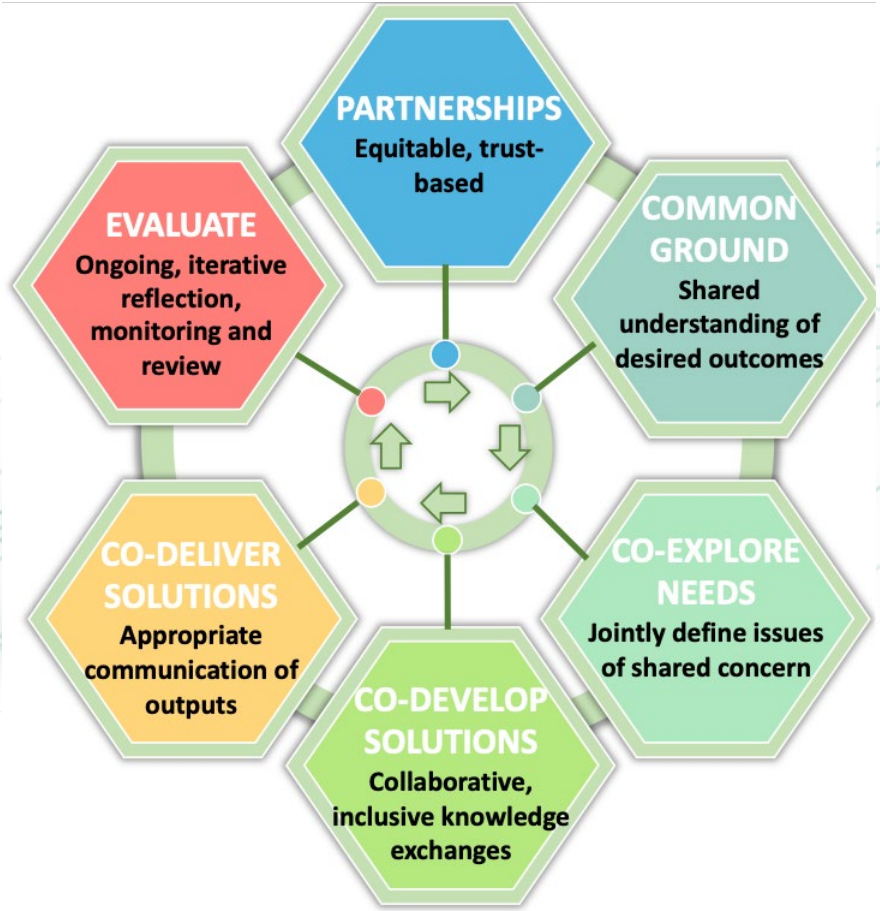
A co-production approach

Co-production: brings together different knowledge sources, experiences and working practices to jointly develop new knowledge for addressing societal problems of shared concern.

Sub-seasonal Forecasting testbeds: a forum where prototype forecast products are co-produced and operationally trialled in real-time. Examples:

- **GCRF African SWIFT** (2019-2021) – S2S Real-Time Pilot.

- **ACACIA** – TC and flood early warning in Madagascar and Ethiopia (2024 – 2028)
- **POWER-Kenya –** Energy (2025- 2027)



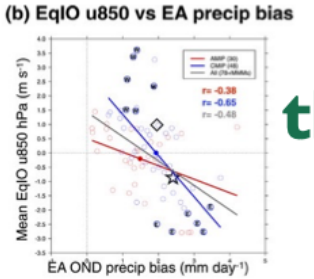
Adapted and synthesized from Carter et al 2019 Manual for Co-production (FCFA)

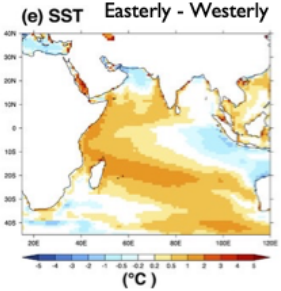
East Africa focus

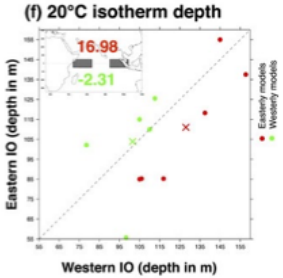
- Oct-Dec (OND) – mean state biases affect teleconnections – Indian Ocean Dipole (IOD)
- Mar-May (MAM) – skill affected by poor response to large-scale driver - Madden Julian Oscillation (MJO)
- Jul-Sep (JAS) – links to subtropical highs

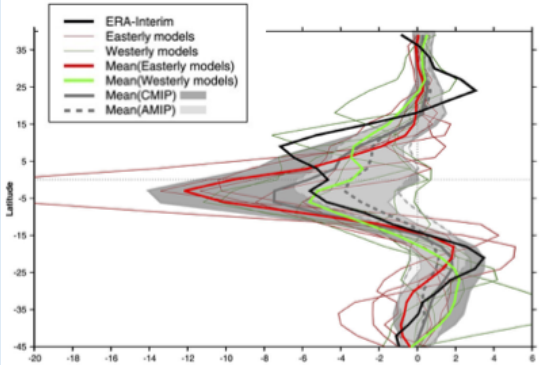
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Mean state biases can affect the interactions between large-scale drivers and local African weather







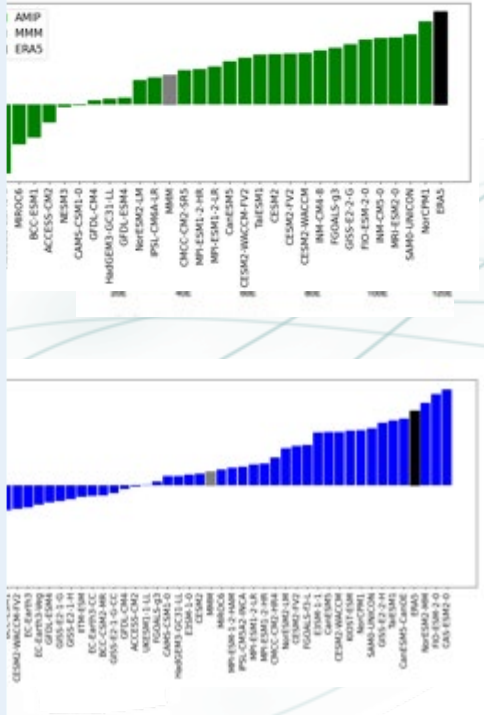


Hirons et al. 2018 [3]

Figure 2: Mean-state bias in EA short rain precip versus Indian Ocean low-level wind. SST and 20°C isotherm depth for Easterly versus westerly IO wind models. Vertically integrated moisture flux (uq) at 56°E regressed onto Indian Ocean Dipole (IOD) index.

Half the models have the mean-state OND winds flowing in the opposite direction (easterly) from observations (westerly). Leading to weaker Walker circulation, warmer coastal SSTs (IOD-like), reduction in SE trades, upward tilt in thermocline towards eastern IO. Easterly models are unable to capture the observed latitudinal structure of moisture advection into EA associated with the IOD.

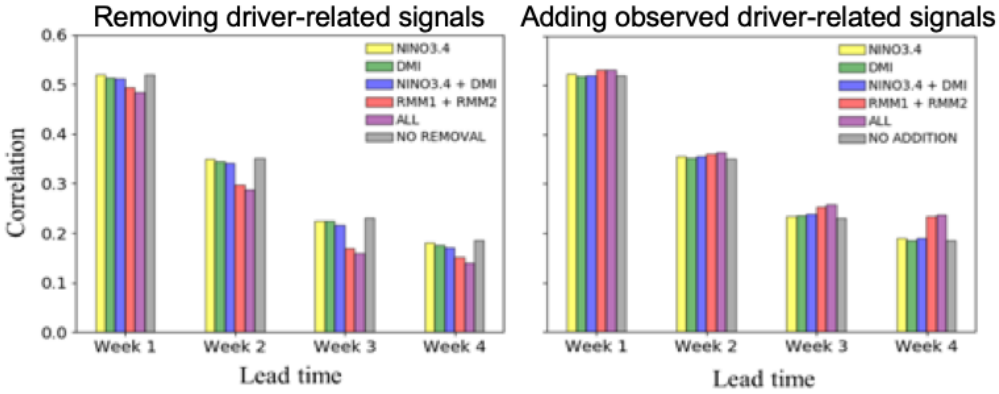
All this results in larger EA short rains wet bias.



Gler et al. 2025 (in prep; UoR PhD student) Exploring IOD in CMIP6 and GloSea6

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

MAM skill



de Andrade et al. 2021 [5]

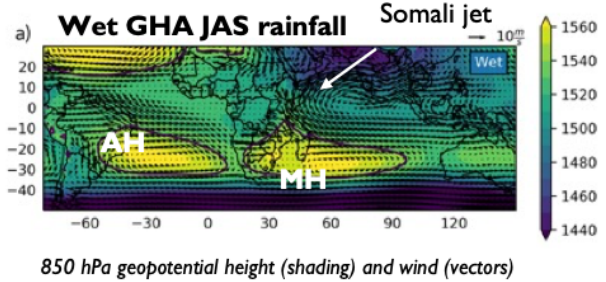
Poor response to large-scale drivers in models affects skill

Figure 4: Modulation of forecast skill by large-scale drivers. East Africa; MAM. ECMWF hindcasts x GPCP

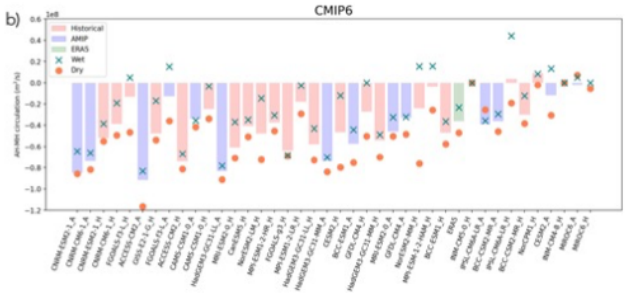
Removing modelled and observed linear response to drivers (ENSO, IOD, MJO) shows role of **drivers** as source of skill. Drop in skill when removing MJO-related rainfall pattern after week 1. Skill improvements after correcting modelled driver-related rainfall patterns using observations (e.g., MJO signal in weeks 3-4). Shows role of poor **response to drivers** as source of skill.

de Andrade et al. 2021

New links between large-scale drivers and interannual variability in African rainfall



850 hPa geopotential height (shading) and wind (vectors)



Dyer et al. 2021 [4]

Figure 3: Drivers of wet JAS rainfall in the Greater Horn of Africa (GHA).
Developed a mixed metric combining strength of Atlantic (AH) and Mascarene (MH) Highs as a driver of JAS rainfall variability over Ethiopia.

Better combined than individual drivers. Linked to changes in Turkana Jet and Central Africa westerly wind flux (CAF). Positive AH-MH associated with increased rainfall.

REACH
Improving water security for the poor

FUTURE CLIMATE FOR AFRICA

UNIVERSITY OF OXFORD

IWMI
International Water Management Institute

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Examples of a co-production approach in practice:

Sub-seasonal Forecasting testbeds: a forum where prototype forecast products are co-produced and operationally trialled in real-time.

- **GCRF African SWIFT** (2019-2021) – S2S Real-Time Pilot.
- **ACACIA** – TC and flood early warning in Madagascar and Ethiopia (2024 – 2028)
- **POWER-Kenya –** Energy (2025- 2027)

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

GCRF AFRICAN SWIFT

SCIENCE FOR WEATHER INFORMATION AND FORECASTING TECHNIQUES

The SWIFT Team

ELSEVIER

Climate Services

Volume 23, August 2021, 100246

Using co-production to improve the appropriate use of sub-seasonal forecasts in Africa

Linda Hirons [a], Elisabeth Thompson [a], Cheikh Dione [c], Victor S. Indasi [c], Mary Kilavi [e], Elias Nkiaka [f], Joshua Talib [b], Emma Visman [b], Elijah A. Adefisan [c], Felipe de Andrade [g], Jesse Ashong [g], Jasper Batureine Mwesigwa [d n], Victoria L. Boult [o], Tidiane Diédhiou [h], Oumar Kante [h], Masilin Gudoshava [d], Chris Kiptum [e], Richmond Konadu Amoah [o], Benjamin Lamptey [f], Kamoru Abiodun Lawal [i j], Richard Muita [e f], Richard Nzekwu [l], Patricia Nying'uro [e], Willis Ochieng [k], Eniola Olaniyan [i], Nana Kofi Opoku [g], Hussen Seid Endris [d], Zewdu Segele [d], Pascal Moudi Igri [m], Emmah Mwangi [p], Steve Woolnough [a]

GCRF

Subseasonal-to-Seasonal S2S Prediction Project

WWRP World Weather Research Programme

WCRP World Climate Research Programme

S2S Real-Time Pilot Initiative [2019 – 2022]

Joanne Robbins (UKMO)

16 projects participating

http://s2sprediction.net/file/documents_reports/16Projects.pdf

SWIFT

ForPAc: Towards Forecast Based Preparedness Action

GCRF AFRICAN SWIFT
SCIENCE FOR WEATHER INFORMATION AND FORECASTING TECHNIQUES

Testbed operational groups;

Hirons et al 2021 https://doi.org/10.1016/j.cliser.2021.100246

Health early warning for Meningitis outbreaks

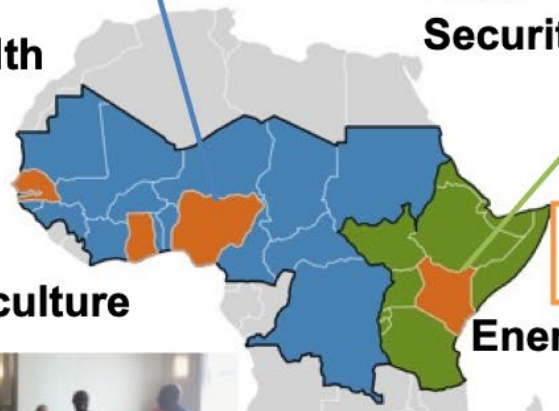
Igri et al. 2023

Food Security and Nutrition planning through regional multi-stakeholder platform

Gudoshava et al. 2022

African Meningitis Belt; ACMAD

East Africa; ICPAC



Dione et al. 2022

Kenya

Energy: Hydropower generation planning

Mutai et al 2021

Senegal

Agriculture: supporting multi-disciplinary planning decisions

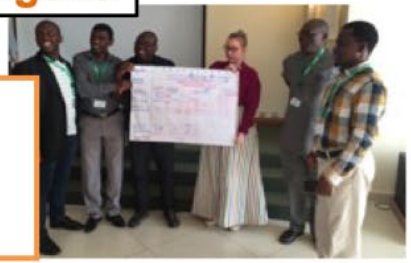
Hirons et al. 2023

Ghana

Providing improved **agricultural** information through national ministry

Nigeria

Lawal et al 202



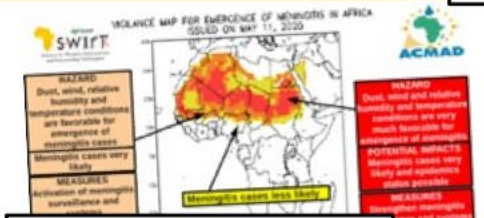
Supporting farmers **agricultural** planning decisions through UN financial institution

NATURAL ENVIRONMENT RESEARCH COUNCIL

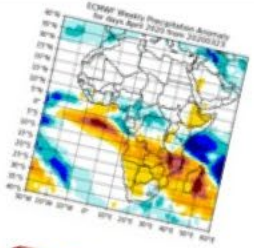
GCRF AFRIC
SCIENCE FOR WEATHER INFORMATI

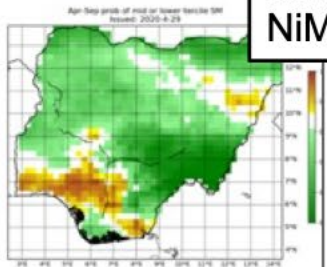
Weekly precip anomalies (all)

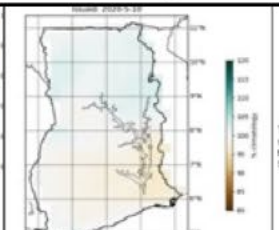
TAMSAT ALERT soil moisture for Nigeria and Ghana (UoR – NiMet, GMet)

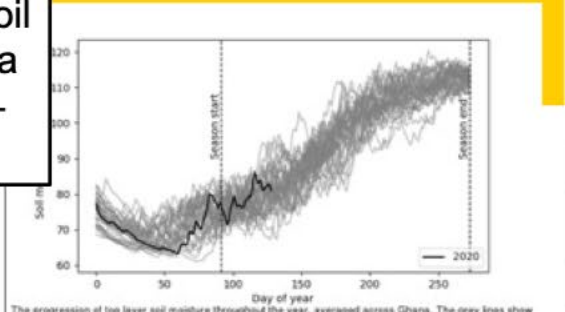


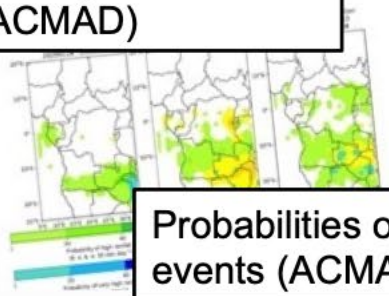
Meningitis bulletins (ACMAD)

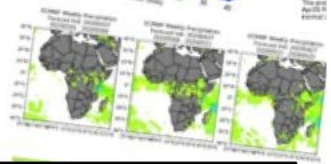




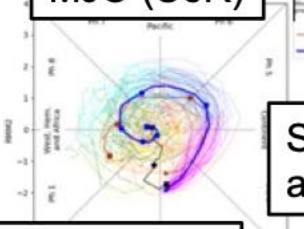


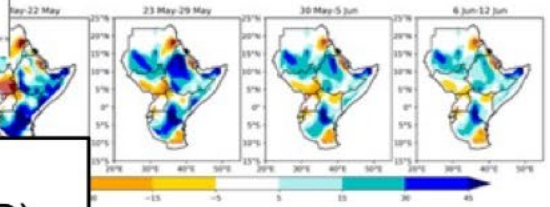






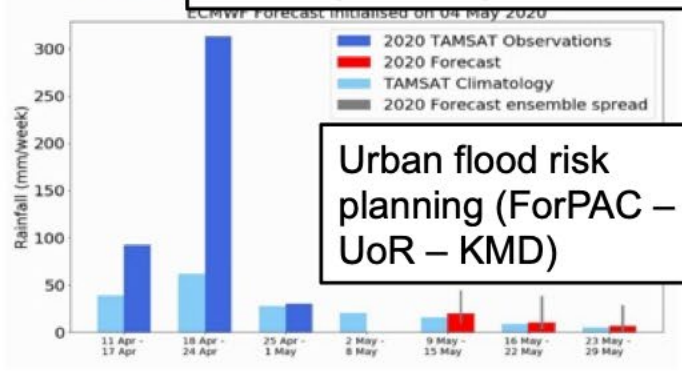
MJO (UoR)





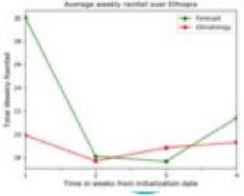
Probabilities of extreme precip events (ACMAD)

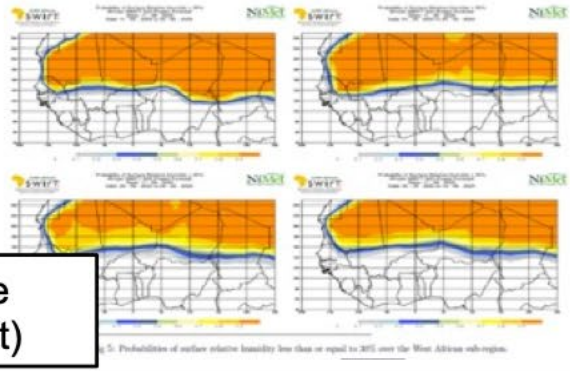
Soil Moisture anomalies (KMD)



Country specific weekly precip (ICPAC)

Urban flood risk planning (ForPAC – UoR – KMD)





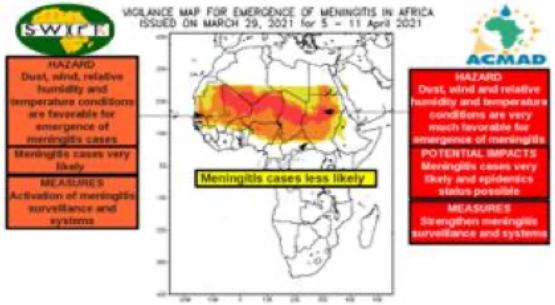
Surface relative humidity (NiMet)

Dione et al 2022; https://doi.org/10.1016/j.cliser.2022.100326

1. Health Case Study: Meningitis Vigilance for the African Meningitis Belt

ACMAD[1] working with WHO[2] to supply bespoke, multi-variable sub-seasonal forecast products for meningitis vigilance across 26 countries in the meningitis belt (~300 million people).

- Used known links between environmental conditions and meningitis outbreaks (temperature, relative humidity, wind speed and direction; lag: outbreaks occur 1-2 weeks after dust events)
- Pre-SWIFT vigilance used observations. With S2S forecast data extended window for preparedness action by 2 weeks. Transformational for early action.
- Direct access to real-time data key to co-developing and implementing user-directed iterations.
- See Dione et al 2022 for details and evaluation. https://doi.org/10.1016/j.cliser.2022.100326



Red: RH < 20%; sfc dust > 400 µg m^{-3}, dmean T > 27°C and wind northerly


Sub-Saharan meningitis epidemics could be signalled by weather forecasts

Pilot scheme is under way to harness forecasts to predict where conditions that fuel cases are likely to develop

A weather-based surveillance system that could offer advanced warning of outbreaks of meningitis is being piloted across sub-Saharan Africa in a bid to

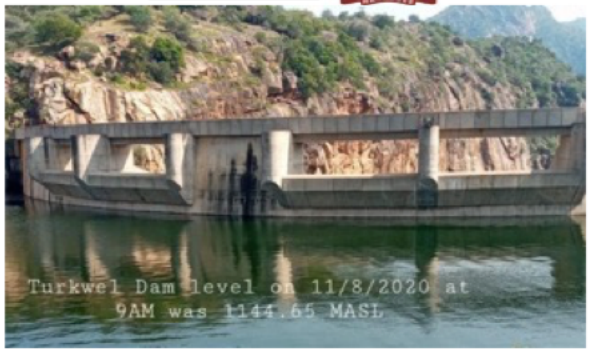
Guardian article

[1]ACMAD – African Centre of Meteorological Applications for Development
[2] WHO – World Health Organization

2. Energy Case Study: Hydropower Generation planning for Kenya

KMD[1] working with energy company KenGEN[2] to supply bespoke forecast products to support hydropower (~45% of total) generation planning.

- KenGEN user involved in the co-production process from the start of the testbed
- Forecasts (e.g., weekly probabilities of user-defined T and precip extreme thresholds) help manage dam levels – maximise levels available for hydropower generation without downstream flooding
- Impact of S2S forecasts during testbed:
  - uninterrupted power for Kenya during testbed
  - eliminated use of emergency diesel generators.



"Because the forecasts help us go through dry periods without losing adequate hydropower generation, we've been able to eliminate emergency diesel generators from the national electricity grid entirely. We're now eliminating thermal power plants, moving closer to 100% renewable energy in Kenya." Chief Energy Planner, KenGEN

[1]KMD – Kenya Meteorological Department
[2] KenGen – Kenya Electricity Generating Company PLC

Co-production lessons taken forward into new projects

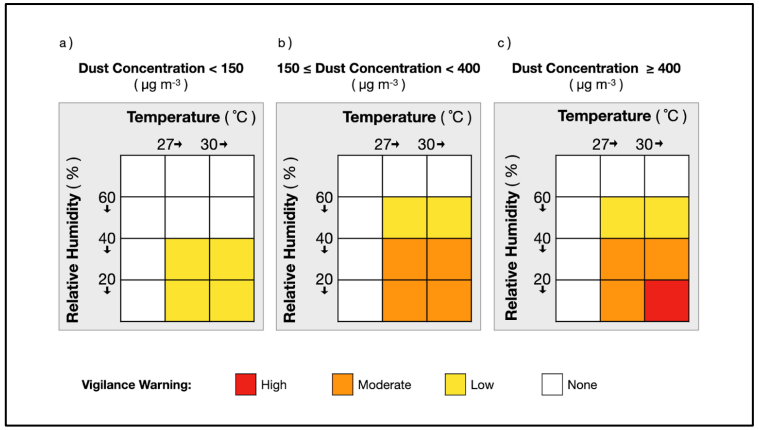
- ***Ensure sufficient resource to support the co-production process***
  Process suffers if sufficient resource is not invested in the early, relationship building stages.

- ***Support capacity building in all groups involved***
  Co-production is a new way of working for many, requires capacity building of all groups. Strengthening decision-makers' understanding of key forecast concepts.

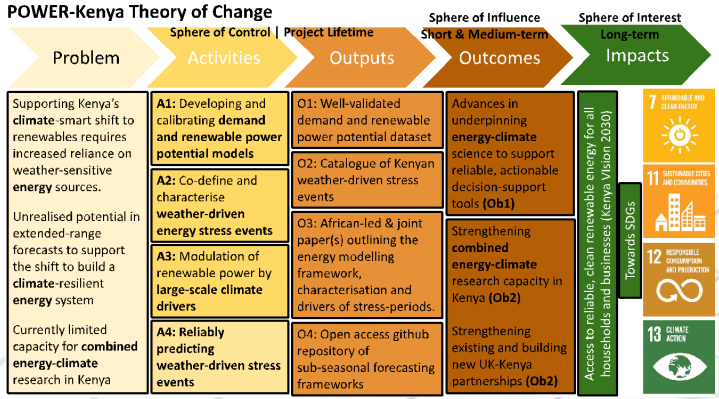
- ***Include decision-makers in forecast evaluation***
  Systematic meteorological verification of new products is key, and ongoing. New product only as useful as the decisions it's able to support, this requires user evaluation. It is an iterative process.

- ***Direct access to forecast data was transformational for African NMHSs***
  Enabling agency to make user-directed iterations.
  e.g. Multi-variable metrics, user-defined thresholds, bespoke visualisation.

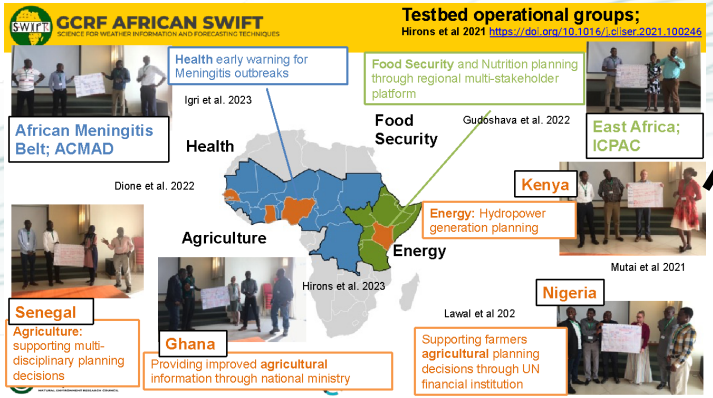
Hirons *et al. 2021* https://doi.org/10.1016/j.cliser.2021.100246



Health: Exploring beyond the ensemble mean; uncertainty of dust; integrating climate thresholds into health operations

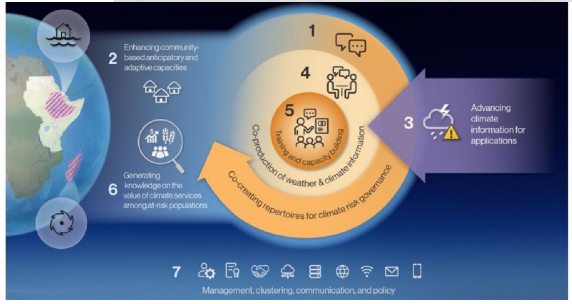


Energy: Moving beyond hydropower applications



Food and Tropical Cyclone Early warning: Applying a co-production approach

ACACIA



POWER-Kenya: Potential of sub-seasonal **O**perational **W**eather and climate information for building **E**nergy **R**esilience in Kenya

UK Research and Innovation

UNIVERSITY OF NAIROBI

KenGen
Energy for the nation.

Newcastle University

UNIVERSITY OF LEEDS

University of Reading

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

POWER-Kenya Theory of Change

Problem	Activities (Sphere of Control | Project Lifetime)	Outputs	Outcomes (Sphere of Influence, Short & Medium-term)	Impacts (Sphere of Interest, Long-term)
Supporting Kenya's **climate**-smart shift to renewables requires increased reliance on weather-sensitive **energy** sources. Unrealised potential in extended-range forecasts to support the shift to build a **climate**-resilient **energy** system Currently limited capacity for **combined energy-climate** research in Kenya	**A1:** Developing and calibrating **demand and renewable power potential models** **A2:** Co-define and characterise **weather-driven energy stress events** **A3:** Modulation of renewable power by **large-scale climate drivers** **A4: Reliably predicting weather-driven stress events**	O1: Well-validated demand and renewable power potential dataset O2: Catalogue of Kenyan weather-driven stress events O3: African-led & joint paper(s) outlining the energy modelling framework, characterisation and drivers of stress-periods. O4: Open access github repository of sub-seasonal forecasting frameworks	Advances in underpinning **energy-climate** science to support reliable, actionable decision-support tools **(Ob1)** Strengthening **combined energy-climate** research capacity in Kenya **(Ob2)** Strengthening existing and building new UK-Kenya partnerships **(Ob2)**	Access to reliable, clean renewable energy for all households and businesses (Kenya VIsion 2030) Towards SDGs 7 AFFORDABLE AND CLEAN ENERGY 11 SUSTAINABLE CITIES AND COMMUNITIES 12 RESPONSIBLE CONSUMPTION AND PRODUCTION 13 CLIMATE ACTION

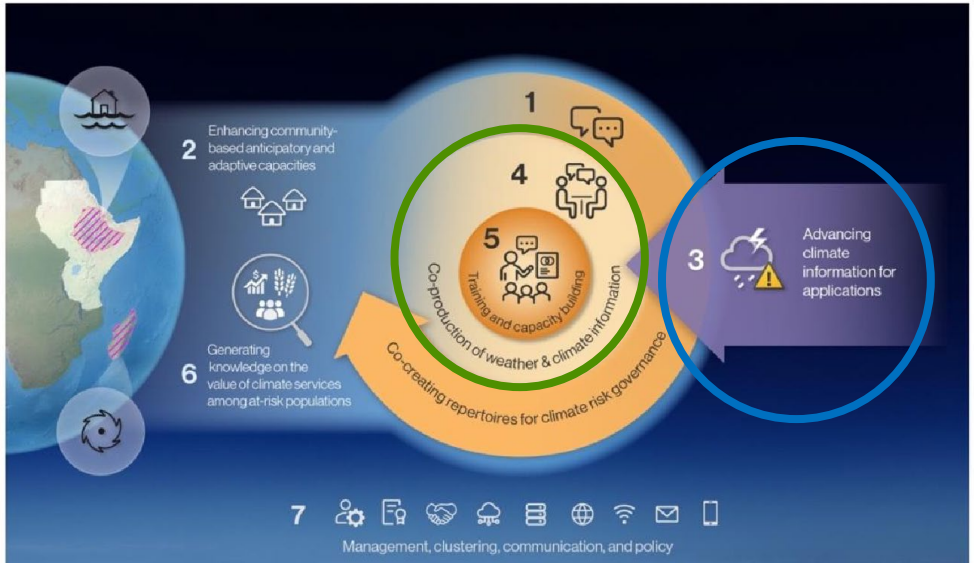
POWER-Kenya: Potential of sub-seasonal **O**perational **W**eather and climate information for building **E**nergy **R**esilience in **Kenya (2025 – 2027)**

- **Kickoff** workshop in Nairobi in March 2025
- Engaging with Kenyan energy stakeholders to **co-define weather-driven energy stress events**
- Workshop outcomes **shape research co-design**
    - Focus on Wind and Solar

UK Research and Innovation

Anticipatory Climate Action for Communities In Africa (ACACIA) WP3 and WP4 Teams

ACACIA (Horizon Europe)
ACACIA is funded by the European Union under Grant Agreement No. 101137847



https://acacia-climate.net

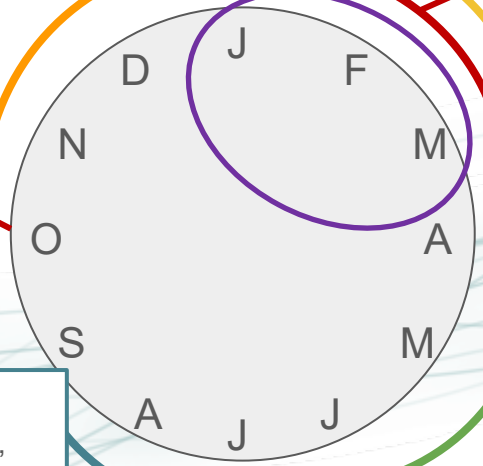
ACACIA WP4: Informing Testbed co-design

Exploring **seasonal calendars** in Madagascar Focus Groups

Evacuation, water collection for storage, reinforce buildings (roofs), remove tree branches, food and candle storage, seed storage for re-planting

Main cyclone season. Radio alerts 3-4 days in advance. Nowcasting - movement of clouds used by elders

Seasonal Outlook before the season



Strong winds and flooding, landslides., debris. Stop fishing. Evacuate to safe zone or just “stay home”, feel “stuck”.
Flooding stops activities: women weaving, brooms; can’t get produce to market. Limited access to products (e.g. soap & petrol). Limited savings for contingency. Sell livestock.

“Back to normal” main activities: tending to fields, accessing markets. Harvest - Jul/Aug; plenty “party months” food & cash available

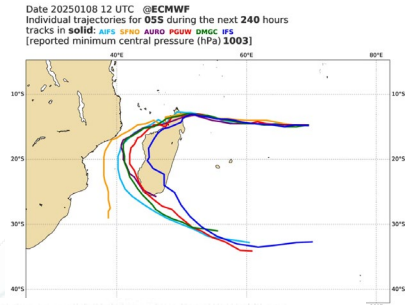
~2 weeks for water to recede and roads passable. Recovery quicker in urban area. Repairing and cleaning damaged housing. Re-planting; make use of moisture- grow new crops on riverbanks (tobacco, sweet potatoes, potato)
Famine and illness: poor water quality - children get diarrhea.

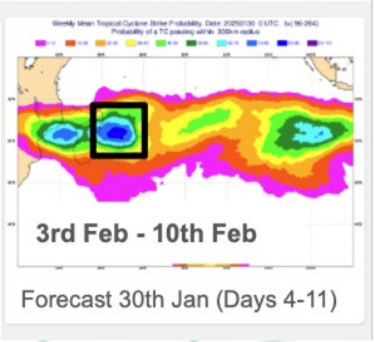
Climate Information | Prepare | During | After | Recovery | Testbed cycle |

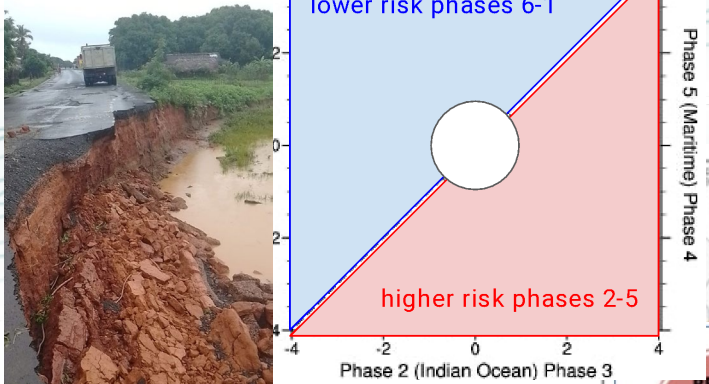
ACACIA sub-seasonal forecasting Testbeds

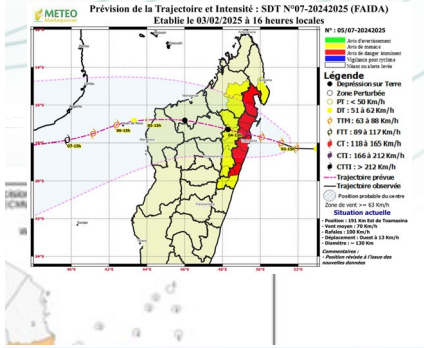
Madagascar
First Baseline Testbed complete: JFM 2025
Weekly online forum between forecast producers (15), forecast users (10) and researchers (13).

Ethiopia
Focus on flooding in the Awash basin during JAS
First baseline testbed in JAS 2025









Summary

- A **co-production approach** is needed to develop reliable and actionable weather and climate services that are equitable and sustainable.

It is important that communities continue to work together in transdisciplinary teams to maximise forecast value.

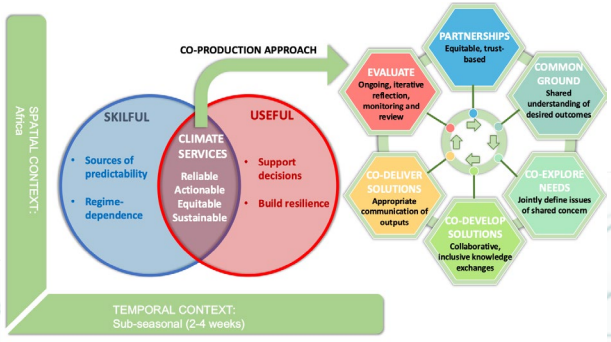
- To do so effectively takes time and resources and **long-term trusted partnerships.**

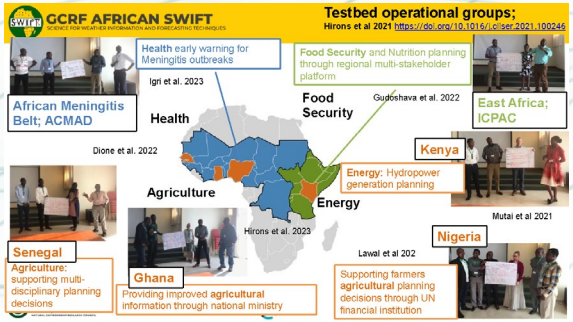
How can we move away from cycles of project funding which perpetuate project-initiated services that are not sustainable?

- **Direct access to forecast data** is crucial for these tools to be locally owned and sustained by African Met services

This does not stop at the data being 'available' but rather working together to ensure sufficient capability to incorporate available data into existing operating procedures.

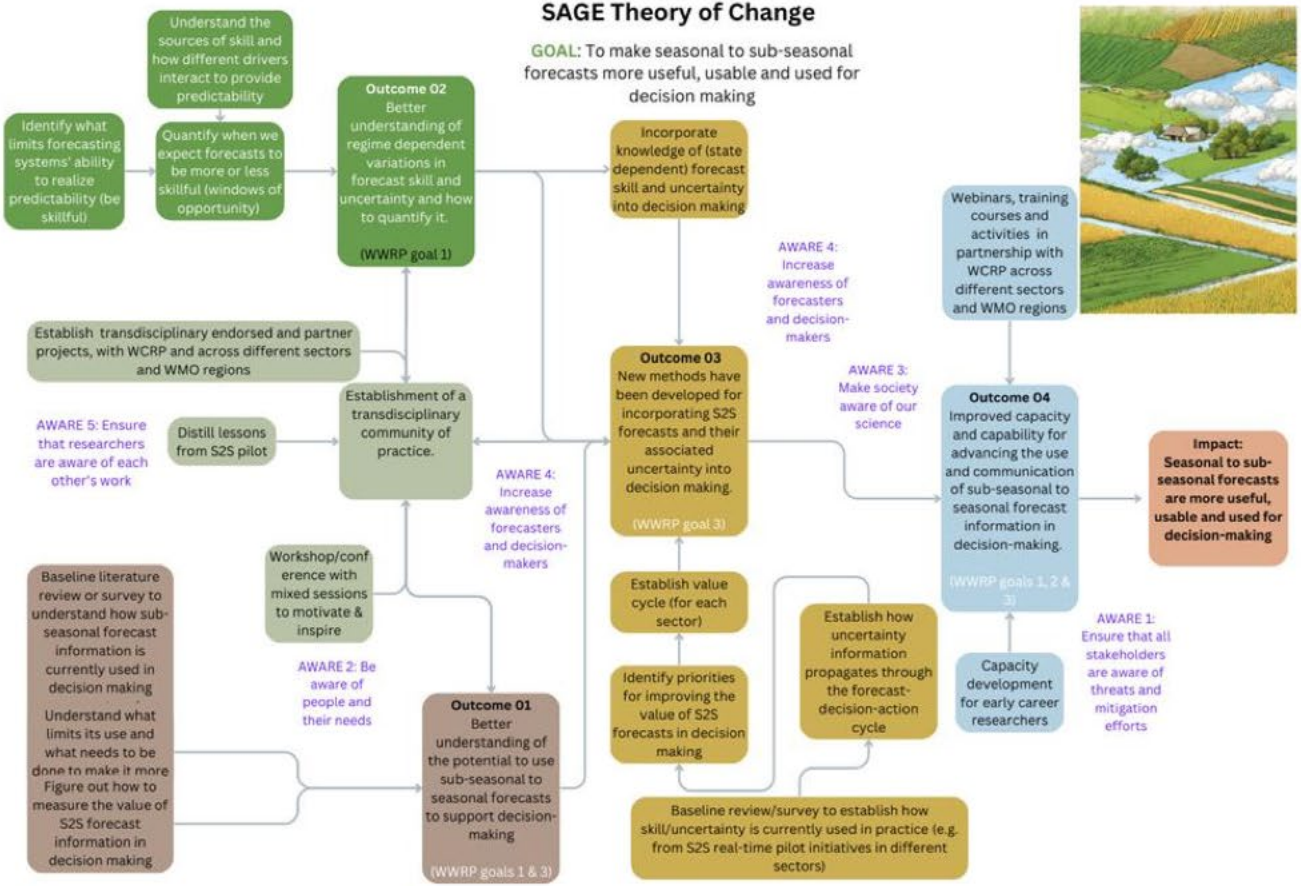
ACACIA/POWER-Kenya PDRA Job opportunity at University of Reading. Deadline 30/04/2025





SAGE Theory of Change

GOAL: To make seasonal to sub-seasonal forecasts more useful, usable and used for decision making



Goal: To make sub-seasonal to seasonal forecasts more **useful, usable, and used for decision-making**

O1: Advance our understanding of how and where sub-seasonal to seasonal forecast information is and can be used to support decision-making

O2: Advance our understanding of the skill and uncertainty and their sources in impact relevant sub-seasonal to seasonal forecasts.

O3: Develop methods for incorporating sub-seasonal forecasts and their associated uncertainty into decision-making and evaluating the worth of forecast information

O4: Develop the community of scientists and practitioners who can advance the use of sub-seasonal to seasonal forecasts in decision-making

WORLD METEOROLOGICAL ORGANIZATION

WWRP WORLD WEATHER RESEARCH PROGRAMME

Sub-seasonal Applications for Agriculture and Environment (SAGE)