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Beneficial and important role of forecasts for agriculture in Africa

Unexpected weather conditions can have devastating effects on crop yields in Africa, which for many African farmers, comprise their sole source of income and subsistence. For example, prolonged dry spells following planting can cause low yields or crops to fail and then require subsequent replanting, incurring additional cost and resource. Heavy rainfall following the application of pesticide or fertiliser can lead to them being washed away, potentially polluting nearby watercourses and necessitating re-application and additional costs. Unseasonably low temperatures, if not properly prepared for, can damage crops and livestock, especially for dairy herds. More broadly, anomalously wet or dry, or hot or cold, conditions can damage crops and livestock in a myriad of different ways, potentially leading to loss of livelihoods and issues around food provision and security. Additionally, other parts of the agricultural value chain are also weather-sensitive, for example, post-harvest activities and access and timing of transportation to market. All these weather-dependent vulnerabilities are heightened in countries in sub-Saharan Africa, where restricted resources limit resilience to respond to unfavourable weather. For example, inadequate resources for irrigation often mean that precipitation is the sole source of water for crops.

Therefore, agricultural planning (comprising decisions on timing of planting, timing of harvest, livestock management, etc.) can greatly benefit from forecast information, especially at longer sub-seasonal lead times of 1–4 weeks ahead (Vitart, 2014; White *et al.*, 2017). Provided this information is reliable and actionable, it can help unseasonal or unexpected conditions be suitably prepared for, and negative impacts on crops and livestock can be minimised. Sub-seasonal forecasts can inform agricultural planning, which has potential to increase yields as well as reduce additional costs for farmers (e.g. of extra seeds and multiple applications of pesticide/fertiliser). More broadly, the provision of sub-seasonal forecasts can enable optimisation across the value chain (including post-harvest procedures and transport to market).

Sub-seasonal forecasts provide forecast information on the 1–4 week timescale and are produced by a number of global weather forecast providers, including the European Centre for Medium-Range Weather Forecasts (ECMWF). Recent work by de Andrade *et al.* (2021) shows that probabilistic sub-seasonal forecasts have reasonable skill out to weeks 3–4 over parts of Africa, with more skilful predictions for ECMWF compared to other global weather forecast providers, and more skill over East Africa compared to other regions, suggesting that S2S forecasts could be used to enhance agricultural planning in parts of Africa.

However, limited capacity within National Meteorological and Hydrological Services (NMHS) across sub-Saharan Africa, coupled with restricted access to sub-seasonal forecast data, has meant that until recently, provision of forecasts on sub-seasonal timescales has been limited, and in most places, non-existent. While forecasts for daily and seasonal timescales (produced by NMHS across sub-Saharan Africa) provide some useful information for agricultural planning, the S2S (sub-seasonal to seasonal) timeframe is highly relevant to agriculture. Previous studies (including Clements *et al.*, 2013; White *et al.*, 2017) have noted a range of uses for sub-seasonal forecasts in agriculture, including crop management and irrigation decisions.

Although sub-seasonal forecasts have been found to be skilful over Africa and could be of immense value to the agriculture sector, limited data availability and capacity within NMHS has meant that previously such products have not been available for the majority of farmers across sub-Saharan Africa. Recently through the Global Challenges Research Fund (GCRF) African SWIFT project (Science for Weather Information and Forecasting Techniques[1]; Parker *et al.*, 2022) and the S2S Prediction project Real-time Pilot Initiative (Vitart *et al.*, 2017; WMO, 2018), tailored sub-seasonal forecast products have been made available to specific users in the agriculture sectors in Kenya and Ghana. Here, we present our experiences of co-producing sub-seasonal forecast products for two different agricultural applications in Ghana and Kenya, including the products produced, examples of how they assist in decision-making and lessons learnt for future applications.

The African SWIFT project and sub-seasonal forecasting testbed structure

The GCRF African SWIFT project was a £9 million initiative aimed at delivering a step change in African weather forecasting capability across hourly to seasonal timescales, as well as building capability to continue forecasting improvements (Parker *et al.*, 2022). A major activity within African SWIFT was a two-year sub-seasonal forecasting testbed (Hirons *et al.*, 2021a). A *forecasting testbed* is a forum where prototype forecast products are operationally trialled

[1]https://africanswift.org

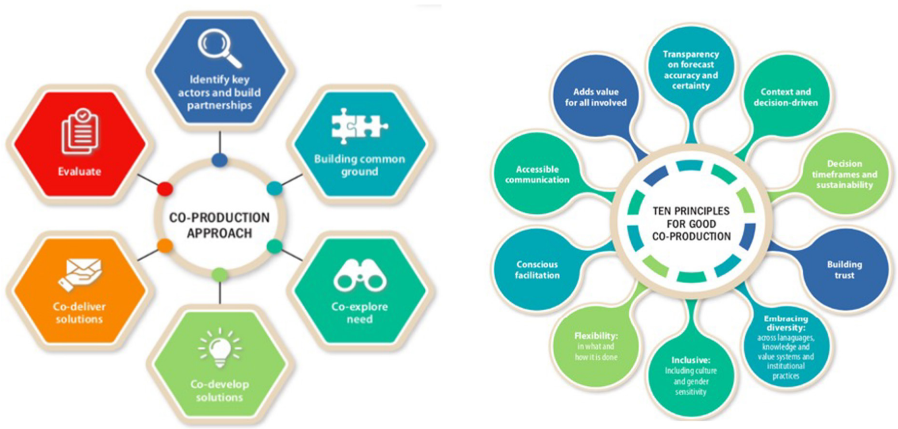

Figure 1. The building blocks and principles underpinning the co-production approach used in the African SWIFT (Science for Weather Information and Forecasting Techniques) sub-seasonal forecasting testbed from Carter et al. (2019).

B1. Identify key actors and build partnerships
In order to form an effective basis for co-production, it is essential to develop equitable, trust-based relationships.
B2. Build common ground
Develop a shared understanding, across actors, of the intention and desired outcomes of the co-production process. Consider competing priorities, managing expectations and capacity development.
B3. Co-exploring needs
Cementing the relationships and understanding between actors. Creating a space where jointly defined issues can emerge.
B4. Co-developing solutions
Solutions to the identified issues are developed through collaborative knowledge exchanges with contributions from a variety of expertise from across the actors.
B5. Co-delivering solutions
Requires agreement about how to communicate the collaborative outputs to ensure they are accessible; that cultural considerations have been taken into account; and that all contributors are appropriately acknowledged.
B6. Evaluate
Importance of scheduling regular time for reflection and monitoring. Additionally, each co-production building block should be evaluative to enable regular review, ongoing feedback and highlight lessons learnt.

Figure 2. The building blocks of co-production after Carter et al. (2019).

in real time. The sub-seasonal forecasting testbed was made up of representatives from the African SWIFT partner organisations, comprising of pan-African (African Centre of Meteorological Applications for Development (ACMAD); Niger) and regional (Intergovernmental Authority on Development (IGAD) Climate Prediction & Applications Centre (ICPAC); Kenya) climate centres, as well as National Meteorological Services and Universities in four SWIFT partner countries: Ghana (Ghana Meteorology Agency (GMet), Kwame Nkrumah University of Science and Technology (KNUST)), Kenya (Kenya Meteorological Department (KMD), University of Nairobi (UoN)), Nigeria (Nigeria Meteorology Agency (NiMet), The Federal University of Technology Akure (FUTA)) and Senegal (National Agency of Civil Aviation and Meteorology (ANACIM), Université Cheikh Anta Diop de Dakar (UCAD)). African SWIFT UK organisations (National Centre of Atmospheric Science (NCAS), UK Centre of Ecology and Hydrology (UKCEH), University of Reading (UoR) and University of Leeds (UoL)) also supported the S2S testbed activities.

The SWIFT sub-seasonal forecasting testbed started with a kick-off workshop in Ngong, Kenya, in November 2019. This workshop brought together forecast users, forecast producers and researchers to co-explore and identify key decisions in a variety of sectors where sub-seasonal forecasts could potentially add valuable information. The sectors represented by the forecast users included health, agriculture, energy and disaster risk reduction. Specifically, it was a chance for forecast producers and researchers to better understand the decision-making context of users and for users to better understand the scope and limitations of sub-seasonal forecasting. Following the kick-off workshop, the testbed ran for a two-year period, with regular interactions and feedback between forecast users and producers in each operational group, with support from the UK team (see Hirons *et al*., 2021a for details). Whilst the sub-seasonal testbed comprised six operational groups from across the SWIFT project working in a variety of sectors, the case studies presented here will focus on agricultural applications in Ghana and Kenya.

Co-production approach

The SWIFT sub-seasonal testbed used the guiding processes and principles outlined in the co-production in African Weather and Climate Services Manual (Carter *et al*., 2019; Figures 1 and 2). Co-production is the process of bringing together different knowledge sources, experiences and working practices to jointly develop new knowledge for addressing societal problems of shared concern (Visman *et al*., 2018). In the weather services context, it transforms the role of the forecast user from recipient of forecast information to participant in the forecast product development process (Vincent *et al*., 2020).

Within each operational group of the sub-seasonal testbed, forecast users, forecast producers and researchers worked together to co-produce new sub-seasonal forecast products tailored to the specific decision-making contexts of their users. Forecast users represented the agriculture, food security, energy and disaster risk management sectors; however, this article focuses on applications in the agricultural sectors of Ghana (Figure 3) and Kenya (Figure 4). Having forecast users involved in the testbed collaboratively from the outset enabled new forecast information to be appropriately tailored to specific decision-making contexts, thereby maximising its relevance for the intended sector.

Sub-seasonal forecast data

As part of the S2S Prediction project Real-time Pilot Initiative (Vitart *et al*., 2017), GCRF African SWIFT, along with 16 other projects, was granted real-time access to sub-seasonal forecast data from selected centres, including ECMWF. Data access was granted for a period of three years from November 2019 to October 2022. The S2S Prediction project is a World Meteorological Organization

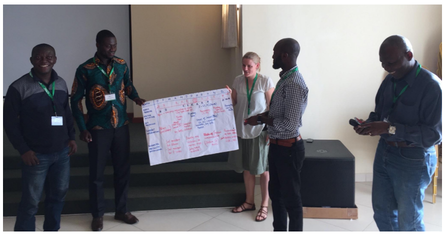

Figure 3. Ghana sub-seasonal testbed co-production group at the kick-off workshop.

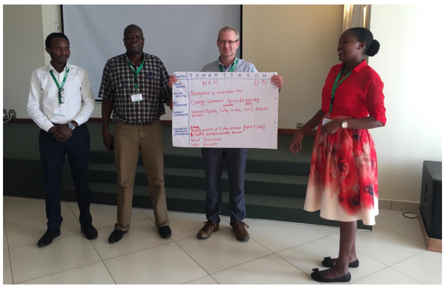

Figure 4. Kenya sub-seasonal testbed co-production group (the Kenyan users pictured here are from the energy sector; agricultural users joined the testbed after the kick-off workshop.

initiative to improve forecast skill and understanding on the sub-seasonal to seasonal timescale and increase the uptake of sub-seasonal forecasts in user decision-making and applications (WMO, 2018; Hirons *et al*., 2021b).

The SWIFT sub-seasonal testbed used real-time forecast data from the operational configuration of the ECMWF model; the real-time data are available from the S2S database at a horizontal resolution of 1.5° (~167km). Meteorologists from the operational groups directly accessed weekly forecast initialisations, which were downloaded on Mondays, with data available on Tuesdays for product development for weeks 1–4. For most groups, week 1 of the forecast (days 5–11) started on the Saturday following the Tuesday on which the forecast data became available. The real-time forecast data were used to create climatologies, probabilistic and deterministic forecast products, as well as subsequent anomalies for a number of different meteorological variables. In order to produce these products, the model climatology was calculated using hindcasts (historical 're-forecasts') of previous years. Consistent with ECMWF operational procedure, the three closest hindcast initialisation dates to the forecast initialisation date are chosen to create a larger, more statistically robust ensemble for these calculations (see Hirons *et al*., 2021a for more detail).

Below we explore the experiences of the co-production process in the Ghana and Kenya operational groups of the sub-seasonal forecasting testbed, followed by a discussion of the overall lessons learnt.

Experiences from Ghana

How the testbed worked in Ghana

The NMHS in Ghana (GMet) created the forecast products, which were sent to the Ministry of Food and Agriculture (MoFA) who distributed these onto agricultural extension officers, who then shared the forecast with local farmers. The agricultural extension workers communicated farmers' feedback to MoFA and the Ghana testbed team (GMet, MoFA and UoR) who were able to iterate the forecast product accordingly. During this trial, the forecasts were mostly communicated to agricultural extension officers and farmers (largely arable rather than pastoral) in the northern region of Ghana.

Pre-testbed status quo

Prior to the testbed, there was no provision of forecast information on sub-seasonal timescales. Agricultural extension workers obtained weather forecasts from GMet, Google Weather, Esoko Weather[2] and ISKA[3], which provide daily, monthly and seasonal forecasts. A range of indigenous knowledge was used to inform traditional weather forecasting methods, including the movements of ants (especially when they carry their eggs to higher lands), the sound of some birds and the flowering of some grasses or plants. Some farmers and extension officers observe the atmosphere in real time for forecasting (heat build-up, cloudiness, sound of thunder, direction of winds and visibility of stars). All these indigenous knowledge-based traditional methods are used for short lead times (nowcasting up to a few days) rather than longer lead times for anticipatory action.

Co-developed solutions

Together, GMet and SWIFT, in collaboration with MoFA, developed three new sub-seasonal forecast products to provide to farmers. Within the testbed, MoFA indirectly represents the farming community; during the kick-off workshop (Figure 3), an extensive network mapping exercise captured the forecast communication pathways between MoFA, extension officers and farmers to ensure effective dissemination of products. All products showed the forecasts for weeks 1, 2 and 3 (days 5–11, 12–18 and 19–25 of the forecast), with week 1 starting on the Saturday following the Tuesday on which the forecast was issued.

[2]https://esoko.com/portfolio/mobile-phones-help-northern-ghanas-farming-families-beat-climate-change/
[3]https://www.ignitia.se/iska

The three initial forecast products comprise (a) a tercile-based probabilistic forecast, which gives the probability of above and below normal rainfall, (b) the weekly precipitation anomaly, which gives the departure of the ensemble-mean weekly rainfall total from the climatological mean and (c) the exceedance probability forecasts, which indicates the probability that the weekly rainfall total will exceed a given threshold (thresholds used were 10, 20 and 50mm, Figure 5).

These products were chosen to serve different needs and requirements. The tercile-based probabilistic forecast was chosen as it presents the information using a similar format and language to the existing GMet seasonal forecast issued at the beginning of the farming season. Therefore, it seemed appropriate to serve as a sub-seasonal update to the seasonal forecast. Adding to an existing communication pathway maximised uptake with the information being better interpreted and appreciated by the farmers and agricultural extension officers than weekly anomalies or exceedance probabilities.

Farmers in Ghana often have a good idea of the normal seasonal rainfall, thus the weekly precipitation anomaly forecast, which shows the numerical departure from the mean, provided them with a good indication of what to expect. For the exceedance probability forecasts, the thresholds used were chosen in discussion with forecast users to be applicable to the weekly amounts of rainfall needed for farming in the various climatic regions of Ghana, thus giving an indication of the likelihood of these important thresholds being exceeded. Figure 5 shows an example of one of these exceedance probability forecasts, for a threshold of 20mm; this shows that in week 1, there is a low (<10%) probability of this threshold being exceeded over Ghana, while for week 3, the probability is much higher. With the real-time data, this sub-seasonal forecast would be updated weekly.

Following discussion in the co-production process, it was highlighted that some users would prefer to receive the spatial maps with interpretation, therefore the forecast plots were supplemented with additional text interpretation, added by forecasters at GMet and forwarded to MoFA for dissemination. The majority of forecast users received the product through email and WhatsApp. Given the remote location of some users, there were instances when they could not access a stable internet service and therefore could not access the forecast. To enable better access to services in remote locations, other methods of communication are also being considered (e.g. SMS), although these come at an additional cost for the service provider, which is an important consideration in the sustainability of new services.

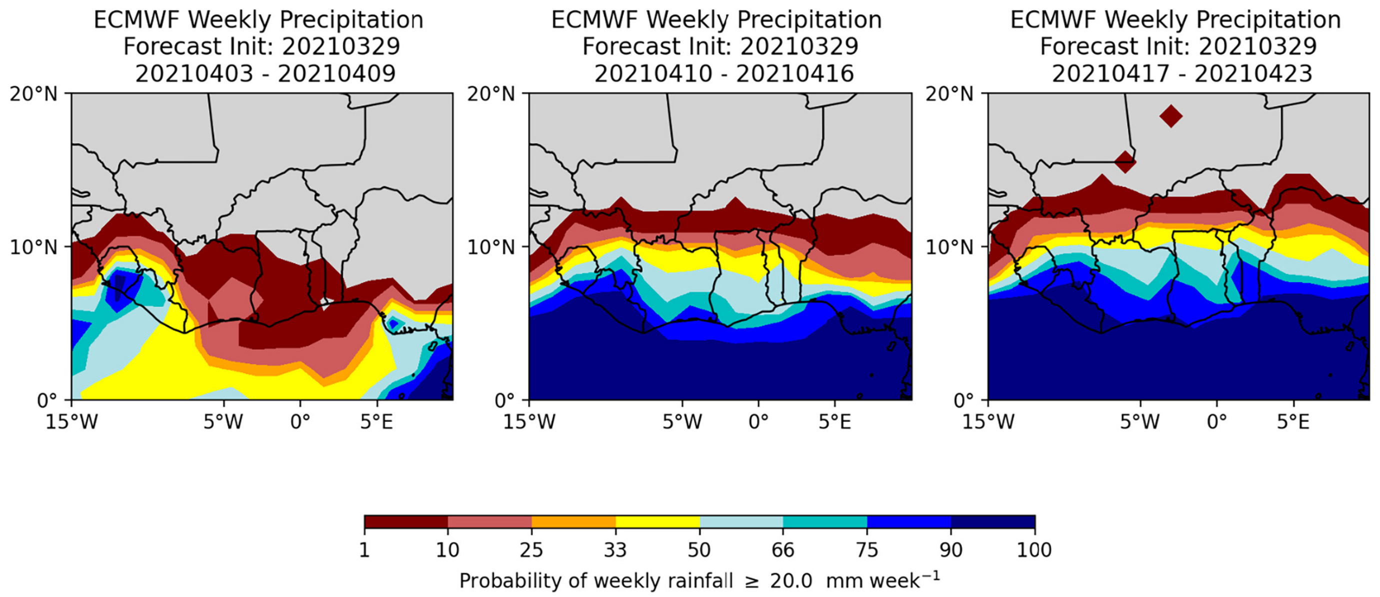

Figure 5. Example sub-seasonal forecast product produced by Ghana Meteorology Agency (GMet) for agriculturalists in Ghana. Forecast issued on 29 March 2021 showing the probability of weekly rainfall exceeding 20mm in weeks 1–3.

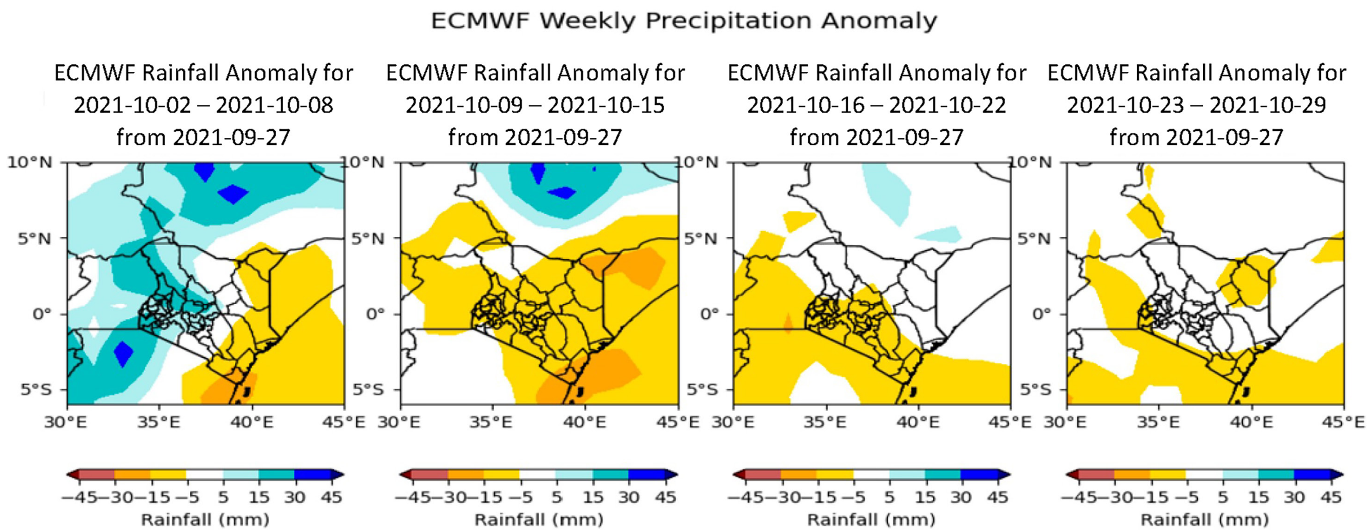

Figure 6. Sample rainfall anomaly forecast generated for inclusion in forecast disseminated to Brookside.

Applications

The majority of agricultural extension officers surveyed (13 out of 15) reported that their farmers found the sub-seasonal forecasts helped to inform their agricultural decision-making in Ghana. Since most of the farmers who received the forecasts in Ghana are arable rather than pastoral, the examples below are specific to arable farming.

Farmers stated that the sub-seasonal forecasts helped them to plan ploughing activities. Farmers do not always have access to ploughing equipment and must make preparations to secure access ahead of time. This means that they require knowledge of when it will rain, as ploughing must be done shortly after rainfall. Furthermore, there must be rain immediately after ploughing, to prevent the soil from hardening again and to aid in seed development. Therefore, sub-seasonal forecasts of rainfall for the next 3 weeks were incredibly useful in helping farmers to plan the best time to obtain access to ploughing equipment and plough their farms.

Other farmers stated the sub-seasonal forecasts helped them to plan when to apply pesticide. There have previously been scenarios when farmers have had to incur double costs of pesticide application because the first application was washed away by unexpected rains. Informed by the forecast of impending rainfall, one particular farmer delayed a pesticide application, thus avoiding polluting nearby watercourses as well as saving the costs of a wasted application.

Another group narrated that the forecast helped them to decide on when to dry their farm produce to prepare it for transportation to market or further post-harvest activities and processing. For example, effective post-harvest drying requires uninterrupted, or consistent periods of sunshine for at least a few days (total drying period also depends on crop type). If the S2S forecasts showed a consistent period of dry weather and sunshine, this helped inform when to start the drying process.

Other farmers and agricultural extension officers reported that farmers were able to use the sub-seasonal forecast to plan when to start clearing their land and preparing them for the planting season.

Challenges and potential future directions

Generally, users found the new sub-seasonal forecast products useful; however, some agricultural extension workers (2 out of 15) reported that they had difficulty interpreting the forecast information without direct explanation. Possible methods to overcome this should include additional training and improved iterative interaction between MoFA and GMet to develop user-informed changes to the visualisation and communication of the forecast information. The former will enable the forecast information to stand alone without the need for expert guidance in interpreting it, while the latter is crucial to making new services useful and beneficial for users' needs. Diversifying the modes used to disseminate the forecast, for example via SMS, may increase access and uptake in the most remote regions. However, effectively reducing all the complex information, and uncertainty, from a sub-seasonal forecast into a short text format remains very challenging.

Experiences from Kenya

How the testbed worked in Kenya

Meteorologists from KMD shared the new co-produced S2S forecast products with forecast users in the energy[4] and agricultural sectors. As in Ghana, the focus of this section will be the agricultural case study; details of the energy-sector interactions can be found elsewhere[5]. In contrast to the government ministry forecast user in Ghana, the Kenya example is a private dairy processing company called Brookside Dairy Limited. It is the largest milk processing company in Kenya and controls approximately 45% of the dairy market. The company's products include fresh and powdered milk, cream, butter and yoghurt, and are distributed across the whole East African region to countries such as Tanzania, Uganda, Rwanda and Burundi. Brookside Dairy was identified as a user for this S2S forecasting testbed because their planning decisions for production and transportation are weather-sensitive, and improved forecast information on sub-seasonal timescales has huge potential to inform production and supply.

Pre-testbed status quo

Prior to the GCRF African SWIFT, S2S forecasting testbed KMD produced monthly forecasts that were disseminated to all users from all sectors. The forecast included sector-specific sub-sections for key sectors within the country that rely on weather and climate information. These bulletins included expected impacts and advisories. For example, in the event that the forecast being issued indicates above normal rainfall, regions potentially prone to flooding and landslides would be highlighted, as well as the expected disruption to transport links.

Prior to the testbed, KMD did not have a direct relationship with Brookside. As with KMD's other forecast users, Brookside would access the general monthly forecast information, available via a mailing list and the KMD website. However, even before the testbed Brookside were a proactive forecast user and would directly contact the KMD customer support service if information was late or required clarification.

Co-developed solutions

During the sub-seasonal forecasting testbed, Brookside had access to a number of bespoke forecast products in addition to the existing monthly bulletin. The real-time data were accessed on Tuesdays with the sub-seasonal bulletin ready to send to Brookside between Wednesday and Friday each week. Each week the bulletin included: (a) weekly average temperature and rainfall anomaly forecast out to a 4 week lead time, (b) monthly average rainfall anomaly forecast, (c) probability of extreme rainfall (both very heavy and very low) and (d) a 3-week tercile forecast of the probability of above or below normal rainfall. Spatial maps (e.g. Figure 6) of these forecast products for weeks 1 (days 5–11), 2 (days 12–18), 3 (days 19–25) and 4 (days 26–32) are compiled into a bulletin with added text explanation of the maps.

Applications

As a weather-sensitive industry, Brookside used these sub-seasonal forecasts to make timely planning decisions around their production and logistics. Temperature forecast information is important for decisions around the quantity of milk to be purchased from farmers and logistically whether the transportation of milk requires refrigeration. Rainfall forecasts give an indication of the state of the pasture in the weeks ahead, information that directly influences the likely quantity of milk supply. Rainfall forecasts also inform logistic decisions by providing information on the state of the roads and transport links to regions where the farmers are located.

In-company planning meetings occur at Brookside on Saturdays so the arrival of the weekly S2S forecast information between Wednesday and Friday of the preceding week is useful and timely to be integrated into this existing discussion and decision-making process. Linking with existing structures of decision-making in this way maximises the uptake and usefulness of forecasts for anticipatory action.

Challenges and potential future direction

New sub-seasonal forecast products have been generally useful for informing planning decisions for Brookside dairy. However, there have been instances of user requests for simplification of information to ease their interpretation and application of products. The co-production process is inherently iterative – continually journeying through the co-production building blocks (Figure 1). However, collating regular user feedback and evaluation has been an ongoing challenge, but has improved significantly as the testbed has gone on. Owing to the very particular nature of Brookside's operation within the agricultural sector, they need very specific products that have never before been produced for them, this creates a challenge in developing methods and software to create those products. On the other hand, this same challenge provides the opportunity for capacity building and improvement of scripting experience of the forecasters.

Concluding remarks and lessons learned

This article describes the development and application of new sub-seasonal forecasting products in the agricultural sectors of Ghana and Kenya. Using a co-production approach transforms the role of the forecast user from merely a recipient of forecast information to being involved in the forecast product development process (Vincent *et al*., 2020). Such an approach aims to make forecasts more useful and actionable in the decision-making contexts for which they are designed. These case studies from the agriculture sectors in Ghana and Kenya present an interesting comparison because of the diverse nature of the forecast users involved: national-level government ministry in Ghana and private sector business in Kenya. Here, we can reflect on the impact of having direct access to raw sub-seasonal forecast data to co-develop new products in each of these contexts.

In the Ghana case, the user was a national-level government ministry trying to incorporate sub-seasonal forecast information into an existing pathway of forecast information on other timescales (e.g. via agricultural extension officers). Using established networks for communication has many benefits: it increases the likelihood that the information will be seen, it ensures uptake because the information is coming from a trusted source and it enables a consistent storyline with other existing products (such as daily/monthly forecast products). However, it is very hard to identify exactly how and if the new sub-seasonal information is actually being incorporated into decision-making for preparedness action. This is partly due to the scale of the collaboration being currently at the national level. Receiving better, more specific feedback to improve sub-seasonal forecast information in the future would

[4]KenGen (Kenya Electricity Generating Company PLC) is the forecast user for the energy sector.
[5]https://africanswift.org/2021/07/07/weather-forecasts-prevent-kenyas-electricity-blackouts/

require resources to engage more directly with the agricultural extension officers, and through them rural farmers, in each sub-region. Having more resources to explore the co-production process along the entire communication chain would improve the forecast users understanding of the potential of sub-seasonal information and also improve the forecast producers understanding of the context of agricultural decision-making. This would help inform where to prioritise resource in the future to continue SWIFT-initiated services.

In Kenya, the new direct partnership with a private sector business is a new pathway for bespoke sub-seasonal forecast information. On the one hand, this is advantageous because it is a direct collaboration with a proactive user who is clearly using and incorporating the new sub-seasonal forecast products straight into their decision-making processes. However, on the other hand, it is a resource-intensive way to benefit one business in the region and therefore, not easy to scale and apply to other users. Ensuring that the collaboration is documented through developing sub-seasonal standard operational procedures will go some way to making new knowledge institutionalised and scalable. Furthermore, there is potential with private sector business partners, such as Brookside, to establish networks that recognise the benefits of access to sub-seasonal forecast information and would be willing to contribute financially to ensure sustainable service after the lifetime of a project like SWIFT.

In summary, some key lessons have been learnt from these case studies about how the co-production process can improve the approach, application and agility of sub-seasonal weather forecasts to support agricultural decision-making in Ghana and Kenya:

- *Approach*: Using a co-production approach effectively is resource-intensive and requires investment in the process as well as its outcomes. For co-production to be institutionalised as a method for weather and climate services, future workload models need to allocate sufficient resource to the process (Visman *et al*., 2022).
- *Application*: A co-production approach has highlighted that involving forecast users in the product development process can improve both how the information is used and applied in decision-making and the timeliness of its delivery. To realise the potential added benefit that user-interaction can have requires building better relationships with users from the start of and throughout the process to enable consistent dialogue that can iteratively improve services.
- *Agility*: Direct access to the underlying sub-seasonal data has enabled in-country forecast producers to co-develop bespoke forecast products with users. This is something that would not be possible with 'off-the-shelf' forecast products provided by modelling centres who are unaware of their likely application. For continued development and maximised agency, it is imperative that NMHSs continue to have access to the underlying data rather than forecast products.

While many studies have highlighted the theoretical utility of sub-seasonal forecasts for agricultural applications (Vitart, 2014; White *et al*., 2017), the SWIFT sub-seasonal testbed has shown a strong desire for this information from agriculturalists in Kenya and Ghana, a willingness to incorporate this information into their decision-making processes and a range of potential decisions that this information may be beneficial for. This article shows the benefit that access to sub-seasonal forecast information can have in building more resilient livelihoods across the African continent (Hirons *et al*., 2021a,b; Visman *et al*., 2022).

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