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Application of real time S2S forecasts over Eastern Africa in the co-production of climate services

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ABSTRACT

A significant proportion of the population in Sub-Saharan Africa are vulnerable to extreme climatic conditions, hence there is a high demand for climate information. In response to this need, the Global Challenges Research Fund African Science for Weather Information and Forecasting Techniques has been undertaking a two-year testbed to co-produce tailored forecasts for different sectors using the sub-seasonal to seasonal forecast datasets from the sub-seasonal to seasonal Real Time Pilot Initiative project. Sub-seasonal forecasts are essential for early warning and informed decision-making in the agriculture and food security sector. This study summarises the co-production process of climate services between the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre and the Food Security and Nutrition Working Group for Eastern and Central Africa, highlighting the importance of efficient communication as well as the lessons learnt and challenges faced in the co-production process. A case study approach is utilised to evaluate the model performance. Two contrasting case studies, one for an extreme rainfall event in week three in April and another for the evolution of tropical cyclone Gati were conducted for the year 2020. Skillful and timely climate information and services co-produced has the potential to increase the uptake, ownership, and appropriate use of sub-seasonal forecasts for resilience building in Eastern Africa.

Practical Implication.

In the past decades Eastern Africa has been plagued by numerous climate related disasters including flooding and drought. Eastern Africa has a relatively dry tropical climate with a high percentage of the region being arid or semi-arid. To properly plan for these events there is need for provision of weather and climate forecasts. Traditionally forecasts have been mostly issued out at short range and seasonal timescales. Creating a glaring gap in the provision of forecasts between the short-range and seasonal forecasts, thus raising the need for sub-seasonal forecasts. Sub-seasonal forecasts bridge the gap between the short-range and long-range forecasts and are critical for informed decision making in the agricultural and disaster risk reduction sectors over Eastern Africa.

Here we propose utilisation of a co-production process to increase sub-seasonal forecast uptake over Eastern Africa. The co-production is implemented through a two-year testbed under the Global Challenges Research Fund African Science for Weather Information and Forecasting Techniques. The IGAD Climate Prediction and Applications Centre collaborated with the Food Security Nutrition Working Group (FSNWG) for Eastern and Central Africa in the co-production process. The FSNWG coordinates regional food security, and nutrition updates to

Abbreviations: FSNWG, Food Security and Nutrition Working Group; S2S, Sub-Seasonal to Seasonal.

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planners and decision-makers (e.g in disaster and risk reduction, agriculture, livestock sectors). In the region the main drivers of food insecurity include climate, conflict and macro-economic drivers. The European Centre for Medium Range Weather Forecasts (ECMWF) model outputs are utilized to derive the forecast information. The co-produced products include weekly total rainfall, rainfall anomalies, probability of exceedance, soil moisture anomalies, maximum and minimum temperature anomalies and also the maximum wet and dry spells. The forecast information is disseminated through bulletins and also during the monthly FSNWG plenary sessions. Sharing of the sub-seasonal forecasts in the monthly meetings allows for further direct interaction between the climate information users and producers. The forecasts are mostly used for crop choice, planting timing, drought risk, flood risk, disease outbreaks, early assistance appeals, disaster relief preparation, and early warning with drought and flood risk tied on top decisions made.

One major challenge that is often faced by climate producers and users is the communication of the forecasts. In this study the challenge is addressed by incorporating a communication and user service team based at ICPAC. The communication and user service team is composed of social scientists, climate information experts and journalists. Improved communication is fundamental in increasing the uptake of the sub-seasonal forecasts and appropriate use of these climate products by climate information users. In consequence the communication and user services team at ICPAC simplifies the language that is utilized in the forecast bulletins and also improves on the layout of the bulletins. This improves the readability and usage of the forecast outputs. For example, initially forecast bulletins were written in paragraph format, which potentially makes the readability of the document harder. Hence, it was suggested that the forecast bulletins be produced in bullet point form.

To evaluate the model a case study approach is utilized for two extreme events that occurred in 2020. One case focused on an extreme rainfall event in week 3 in April and another for the evolution of tropical cyclone Gati. Tropical cyclones that make landfall over Somalia are rare during the October-December season. Results showed that the model is able to capture the wet anomalies for both case studies, hence giving an indication to stakeholders of potential flood risk. However, the model underestimates the rainfall intensity over the region thus use of anomalies might provide more information on the risk of flooding or extended dry spells in comparison to the total rainfall.

In conclusion this study has shown that the S2S forecast information have a potential to provide early warning systems and hence, increase the Eastern Africa community resilience. However, to ensure long term viability of the co-production process there is need for continued support in access to the real time S2S forecast datasets.

Introduction

Extreme climatic events pose a high risk to human livelihoods; in some cases, the impacts can be fatal (e.g. Ashley and Ashley, 2008; Watts et al., 2019). A significant number of sectors including agriculture, water, health, energy, infrastructure, and transportation, among others, are climate-sensitive and are impacted negatively by periodic shocks that have lately increased in frequency and intensity. The increased frequency and intensity of weather and climate extremes such as droughts, increased dry spells, floods, and heat waves in the recent decades across Eastern Africa have led to the disruption of livelihoods (e.g., Funk et al., 2008; Mwangi et al., 2014; Ceccherini et al., 2017; Nicholson 2014; Kilavi et al., 2018). The frequency and magnitude of these extremes is projected to increase with the increase in atmospheric greenhouse gases (e.g., Osima et al., 2018; Vogel and Meyer, 2018; Ajayi and Ilori 2020; Gudoshava et al., 2020; Haile et al., 2020; Ogega et al., 2020; Wainwright et al., 2021). Thus, there is a clear need for improved early warning systems over the region. Currently most forecasts over the region are provided at short range (hours to days) or seasonal timescales, however limited products are available at sub-seasonal timescales (2 weeks and beyond) potentially creating a gap in provision of early-warning systems.

Sub-seasonal forecasts bridge the gap between short-range forecasts and long-range forecasts (seasons to years; Vitart et al., 2012; Robertson et al., 2015; Vitart and Robertson, 2019). These forecasts are especially important for operational and strategic decision-making such as procurement of disaster related supplies, hedging for high energy demand, flood warnings, and irrigation scheduling in different sectors including the agricultural sector (White et al., 2017; Baker et al., 2019). In Eastern Africa approximately 70 % of the population (NEPAD 2013) depends directly on agricultural productivity for their livelihood. This region has vast arid and semi-arid areas, with only parts of Ethiopia, most of Uganda, western South Sudan, Burundi, Rwanda and parts of Tanzania being dry sub-humid to humid (Fig. 1). Pastoralism is majorly practised in the arid regions, while agro-pastoralism and agricultural activities are practiced in the semi-arid and humid regions (Coughlan de Perez et al., 2019). The high dependence on rainfall in the arid and semi-arid regions of Eastern Africa increases their vulnerability to food insecurity (Coughlan de Perez et al., 2019). The magnitude of vulnerability to climate shocks in the region was evident during the 2010/2011 drought crisis, which affected nearly 12 million people in Somalia, Kenya,

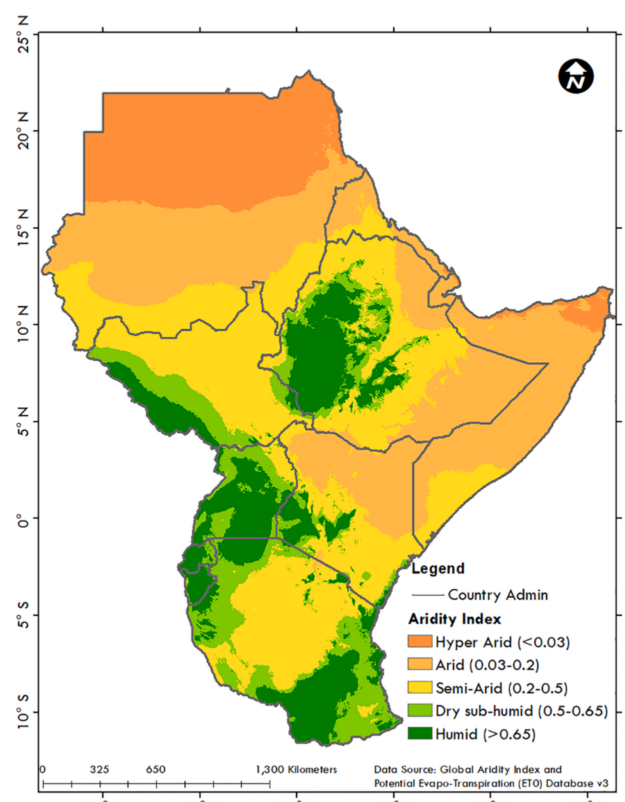

Fig. 1. Aridity Index over Eastern Africa utilising the Global Aridity index data.

Ethiopia and Djibouti (Dutra et al., 2013), and the three consecutive failed rainy seasons (October-December 2020, March-May 2021, and October-December 2021) that as of March 2022 has left approximately 29 million people food insecure (https://www.icpac.net/fsnwg/fsnwg-drought-special-report-apr). Thus, it is critical to provide tailored and reliable sub-seasonal forecasts that can complement the seasonal forecasts to aid agricultural decision-making and build more resilient societies.

In an effort to increase the use of sub-seasonal forecasts for decision-making the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP) granted access to real time Sub-seasonal to Seasonal (S2S) forecasts, via the S2S Real Time Pilot Initiative, to 16 projects (https://www.s2sprediction.net/). The Global Challenge Research Fund (GCRF) African Science for Weather Information and Technology (SWIFT) was one of the projects granted access to the datasets and embarked on a two-year sub-seasonal to seasonal (S2S) testbed (https://africanswift.org/testbed-2/; Hirons et al., 2021; Parker et al., 2022). As part of the GCRF African SWIFT project the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC) accesses the real time S2S datasets. Forecasting testbeds serve as a forum to generate sound interaction between stakeholders (e.g. forecasters, academics and climate information users). Forecasting testbeds are recognised as a key tool to improve weather predictions worldwide (e.g. Ralph et al. 2013). The two-year S2S testbed commenced in November 2019 with a one week kick-off meeting between researchers, forecasters and users of sub-seasonal forecast information. Utilising co-production methodology throughout conceptualisation, planning and iterative implementation, this testbed aims to co-produce user-tailored forecasts with various stakeholders for improved early warning systems over East and West sub-Saharan Africa (Hirons et al., 2021).

Co-production promotes a two-way demand-led iterative process of producing user relevant climate information rather than the traditional scientist-led production of climate information (Lemos and Morehouse 2005; Vincent et al., 2018). It has been shown that co-production increases the uptake and use of the forecasts (eg. Meadow et al. 2015), increases trust and capacity for informed decision-making (eg. Lemos and Morehouse, 2005; Lemos et al., 2012)). Although co-production is still in its infancy in the developing world (Kruk et al., 2017; Vincent et al. 2018) it has been utilised successfully in some parts of sub-Saharan Africa (e.g. Steynor et al., 2016; Conway and Vincent, 2021; Carter et al., 2019; ICPAC, 2021), with co-production leading to development of improved climate services (Hansen et al., 2019; ICPAC, 2021).

The uptake of sub-seasonal forecasts over Eastern Africa is still very low despite the relatively high skill of these forecasts over the region (MacLeod et al., 2021; Muita et al., 2021). Lack of downscaled forecasts to local level and limited accessibility to the real time S2S datasets have been found to be the major reasons for low forecast uptake. Shilenje and Ogwang, (2015) suggest that uptake of forecasts in Kenya can be increased through frequent engagement and interactions between forecast producers and forecast users. Therefore, a co-production approach, where users of forecast information are involved in generating new products rather than only receiving them (Vincent et al 2020), has the potential to address the low uptake of sub-seasonal forecasts in the region. The Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC, https://www.icpac.net/), which is a World Meteorological Organisation accredited regional climate center is working in collaboration with the Eastern and Central Africa Food security and Nutrition Working Group (FSNWG, https://www.icpac.net/fsnwg/) in co-producing tailored climate products.

This study aims to summarise the process and benefits of the co-production of a climate service that has occurred so far over Eastern Africa using the real time S2S forecast data. The objectives are:

- Outline the activities of the kickoff workshop where the initial forecast products were discussed.
- Demonstrate how the inclusion of the ICPAC communication and user services team in the co-production process enhances effective communication between the forecast producers and the climate information users.
- Evaluate how well the S2S models reproduced extreme events in the year 2020 for the March-April-May and October-November-December seasons over the region.
- Summarize some of the lessons learnt and challenges faced in the co-production process.

Our paper is organized as follows. Section 2 outlines the study region, data and co-production process that is being utilised in the testbed. Section 3 focuses on detailing the outputs, challenges, lessons learnt and evaluation of the model for the extreme events. Section 4 draws the main conclusions of the study.

Data and methodology

Study region

Eastern Africa exhibits complex topography, having the highest and lowest elevation points in Africa, and several large water bodies that contribute to a unique tropical climate (Anyah and Semazzi, 2006; Camberlin, 2018). Fig. 2a illustrates the complex undulating topography of the region. Due to its geographical position, Eastern Africa is directly impacted by seasonal changes in the Hadley circulation that results in three major rainy seasons that are the March-April-May (MAM), June-July-August-September (JJAS), and October-November-December (OND) (Nicholson, 1996; Mutai et al. 1998, Fig. 2b-d). The northern part of the region has one major season, JJAS which, accounts for up to 80 % of the total annual rainfall (Fig. 2c), while the equatorial region exhibits a bimodal pattern with the major seasons being the MAM (long rains, Fig. 2b) season, and the OND (short rains, Fig. 2d).

Data

The real time S2S forecast datasets from the S2S Real Time Pilot Initiative project are utilised to co-produce forecasts weekly. The initiative formally started on 1st November 2019, allowing real-time S2S forecasts to be made available to a set of individual sub-projects for a two-year period (https://s2sprediction.net/xwiki/bin/view/dtbs/RealtimePilot). Although several S2S model outputs are available, the SWIFT S2S testbed has mostly utilized the European Centre for Medium Range Weather Forecasts (ECMWF). The initial focus on this model is because its skill is relatively high over the region in comparison with other models (Vigaud et al 2019; de Andrade et al., 2021; Endris et al., 2021). Weekly forecast and hindcast initialisations are downloaded on Mondays with the data available on Tuesdays for forecast product development. The datasets are downloaded to the JASMIN supercomputing system for central access to the datasets for the researchers and forecaster providers participating in the SWIFT S2S testbed. The ECMWF forecast has a run length of 46 days and 51 ensemble members. Three closest hindcast initialisation dates are used to compute the climatology for the forecasted variables, consistent with the operational procedure at ECMWF. Each hindcast consists of 11 members thus a total of 33 ensemble members are utilised. The hindcast in ECMWF is for the past 20 years (for example the hindcast for forecasts in 2020 will be from 2000 to 2019). The following variables from the ECMWF model were extracted for further processing, soil moisture (top 20 cm), total rainfall, 2 m temperature (minimum, maximum, mean) and zonal and meridional wind components (10 m).

Several rainfall satellite products are available over the region. We use the Climate Hazard Infrared precipitation with stations (CHIRPSv2; Funk et al. (2015)) daily datasets for evaluation of the extreme events

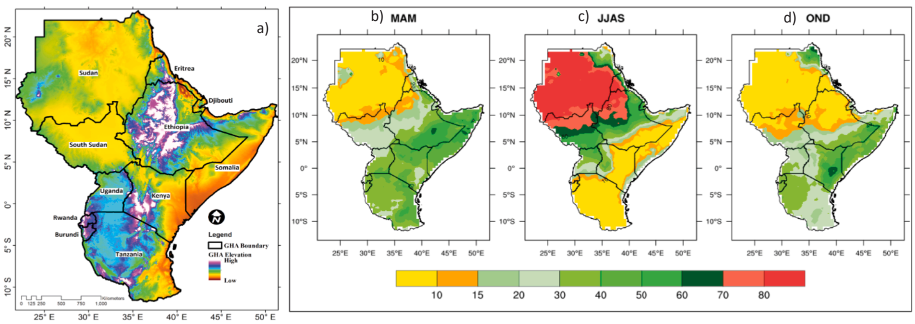

Fig. 2. Topography (a) and percentage contribution of season to total annual rainfall for b) March-April-May (c) June-July-August-September (d) and October-November-December over Eastern Africa. The percentage contribution is calculated from the Climate Hazard Infrared precipitation with stations (CHIRPS) datasets.

over the region during the MAM and OND seasons. The data is available from 1981 to near present and has a high spatial resolution of 0.25°. The data is regrided to 1.5° to match the resolution of the forecast datasets. Previous studies have shown that the dataset is able to reproduce the total rainfall over the region (Kimani et al, 2017; Dinku et al. 2018; Gebrechorkos et al., 2018; Ayugi et al., 2019).

The food security and nutrition working group

The Food Security and Nutrition Working Group (FSNWG), is a multi-stakeholder regional platform, co-chaired by IGAD and United Nations Food and Agricultural Organization (FAO). The FSNWG is a user interface platform for food security and nutrition in Eastern and Central Africa. The FSNWG started in 2002; as an informal forum of food security and nutrition practitioners; meant for discussing food security and nutrition issues over the region. IGAD participation in the work of FSNWG increased after the Heads of Governments Summit in 2011 which called for governments and development partners to make the region more food secure and resilient. Currently the working group is a consortium of organisations across Eastern and Central Africa with current membership including approximately 80 organizations - IGAD, United Nations (UN) agencies, Non-Governmental Organisations (NGOs), donors and research institutions who contribute to the operation and content of the working group. The FSNWG is composed of several Sub-Working groups including Food Security, Climate, Nutrition, Displacement, Livestock, Conflict, Refugees, and Humanitarian Affairs. The diagrammatic depiction of the different organisations that contribute to the working group and the current sub-working groups is represented in Fig. 3.

The working group provides adequate and timely information of food security, nutrition situation to planners and decision-makers (e.g in disaster and risk management sector) at regional level. The group meets once every month to discuss the climate, food security, nutrition, markets, humanitarian response, and displacement status over the region. After the monthly meetings a coordinated report is produced with contributions from the sub-working groups coordinators. This bulletin is then distributed publicly via an email list and also posted on the websites (e.g. https://www.icpac.net/fsnwg/).

The co-production process

Co-production has been defined as the process which brings together

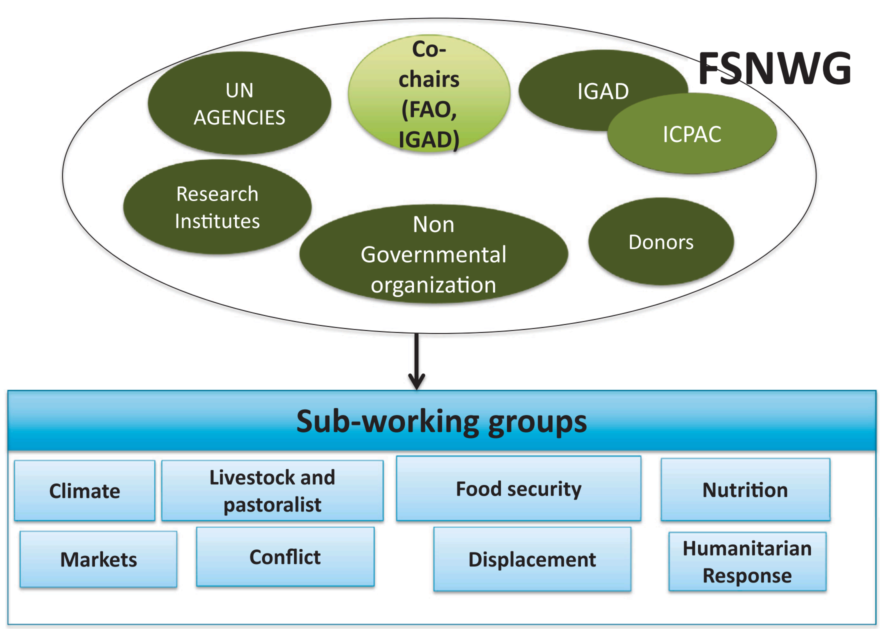

Fig. 3. Schematic representation of the Food Security and Nutrition Working group and the different working sub-groups. The light green represents the co-Chairs of the working group that is the Food and Agricultural Organisation (FAO) and Inter-governmental Authority on Development (IGAD). IGAD Climate Prediction and Applications Centre (ICPAC) is highlighted in a different color and overlaps with IGAD as it is a specialized institution of IGAD.

different knowledge sources and experiences to jointly develop new, combined and relevant knowledge products and systems to enable its intended use in specific decision-making contexts (Carter et al., 2019; ICPAC, 2021). The collaboration between climate information users, communication and user service team and climate scientists offers an opportunity to leverage expertise among the different parties to better deliver climate services to the FSNWG. Co-production under the SWIFT project was implemented following closely the building blocks of the climate services value chain and principles outlined in the co-production guiding manual by Carter et al., 2019. In this process some activities were carried out at consortium level that is from application of access to the real time S2S datasets to the capacity building workshop. Thereafter most activities were carried out at partner level in this case between ICPAC and FSNWG. The following flowchart outlines the timescales at which the different activities were undertaken (Fig. 4). We give a detailed description of the activities in the next sections.

Partnering with FSNWG

The application for access of the real time S2S datasets was done in February 2019. In June 2019 each SWIFT operational centre identified the potential climate information user for the co-prodution of the S2S products. . Since this was a pilot project, building a strong co-production relationship with one partner was more important than scaling up solutions at this stage. ICPAC collaborated with the Food and Nutrition Working Group (FSNWG). The FSNWG was chosen as a key partner because it enabled new S2S forecast products to be integrated into existing decision-making structures rather than create unneeded new pathways. As part of the FSNWG network, ICPAC is responsible for proving the climate information. Prior to the S2S testbed the FSNWG was already receiving monthly and seasonal products during the monthly working group meetings. The monthly and seasonal forecast products were not addressing the required timelines for other key agricultural activities such as application of fertilisers, pesticides and the likelihood of pasture regeneration. Hence, provision of S2S forecasts will bridge the existing gap. Providing these forecasts to the working group has the potential to increase the uptake of the forecasts and diversify the user tailored information that are utilised to make their specific decisions.

Pre-testbed questionnaire

A pre-testbed questionnaire was sent out to the IGAD FSNWG coordinator to find out more about the climate products they currently utilise and what further forecast products they would require to aid their decision-making context in September 2019 (Supplementary material S1). The coordinator collated information from the sub-group coordinators and providided a consolidated response to the questionnaire.

The key messages from the questionnaire responses include:

- Climate is the main driver of food insecurity over most countries in Eastern Africa, closely followed by conflict or insecurity and macro-economic drivers.
- Extreme weather escalates conflict-related food insecurity for example, conflicts over pasture land and water points.
- Poor rains lead to widespread crop failures, loss of livestock and destabilize other livelihood strategies, all of which impact on food availability and access.
- 7–30 day forecasts can help generate and execute tactical or emergency strategies in order to safeguard or reduce impact of extreme events on lives and livelihoods such as crop management practices including crop protection, livestock relocation to a safer place in case of extreme wet spell forecast, and relocation of populations.

The feedback gathered from the questionnaire responses were used to inform and start the conversation on product tailoring for the face-to-face testbed kickoff workshop.

Kick off workshop

The two-year S2S testbed was launched with a one-week kickoff workshop, hosted by ICPAC for 38 SWIFT S2S testbed participants. It was held at ICPAC headquarters in Ngong, Kenya, between the 18th and 22nd of November 2019. The workshop brought together climate information users (including representatives from the agricultural, food security, energy and disaster risk reduction sectors), operational forecasters and researchers from Kenya, Ghana, Nigeria, Senegal, Niger, Cameroon, Uganda and the United Kingdom. Hirons et al., (2021) summarises the workshop format, participants and operational centres participating in the SWIFT S2S testbed. The main purpose of the workshop was to create a common ground and agreement on the process, roles and actual participants in each step of the climate service co-production. Therefore, participants worked mainly in breakout sessions of small groups (country level for members in SWIFT consortium) consisting of forecasters, researchers and the climate information users.

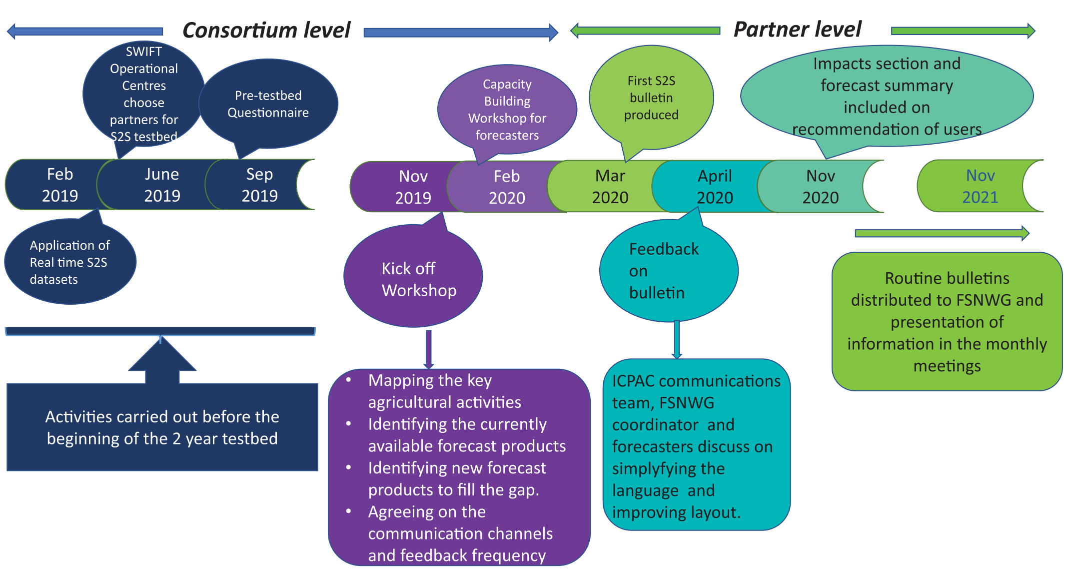

Fig. 4. Flowchart of the co-production activities carried throughout the 2 year S2S Testbed. The activities from application of the real time S2S to Capacity building workshop were carried out at consortium level while those from production of bulletin to regular dissemination of forecast products were carried out between ICPAC and FSNWG.

During the kickoff workshop mapping of key agricultural activities, discussion on new products, methods of communication of forecasts, feedback mechanism and frequency and co-evaluation were delibarated on. In mapping the timelines of key activities, participants had to identify their major rainy seasons, the important activities that will be done during specific months. Fig. 5 shows the timeline for key agricultural activities over Eastern Africa. These timelines are also essential for decision-making such as triggering early assistance appeals and preparedness for drought or flood risk. For instance, if planting has not happened and its half way through the season resource mobilisation by humanitarian organisations could start as the region is likely to be food insecure in the coming months. The key activities include land preparation, planting, weeding, green harvest, and harvesting. The completion of the timeline of the key activities then led to a decision on co-developing the climate products.

To come up with the new products, existing products that were already being produced by ICPAC for the FSNWG were listed. The users were able to identify all the products that were available for their decision making. Targeted forecast products for the FSNWG that were provided during the monthly meetings and bulletins were the monthly and seasonal rainfall and temperature products. This left a glaring gap in the forecast information provided as products with a time period of less than a month were not issued out during the monthly meetings. nor included in the bulletins. However, it must be noted that ICPAC provided the 10 day forecasts bulletins that were posted on the website. Table 1 summarises the forecast products that were produced prior to the testbed kickoff and those that were requested by the climate information users. The decisions the different forecast products will inform are further discussed in section 3.1.

A sketch of the products discussed and presentation to the plenary session is shown in Fig. 6.

As a member, ICPAC provides climate forecasts and related information to the FSNWG on a monthly basis. These products are shared during the monthly FSNWG plenary sessions, and the members are able to raise questions to clarify on the forecast given. Therefore, it was agreed in the workshop that this mode of delivery would still be upheld subject to future amendments as the need arises. In addition to the monthly plenary meetings it was agreed that a bulletin will be produced that focuses on summarising the S2S forecasts. Prior to the S2S project, the FSNWG produced a food security bulletinat monthly timescales that entails all the elements of food security including food security situation, nutrition situation, markets, displacement and also the seasonal forecast information. It was agreed that once the forecast bulletin is ready it will be sent to the IGAD coordinator who then shares with the FAO coordinator. After both coordinators have reviewed the information presented then the bulletin can be shared in the email list to the rest of the FSNWG members. Since the forecast information was still in trial phase and restricted it could not be disseminated through social media or posted on the website.

Table 1
Summary of Sub-seasonal forecast products that were produced before the testbed and the new proposed products.

Forecast products produced prior to the testbed	Proposed Forecast Products
Ten day (dekadal) forecast	Weekly forecasts
• Total rainfall	• rainfall total
• average temperature	• rainfall anomalies
Monthly forecasts	• Probability of exceedance for rainfall
• Precipitation total	• Weekly timeseries rainfall anomalies
• rainfall anomalies	• minimum temperature anomalies
• Probabilistic tercile rainfall	• maximum temperature anomalies
• Average temperature	• soil moisture anomalies
• Probabilistic tercile temperature	Maximum wet and dry spells in the forecast 4 weeks
• Average temperature anomalies	Standardized precipitation index
• maximum wet and dry spells	Standardized precipitation evapotranspiration index

Forecasters capacity building

The sub-seasonal forecasts provided through the S2S real-time initiative are relatively new to the forecasters. Thus, there was need for capacity building of the forecasters to develop the new forecast products. A one week long intensive Hackathon was held in February 2020 at University of Reading, United Kingdom and trained 5 forecasters from Eastern Africa region on developing the new forecast products such as probability of exceedance of a certain threshold, maximum and minimum temperatures and soil moisture utilizing python coding (https://bit.ly/3LfeozN).

Bulletin development and subsequent iterations

After the forecasters training workshop, the first S2S bulletin was produced in March 2020. This was then followed by a discussion between the ICPAC communications and user service team and the FSNWG coordinators on ways to improve the forecast bulletins, in a way that can be easily understood by users. It was also agreed that before the forecasts are disseminated there is need for quality assessment on the language utilised and the bulletin format. This then led to a discussion between the forecasters, communications and user service team and climate

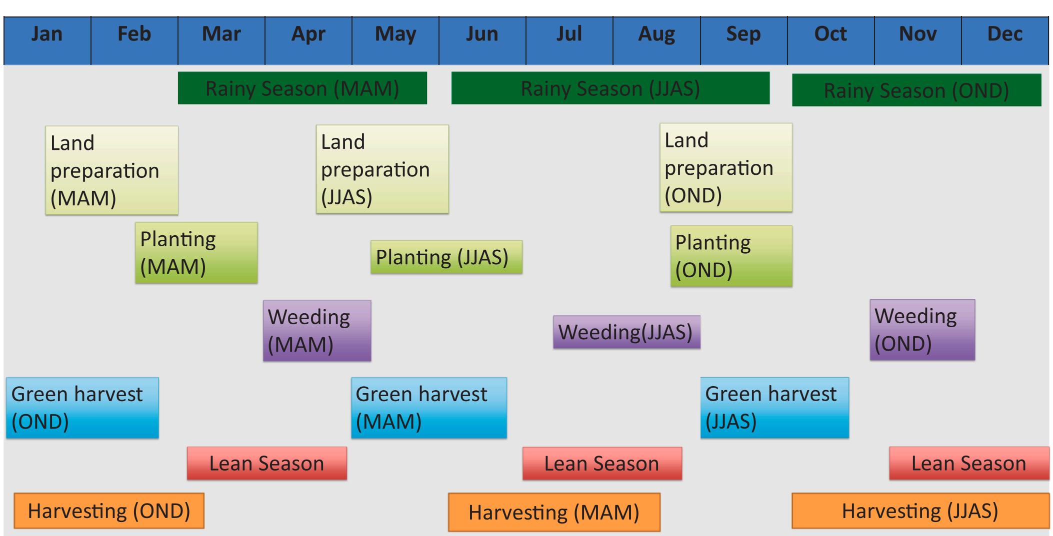

Fig. 5. Example of timelines for key agricultural activities over Eastern Africa as informed by Food Security sub-working group.

Fig. 6. Mapping out of new sub-seasonal forecast products, and the key sector activities to be made by the FSNWG (left) and presentation from Food Security subworking group in the plenary (right).

information users on how to implement the improvements to the bulletin.

In November 2020, the S2S products were intergrated into the monthly and seasonal forecast presentations that are issued out monthly during the working group meetings. During this same time period, it was also suggested by the climate information users that it will be helpful to include a forecast summary and impacts section in the bulletins.

Results and discussion

Tailored co-produced forecast products

Climate forecasters were informed that in the agricultural sector strategic and operational decisions are made at various stages of the season. At the beginning of the season strategic decisions are made, and these require seasonal forecasts. These decisions include land preparation, the type of crop and variant seeds that need to be purchased. However, during the season, operational decisions are put together. Operational decisions are taken to minimize negative consequences of adverse weather and to take advantage of favorable weather conditions. These operational decisions included timing for planting, weeding, application of herbicides, application of fertilizers, application of pesticides, planning for the lean season, diversifying into poultry and goat rearing, harvesting and methods of reducing post-harvest losses influenced by weather conditions. Thus, the sub-seasonal forecasts will aid in operational decision-making and target the major activities that are carried out during the wet and dry seasons.

As mentioned before, prior to the commencement of the two-year SWIFT testbed, ICPAC produced deterministic dekadal temperature and rainfall forecasts using the Weather Research and Forecasting (WRF) Model (Skamarock and Klemp, 2008). In addition to the dekadal forecasts probabilistic monthly temperature and rainfall forecasts were produced using the North America Multi Model Ensemble models (Kirtman et al., 2014). Information on the maximum wet and dry spell was also produced from the WRF model output. The suggested new forecast products are summarized in Table 1. Some requests from the representatives were not feasible such as information on the peak of the rainy season. The available datasets from the S2S database are run for up to a maximum of 60 days, with ECMWF, the model that is primarily used in the testbed being run for 46 days, thus information on when the maximum rainfall will be received during the wet season cannot be retrieved. In addition, the sub-seasonal forecasts are normally issued out as averages over a period, rather than on a daily basis. In order to reach a consensus with the users we had to explain the differences in the seasonal and sub-seasonal forecasts in terms of the temporal timescale and the reasons why we do not have data that can give us the information of the peak of the rainy season. Below we outline the products that were co-produced (Table 1) and the decision(s) each product was designed to inform.

Weekly total rainfall

Crop productivity depends on the total rainfall distribution; its variability is a potential threat to food security (Kyei-Mensah et al., 2019). The climate information users informed forecasters that they would prefer a more regular update to what is currently available. The four week long forecasts broken down in weekly timescales help in planning for weeding, harvesting, application of herbicides, pesticides, fertilizers or irrigation.

Weekly rainfall anomalies

The weekly anomalies inform the farmers that the anticipated rainfall is less than usual or higher than usual. Zaveri et al., (2020) showed that rainfall anomalies lead to changes in agricultural production. On average, productivity increases in response to wet anomalies and decreases with dry anomalies. In addition, the information on anomalies could be used to decide the acreage on which to plant a certain crop. They found that repeated dry anomalies increase cropland area as the farmers try to compensate for anticipated low yields. Likewise, forecasters were informed that information on anomalies could inform farmers if they need to keep investing in their crop, or they need to diversify to other activities such as poultry or goat rearing. Information on the weekly rainfall anomalies is also important during the harvesting period as wet anomalies could contribute to problems in food storage and post-harvest losses.

Probability of an extreme event

Knowledge of the probability of receiving rainfall above a certain threshold is fundamental for planning to take action to mitigate an impeding natural disaster. The availability of a number of ensemble members allows for calculation of these thresholds. Forecasters were informed that the information will be critical in both the agricultural and humanitarian decision making. An initial threshold of the probability of receiving more than 30 mm per day was proposed by the climate information users based on past experience.

Weekly maximum and minimum temperatures

Temperature plays a fundamental role in the productivity of many crops. Eastern Africa grows several crops that are sensitive to temperature extremes, for example tea, coffee, and wheat. While tea and coffee are extremely sensitive to minimum temperature, due to their high likelihood to suffer from frostbite, wheat is sensitive to the maximum temperatures. Sustained high temperatures shorten wheat growth period by accelerating phenological development, resulting in reduced yield (Asseng et al., 2011). Accordingly, information on the temperature helps the farmers to decide if they should invest more in increasing the yield or if they should diversify. Sustained high temperatures are also likely to cause water stress in crops hence decisions are taken on whether crops should be irrigated. Pest outbreaks and livestock disease outbreaks such as foot and mouth disease are also dependent on the temperature, (Scott et al., 2010; Cohen and Leach, 2020) hence knowledge on the temperature condition in the next four weeks can help a farmer in securing the required pesticides or vaccinations on time.

Weekly soil moisture conditions

Soil moisture conditions have a great influence on crop growth, cultivation and are considered an essential variable in drought and flood analysis (Sheffield et al., 2004; Shukla et al., 2014; Eswar et al., 2018). Operationally at ICPAC no forecasts were given on the soil moisture conditions before the SWIFT testbed. Soil moisture conditions have been applied to anticipatory drought management over some parts of Sub-Saharan Africa (Brown et al., 2017; Boult et al., 2020). This information can be essential in triggering timely humanitarian responses to agricultural and hydrological droughts. Sustained low soil moisture conditions early in the season can be an indication of drought in the season. In crop growth application, insufficient soil moisture content can cause reduction in the biomass production, and subsequently lead to withering of crops if no mitigative measures are taken. In addition, if cultivation is done and the soil moisture conditions are low the crops are likely to wither. Too high soil moisture content is likely to cause water logging of the crops and hence reduce the yield over the region. Information of potentially elevated soil moisture can be used to take mitigative measures such as building gullies.

Monthly maximum dry and wet spells

Sub-seasonal forecasts are used to monitor the evolution of droughts and the possibility of flooding. A prolonged dry spell or wet spell that exceeds a certain rainfall threshold is likely to affect livelihoods and crop productivity. Prolonged dry spells are used to inform farmers on deciding whether they should irrigate their crops or stop investing more in field activities such as weeding and the application of pesticides and herbicides. While on the other hand prolonged long periods of rainfall can cause major flooding events such as the widespread flooding in 2018 (Kilavi et al., 2018) and 2020 (Chang'a et al., 2020; Wanzala and Ogallo, 2020) over Eastern Africa during the MAM season. This information is fundamental to humanitarian organizations within the FSNWG to prepare to evacuate people to safer places and minimize the possible damage that could be caused. Evacuation of people requires planning and hence to be carried out effectively requires a longer lead time of an imminent extreme event.

These forecasts are summarised in a bulletin and given out biweekly with a one-month outlook, broken down into weekly totals. The S2S forecasts weekly forecasts seamlessly fill the gap between the weekly and monthly forecasts. Although we are aware that most research have shown that the S2S forecasts are more skillful in week one and two in comparison to week three and four (Vigaud et al., 2019; de Andrade et al., 2021; Endris et al., 2021), the monthly outlook gives the users an indication of variability relevant for longer term decisions.

Forecast dissemination and role of the communication and user services team

One major challenge that has faced climate producers and users is communication of the forecasts. Improved communication is fundamental in increasing the uptake of the sub-seasonal forecasts and appropriate use of these climate products by climate information users. Effective communication utilises knowledge of an audience's interests and prior understanding from the producer in order to tailor the message (Hansen et al., 2019). Thus, even though products are co-developed, it is fundamental that they are packaged in a way that increases usage of these forecast products. In consequence the communication and user services team at ICPAC plays a critical role in the co-delivery of the climate products. The team simplifies the technical language utilized, and improves on the layout of the bulletins. This improves the readability and usage of the forecast outputs.

Initially forecast bulletins were written in paragraph format, which potentially makes the readability of the document harder. Hence, it was suggested that the forecast bulletins be produced in bullet point form. In addition, it was suggested that the discussion of the timeseries forecast plots for the different countries be done under a country subheading and separated out by different weeks. The disseminated bulletins prior to the input of the communications and climate users' can be found in Supplementary material 2 and 3 respectively. Forecast dissemination is conducted mainly through e-mailing, making use of an e-mail marketing software. The information is also disseminated in person during the FSNWG monthly meeting where the S2S information is incorporated in the climate outlook updates. This form of dissemination gives a platform for further direct interaction between the information users and producers, allowing for the clarification of any outstanding issues from the forecast.

Feedback on the forecast

To obtain feedback on the products surveys were sent out to the FSNWG coordinator once every-six months at consortium level. The FSNWG coordinator would consult with the subgroups coordinators to produce a consolidated feedback on the forecasts. The objective of the surveys were to obtain feedback on the usefulness of the forecasts and the decisions that have subsequently been informed. In summary it was reported that the products were very useful, however, for some users the interpretation of the precipitation probabilities, soil moisture, maximum wet and dry spells and time series products was difficult. The forecasts are mostly used for crop choice, planting timing, drought risk, flood risk, disease outbreaks, early assistance appeals, disaster relief preparation, and early warning. The challenges in interpretation of some of the forecasts could be due to the fact that since this was a pilot project not all members of the working group were invited to the co-production process.

To improve on the bulletin and uptake of the climate information it was suggested that the first section include the forecast summary as well as likely impacts from the issued forecast. The likely impacts section is aimed at climate information users who might not be familiar with the terminology and have difficulties interpreting the sub-seasonal forecasts issued. Some examples of these likely impacts include; if persistent dry anomalies are forecast an advisory on irrigation over croplands can be issued to minimise crop loss due to moisture stress; if extreme wet anomalies are expected in a region that has persistently been wet in the past weeks a flood warning is issued so that a humanitarian organisation could prepare for evacuation.

An evaluation of the forecast from the user's perspective showed that during the first 2 weeks of April in 2020 around the Lake Victoria region, the region remained dry despite predicted above average rains. This information negatively affected some users as they had anticipated above average rainfall over the region.

Case study: evaluation of March - May and October-December extreme events in the S2S models in 2020

We evaluate the ECMWF model's ability to capture excessive rainfall during two major seasons in 2020. We evaluate the performance during the high impact events from 18 to 24 April 2020 and 21–27 November 2020 over the region. The two events caused widespread flooding and loss of livelihoods. Tropical cyclone Gati which occurred from 21 to 27 November 2020 is on record the strongest cyclone to make landfall over Somalia (LeComte, 2021).

Excessive rainfall for 18–24 April 2020

In March-May 2020 Eastern Africa experienced widespread flooding, exceptionally high peak river flows and lake levels that led to loss of livelihood over the region (Wanzala and Ogallo, 2020; Chang'a et al., 2020). The MAM 2020 season followed an already extremely wet OND 2019 season (Wainwright et al., 2021), which had some regions receiving over twice the total rainfall normally received. The excessive rainfall from the OND season continued into the MAM season, with numerous weather stations recording the highest amount of rainfall in the past 40 years (Wanzala and Ogallo, 2020). Fig. 7 shows the timeseries of the daily total rainfall received over the region (-8^{o}S-8^{o}N, 30^{o}E-45^{o}E), calculated using CHIRPS datasets. The area is consistent with the region used in Kilavi et al., (2018). In general, for most days during the MAM 2020 season, the region received higher rainfall compared to the daily climatological mean. Exceptionally high rainfall was received between 18 April and 24 April 2020 (Fig. 7a, shaded blue region). During this week the southern parts of Ethiopia, central Kenya, southern parts of Uganda, and the northern parts of Tanzania normally receive at least 100 mm of total rainfall (Fig. 7b). Most of the eastern parts of the region received enhanced rainfall of up to 60 mm (Fig. 7c). We chose this week to evaluate the ability of the ECMWF model to forecast the enhanced rainfall.

Fig. 8 shows the S2S total rainfall and anomalies forecasts for one week to three weeks leading to the extreme rainfall event. The S2S forecasts indicated total rainfall of up to 100 mm a week and 2 weeks before the extreme event (Fig. 8a-b). In terms of anomalies the S2S forecasts indicated enhanced rainfall over the region 3 weeks leading to the high rainfall event (Fig. 8d-f). The forecast 3 weeks ahead of the event shows weaker rainfall anomalies than what was observed in addition it was expected that the total rainfall over the coastal parts of the region was near the usual. A forecast 2 weeks ahead of the event shows displaced regions of enhanced rainfall, with the region forecast to receive higher rainfall anomalies over most of western Kenya and eastern Uganda. One week towards the anticipated extreme event the forecast indicates enhanced rainfall (45 mm more than usual) in the regions that received the high rainfall (Fig. 8f).

During the week of 18 to 24 April 2020 most parts of the region received above 50 mm of weekly total rainfall, with parts of Kenya receiving up to 150 mm (Fig. 9). Evaluation of the model's ability to reproduce the total rainfall indicates that the model underestimates total rainfall in regions that receive enhanced rainfall. Low rainfall biases are in week 1 and the highest in week 3 consistent with previous studies over the region (de Andrade et al., 2021; Endris et al., 2021). Total rainfall biases are up to 45 mm over these regions (Fig. 9).

Tropical cyclone Gati during the short rains

Tropical cyclones (TCs) are among the most destructive weather phenomena. Tropical cyclones have typical lifetimes of 7 days (Robertson et al., 2020). Cyclone Gati occurred in the week of 21–27 November 2020, and brought torrential rainfall over Somalia, Djibouti and Ethiopia. An estimated 180,000 people in the Bari region were affected and almost 4,000 properties belonging to nomadic communities in the affected areas were destroyed (Ocha, 2020). Historically during this week, the northern region is dry, with most of the rainfall concentrated over the equatorial region (Fig. 10). Compared to the weekly climatological mean (21–27 November from 1999 to 2019) some parts in northern Eastern Africa received over 50 mm more of total rainfall. White et al. (2017) showed that the S2S models could predict tropical cyclones on lead times of up to 28 days, but it is yet to be determined if S2S forecasts can predict such events with sufficient skill and reliability for decision making in different sectors. Vitart and Robertson (2018) state that in order for models to skillfully predict tropical cyclones it is important for S2S models to correctly reproduce the Madden-Julian Oscillation (MJO) phase and intensity. The ECMWF has been found to be skillful in producing the MJO forecast over the region (Vitart 2017; MacLeod et al., 2021). Here we analyse the ability of the ECMWF model to capture the enhanced rainfall due to cyclone Gati at different lead times.

Fig. 11 shows the rainfall anomaly forecasts that were issued out over Eastern Africa. In Fig. 11, week one indicates a forecast that is one week ahead of the time the simulation was conducted. For example, the top panel plot in Fig. 11 is for a forecast that was conducted on the 26th of October 2020 and at this time the Tropical cyclone was 4 weeks away from occurring. The red box highlights the week that the cyclone was active. Evidently the model was unable to capture the wet anomaly until 1 week ahead of the extreme event. The forecasts with 2 to 4-week lead times generally indicated near-usual conditions over Somalia, Djibouti and Ethiopia. The week 1 lead forecast up to 25 mm more than usual over most parts of Ethiopia, however only up to 15 mm more than usual was expected over Somalia. Although the model was able to forecast enhanced rainfall over the northern part of the region, the anomalies were weaker than what was observed, consistent with the results for the extreme event in April 2020. These results, of low skill at lead times of more than 2 weeks, are consistent with studies that have shown that successful tropical storm track forecast beyond 2 weeks is still rare, thus more research is required (Vitart and Robertson, 2018).

Challenges faced and lessons learnt

The coproduction process undertaken, from the testbed kickoff to date, is a fairly new practice in the global south, and there have been a number of challenges and lessons learnt by both forecasters and climate information users. Here we outline some of the major challenges faced and lessons learnt in the co-production process.

User feedback

One of the major challenges in the co-production process is establishing an effective, feedback loop with the climate information users. Recognizing that effective co-production is resource-intensive (Dilling and Lemos, 2011; Lemos, 2015), this could be due to insufficient resource invested in the co-production process itself and in establishing

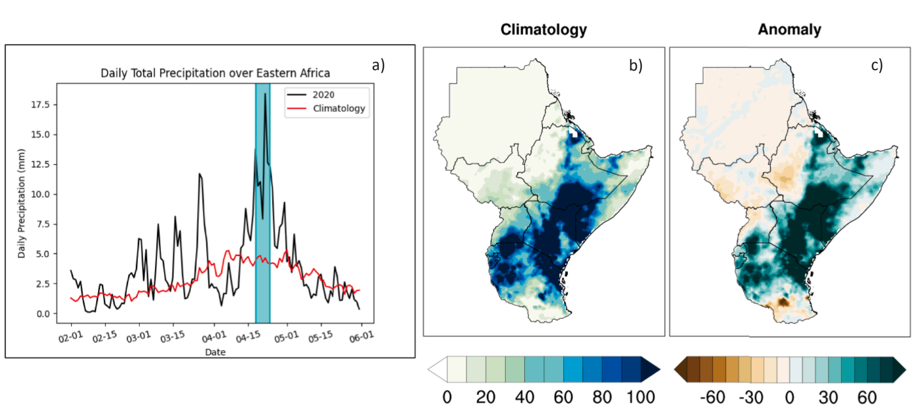

Fig. 7. a) Time Series of Daily Rainfall over Eastern Africa for the Climatology (2000–2019, red) and the year 2020 during the March-May Season (black). Spatial representation for the b) climatology and c) anomalies over the region for the week 18–24 April.

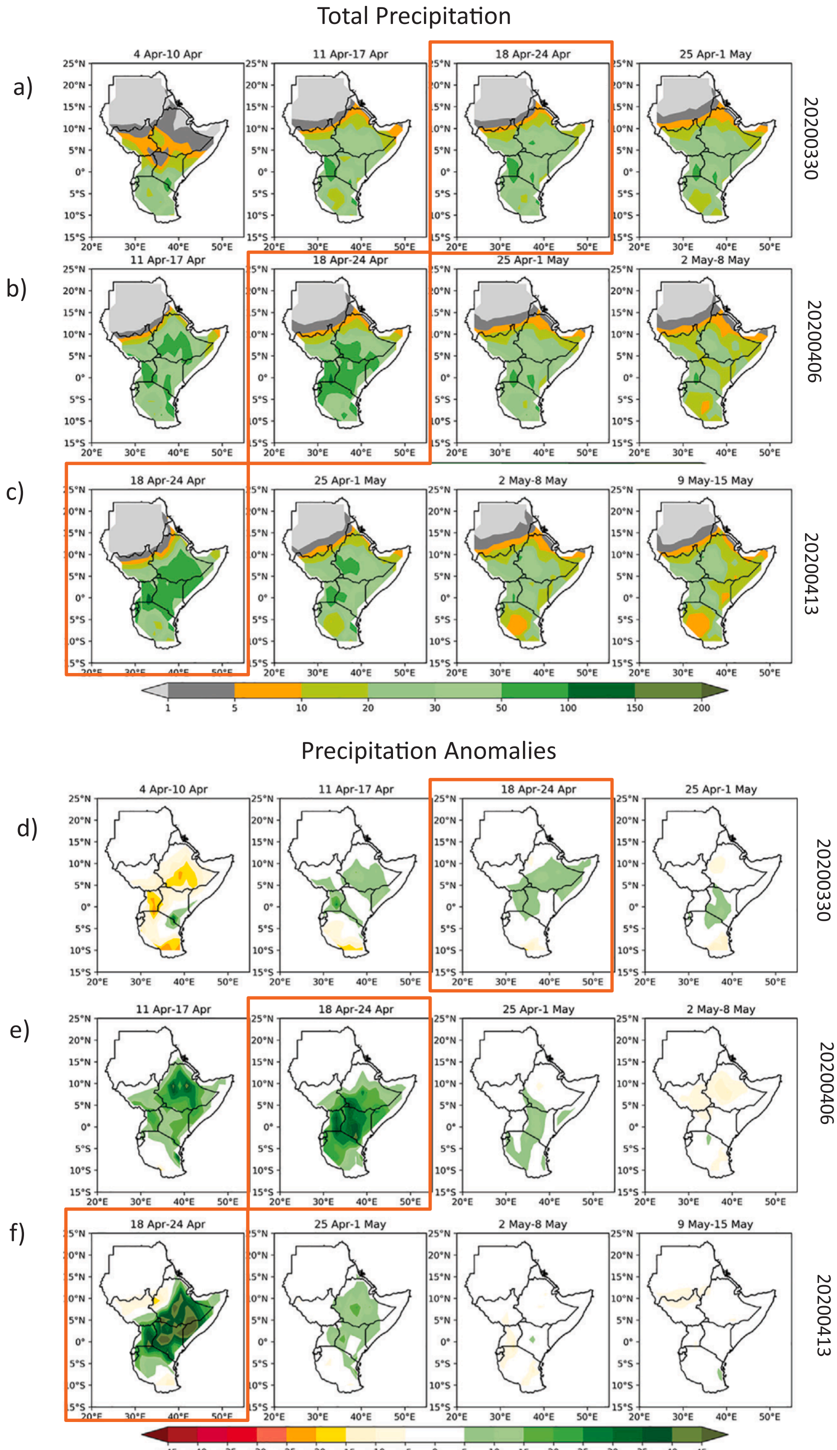

Fig. 8. Total rainfall (a-c) and anomalies (d-f) forecast by the ECMWF model over Eastern Africa for the different lead times leading the extreme event in week 3 of April 2020. The red boxes highlight the forecast for the extreme events with the different lead times.

effective feedback pathways. While most climate information users acknowledged that the new forecast products were extremely useful in their decision-making context, it was difficult to establish specific examples of how decisions were being changed or affected by the real time S2S products provided. The feedback provided was generally not specific enough to attach the forecast to the decision that was made. The lack of specific feedback could be due to time constraints on the part of the climate information users as they might not have had time to record the decisions made using the forecasts. Constant interaction with the climate information users, especially before and after a high impact event, could help in collating information on the decisions made and whether the forecast was provided in a timely manner. A major weakness in the design of the co-evaluation mechanism of collecting the user feedback, is that the time period of extreme events occurring and providing feedback on the usefulness and decisions taken was not considered. Thus, in a design of the feedback mechanism there is need for dedicating in-person and telephone interviews with the coordinators that could be conducted prior to and immediately after an extreme event.

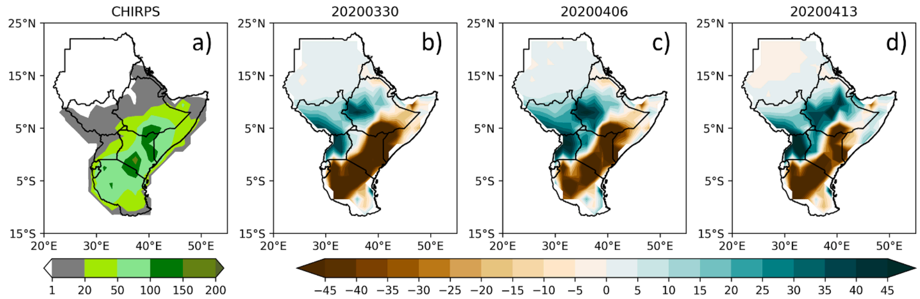

Fig. 9. Evaluation of the total rainfall during an extreme event over the Eastern African between 18 and 24 April 2020. a) Total rainfall received during the week, b) Bias 1 weeks before the forecast date c) 2 weeks before the forecast date c) 3 week before the forecast date of the extreme event.

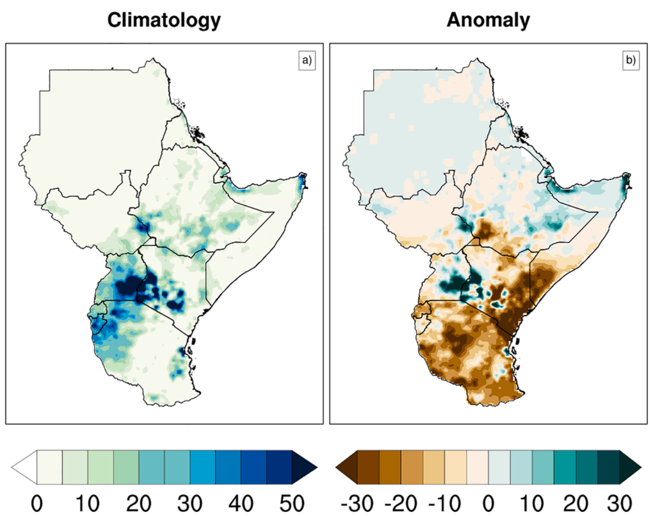

Fig. 10. Climatology and anomaly rainfall for 21–27 November over Eastern Africa. The red circle is the area in which Tropical Cyclone Gati made landfall.

Scale - downscaling of products

One of the new products that was requested by the users included the timeseries plots showing the climatological mean rainfall and zonal climatological areas (Supplementary material 2, Fig. 2). The timeseries provided in the bulletin are averaged over a country. Climate information users highlighted that the spatial extent of averaging was too big for the forecast to be useful for decision-making, so it was request that the timeseries be broken down for each climatological region in the country. This poses a challenge, producing numerous plots over all the 11 countries in Eastern Africa would make the bulletin very long and could discourage some users from utilising it. An online interactive platform that is accessible from mobile phones or computers where users can click the area of interest and obtain tailored information over the specific area could potentially solve this problem. An example of this could follow the East Africa Hazards Watch (https://eahazardswatch.icpac.net/map/ea/).

Communication of uncertainties

The use of probabilistic forecasts has been shown to increase trust in forecasts and could possibly improve decision making (Roulston et al., 2006; Joslyn and LeClerc, 2012; Nadav-Greenberg, and Joslyn, 2009). However, although numerous climate services are issued as probabilistic products, users found the probability of exceedance maps challenging to comprehend. This challenge is not unique to sub-seasonal forecasts but has been reported in other studies focusing on probability of precipitation. It was reported that some users interpret the probabilities as geographical areas that are likely to receive rainfall or a time period (Stephens et al., 2012). For the sub-seasonal forecasts, users felt that the probability of exceedance forecast information was hard for them to comprehend as the colors utilized were not distinct enough to show that an event will be dry or wet. Thus, it was suggested that we remove the probability of relatively dry events and also use the green and blue colors to indicate that there is likelihood of exceeding a certain rainfall threshold. This feedback questions whether there is a need for capacity building in helping different stakeholders in the interpretation and use of probabilistic forecasts, as well as improving how forecasters package the information. At ICPAC this issue is currently being addressed by dedicating a communication team with social scientists, climate information experts and journalists that act as an intermediary between the forecast producers and the climate information users. The team translates the forecast information in a way that is understandable to the user, and communicates on why the forecast information is uncertain. The communications team has also enhanced the interaction between the forecast information users and producers through setting up a user feedback platform. The general ICPAC forecasts are currently disseminated through emailing list, social media and website. Both the emailing list and website have provision for the users to provide feedback. The team also currently conducts capacity building workshops for the journalists over the region.

Inconsistent storylines in the forecasts.

Another challenge was that in some forecast weeks there were significant changes from one week to the next. An example of this, is shown in Fig. 11, where a lead time of 2 weeks had forecast wet conditions over parts of Tanzania, however 1 week lead time was drier than the usual. This inconsistency can put users at a disadvantage in decision making given the general assumption that forecasts get more accurate as the forecast lead time reduces (de Andrade et al., 2021; Endris et al., 2021). The possible reason for the shifts could be the representation of the drivers in the ECMWF model. It has been shown that the MJO, Indian Ocean Dipole, soil moisture and tropical cyclones are the major drivers of sub-seasonal rainfall variability over the region (Kilavi et al., 2018; MacLeod et al., 2021; Kolstad et al., 2021). Previous studies have shown that when the model is initialized with a strong MJO signal, the prediction skill (correlation coefficient) tends to be higher than when initialized with weak or with no MJO signal (e.g., Kim et al. 2014; Lim et al. 2018; MacLeod et al., 2021). The initial mode of the Indian Ocean Dipole (IOD) has also been shown to partially control the rainfall forecast error in weeks 3–4 in the ECMWF model (Kolstad et al., 2021). Positive (negative) IOD states in the initial conditions were associated with too-strong positive (negative) rainfall anomalies over Eastern Africa in the model in weeks 3–4. Clear communication of the limitations of models, utilising bias correction techniques and calibration for the sub-seasonal forecasts could potentially help build trust from the climate information users.

Conclusion

This study focused on summarising the process, challenges, and lessons learnt from dissemination of co-produced sub-seasonal forecasts

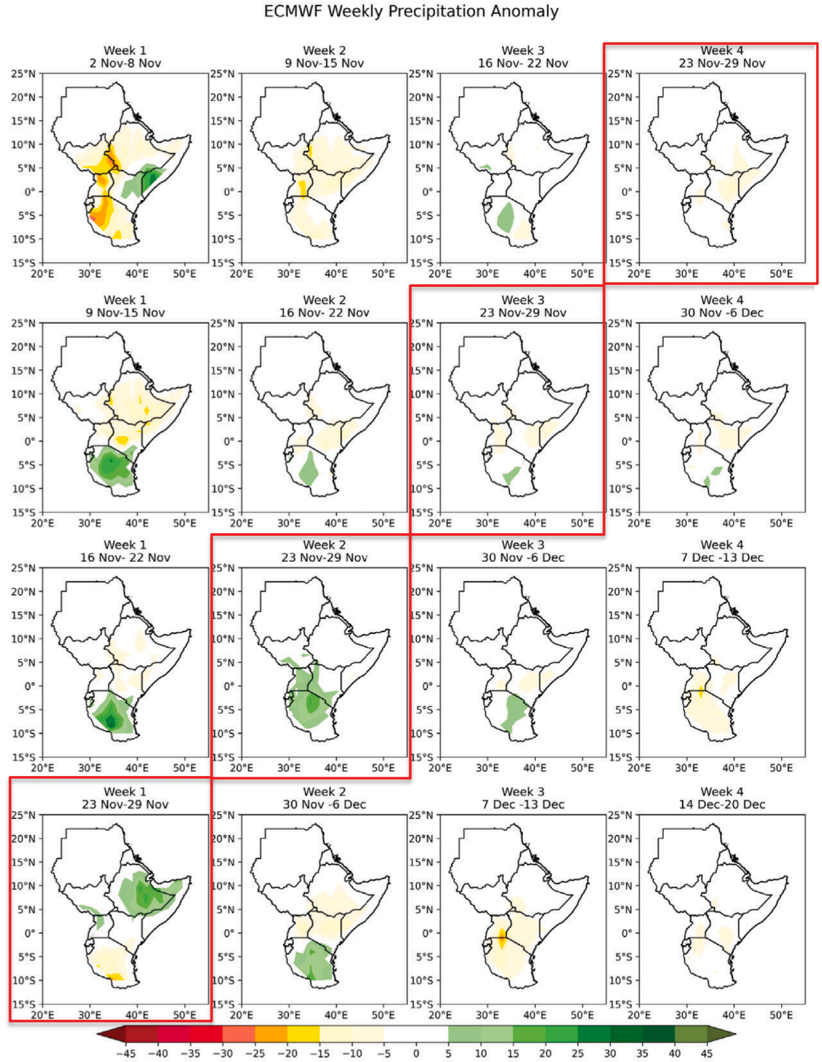

Fig. 11. Weekly forecast rainfall anomalies issued to the FSNWG. The red boxes highlight the week when Tropical cyclone Gati occurred.

over Eastern Africa. The real time S2S forecast datasets were provided by the S2S Real Time Pilot Initiative project. Through a 2-year collaborative S2S forecasting testbed prototype forecast products were co-produced and operationally trialed in real-time. These tailored products were disseminated biweekly to the FSNWG email list and monthly meetings. The co-production carried out between the FSNWG and ICPAC under the GCRF African SWIFT sub-seasonal forecasting testbed was ameliorated by the inclusion of the communications and user services team in co-delivering of the forecast products. The inclusion of the ICPAC communication and user services team in the co-production process as an intermediary improved the communication through simplifying the language used in the bulletins thereby potentially increasing forecast uptake.

A case study approach is used to evaluate the model performance. Two contrasting case studies, one for an extreme rainfall event in week 3 in April and another for the evolution of tropical cyclone Gati were conducted for the year 2020. Results showed that the model is able to capture the wet anomalies in April 2020, hence giving an indication to stakeholders of potential flood risk. Evaluation of the model's ability to forecast enhanced rainfall during tropical cyclone Gati showed that the model was able to anticipate enhanced rainfall one week ahead, however the forecast was unable to anticipate enhanced rainfall 2 weeks before the landfall. Hence, more work is required on improving the understanding of the drivers of variability on these timescales and their impact on local weather. The one-week lead time of forecast of heavy rainfall over the Horn of Africa possibly gave the different stakeholders time to take measures to minimise the negative impacts of the tropical cyclone.

The coproduction of climate services and provision of real time S2S datasets has the potential to increase the appropriate use of the sub-seasonal forecasts over the region. Coupled with the advancement of the scientific knowledge in S2S forecasting such as improving understanding of the drivers of predictability, the modeling of those drivers and the local weather patterns they influence will likely help in providing early warning systems therefore alleviating the associated disastrous impacts of extreme weather.

CRediT authorship contribution statement

Masilin Gudoshava: Conceptualization, Investigation, Visualization, Writing – original draft, Software, Methodology. **Maureen Wanzala:** Writing – original draft, Methodology. **Elisabeth Thompson:** Conceptualization, Data curation, Software, Writing – review & editing. **Jasper Mwesigwa:** Resources, Writing – review & editing. **Hussen Seid Endris:** Writing – review & editing, Resources. **Zewdu Segele:** Conceptualization, Supervision, Funding acquisition, Writing – review & editing. **Linda Hirons:** Conceptualization, Writing – review & editing. **Oliver Kipkogei:** Writing – review & editing. **Charity Mumbua:**

Resources. **Wawira Njoka:** Resources. **Marta Baraibar:** Resources, Writing – review & editing. **Felipe de Andrade:** Writing – review & editing, Resources. **Steve Woolnough:** Supervision, Conceptualization, Funding acquisition. **Zachary Atheru:** Supervision, Funding acquisition. **Guleid Artan:** Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2022.100319.

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