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Strengthening weather forecast and dissemination capabilities in Central Africa: Case assessment of intense flooding in January 2020

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A R T I C L E I N F O

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A B S T R A C T

The first dekad of January 2020 was characterised by heavy precipitation in the capital of the Republic of Congo, Brazzaville, which led to several localised landslides. Satellite-derived rainfall estimates and rain-gauge totals illustrate a strong wet spell between the 6th and 9th January 2020 across southern Congo. This study highlights the generation and implementation of user-driven weather and climate forecast bulletins, developed at the Economic Communities of Central African States (ECCAS) Climate Application and Prediction Centre (CAPC), to reduce the impacts associated with intense precipitation during this dekad. Through doing so, we document the current state of regional-scale climate services across Central Africa. Advisories and outlooks generated by CAPC use risk matrices developed by the World Meteorological Organisation (WMO) and are produced at hourly, daily, sub-seasonal, and seasonal timescales. To develop them, meteorologists and climate scientists at CAPC combine information from a wide range of meteorological observations and forecasts. Regional-scale forecasts are downscaled to individual countries to improve accessibility and relevance.

Central African users have reported that bulletins provide support for mitigating against the impacts of extreme weather and have requested more reliable sub-seasonal and seasonal forecast products. In this paper we take the opportunity to discuss the resources obtained through the Satellite and Weather Information for Disaster Resilience (SAWIDRA) framework, which are often taken for granted in developed nations, including the procurement of a high performance computing system, satellite data and numerical models outputs receiving stations. This study is the first to highlight the current state of regional-scale climate services across Central Africa and motivates further co-production of climate services across the region.

Practical Implications

Across Central Africa people's lives and livelihoods are exceptionally vulnerable to climate variability and extreme weather events. Not only does Central Africa experience exceptional severe weather, such as flash flooding and persistent droughts, but its

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population has minimal resources to limit the impact of hazardous weather and adapt to variability induced by anthropogenic climate change. Alongside the significant knowledge gap in our understanding of the dynamics and processes driving weather and climate variability across Central Africa, there are minimal studies addressing the lack of accessible, informative climate services across the region. In this article we contribute to alleviating the lack of knowledge in climate services across Central Africa by documenting the operational procedures of the Economic Communities of Central African States (ECCAS) Climate Application and Prediction Centre (CAPC) through focusing on a heavy rainfall event in the Republic of Congo during January 2020. Through doing so, we illustrate the current state of climate services across Central Africa, highlight potential areas of future investment, and encourage a continued dialogue to improve forecasting capabilities across the region.

Currently, CAPC combines observations and forecasts from multiple climate centres, such as the European Centre for Mid-Range Weather Forecasts, to generate impact-based forecasts which use a World Meteorological Organisation (WMO) risk matrix. For example, CAPC provides sub-seasonal forecasts of the likelihood of abnormal rainfall totals and the associated impacts to human life and property. Regional user-focused forecasts across multiple timescales, including those on nowcasting (1 to 12 h) to seasonal (3 to 6 months) timescales, are communicated to both National Meteorological and Hydrological Services (NMHSs) and regional private/governmental organisations. As CAPC directly communicates forecasts on a range of timescales to a wide variety of stakeholders, the regional climate centre plays a pivotal role in ensuring climate services support multiple sectors across Central Africa. As well as this, it is thought that the seamless approach to forecasting on multiple timescales by CAPC supports the uptake of climate information, enhances anticipatory action to the impacts of hazardous weather, and enables further development of actionable weather services, as seen in other African forecasting centres. This study also discusses the novel, iterative co-production approach taken to improve advisories/outlooks issued by CAPC.

Whilst initial feedback from NMHSs and private organisations emphasise that forecast products provided by CAPC support decision-making across different sectors, this work has highlighted four key outcomes which can enhance the development of new climate services across the region. First, using a novel co-production approach has highlighted the need to create a consistent feedback communication pathway between forecast users and forecasters at CAPC to ensure the development of more actionable, user-focused forecast products. Second, enhanced training on the latest developments in operational nowcasting techniques will improve the creation of sub-daily early warning systems. Third, in this study we document the creation of bespoke beneficial sub-seasonal forecast products through project-initiated access to real-time forecast data. A continued access to reliable forecast data will ensure state-of-the-art predictions support those most vulnerable to the impacts of hazardous weather. Finally, further developing partnerships between CAPC, NHMSs, and regional organisations will better equip national forecasters with the latest scientific knowledge and operational practices. All of these improvements will support CAPC in becoming a WMO regional climate centre, encourage further development of weather and climate services across the region, and ensure success in global initiatives to create reliable forecasting services in developing nations.

Data availability

The authors do not have permission to share data.

1. Introduction

Across equatorial Central Africa extreme hydrometeorological events are responsible for multiple casualties, significant infrastructure damage, and adverse economic consequences for local communities (WMO, 2020). Despite advances in forecasting across different timescales (White et al., 2017; Parker et al., 2021), weather forecast uptake across Central Africa, alongside the rest of the continent, remains limited (Lemos et al., 2012; Vogel et al, 2019; WMO, 2021). Not only does the region experience exceptional severe weather, but it also contains some of the world's poorest countries (IMF, 2022). For example, from October to December 2019, persistent heavy rainfall caused exceptional flooding in the Central African Republic (CAR) with the Oubangui river overflowing along 600 km of its shoreline. During this unprecedented rainfall season, 10,000 homes were destroyed and approximately 56,000 people were displaced (UNICEF, 2019a). The impacts of flooding were exacerbated by the CAR being one of the most food-insecure countries in the world (Von Grebmer et al., 2019) and ongoing conflicts displacing approximately 670,000 people (UNICEF, 2019b). To support decision-making in multiple sectors across Central Africa, the Economic Communities of Central African States (ECCAS) commissioned a Climate Application and Prediction Centre (CAPC) through the Satellite and Weather Information for Disaster Resilience (SAWIDRA) framework. The SAWIDRA framework, funded by the European Commission and managed by the African Development Bank, aims to improve the creation and delivery of accurate weather forecasts by National Meteorological and Hydrological Services (NMHSs). The framework aims to evaluate success through increased resilience of vulnerable populations to natural hazards across sub-Saharan Africa (AfDB, 2016). However, after an extensive search of recent publications, it remains unclear how SAWIDRA specifically monitors this ambition. Similar regional climate centres have been created in other parts of Africa including the Sahel (Agriculture, Hydrology and Meteorology [AGRHYMET]; Traore et al., 2014) and East Africa (Intergovernmental Authority on Development [IGAD] Climate Prediction and Applications Centre [ICPAC]; Gudoshava et al., 2022). Whilst previous studies have focused on understanding the drivers and mechanisms responsible for extreme weather and climate across Central Africa (e.g. Igri et al., 2015, 2018; Tanessong et al., 2017b, 2020, Baidu et al., 2022, Fotso-Nguemo et al., 2023, Tamoffo et al., 2023), no previous work has discussed operational forecasting practices across the region. In this study we provide an insight into the operational practices at the ECCAS CAPC, which reduce vulnerability to extreme weather through supporting NMHSs, focusing on an intense flooding event in January 2020.

ECCAS has eleven member states including Angola, Burundi, Cameroon, CAR, Chad, Congo, Democratic Republic of Congo (DRC), Equatorial Guinea (EG), Gabon, Rwanda, and Sao Tome and Principe (STP). Fig. 1 is an elevation map illustrating the countries to which CAPC provides weather forecasts. With the exception of Gabon, all of these countries are ranked with either a medium or low human development index highlighting poor health services, inadequate education infrastructure and a high risk of food insecurity (UNDP, 2020). Therefore, there is an urgent need to reduce the risk associated with severe hydrometeorological events through enhancing the capacity of ECCAS member states by providing actionable and timely climate services that support climate risk management and adaptation, and mitigate the impacts of weather-related disasters on lives and livelihoods. The Sendai framework for disaster risk reduction 2015–2030 (UNISDR, 2015) highlights an opportunity to connect efforts by weather and climate communities to global disaster risk reduction activities and planning, as well as developing seamless forecasting and climate services. Priority 4 of the Sendai framework recommends a continued investment in the development, maintenance and strengthening of people-centred, multi-hazard and multi-sectoral climate services which are developed through a participatory process and tailored to the needs of users.

Equatorial Central Africa contains a variety of environments

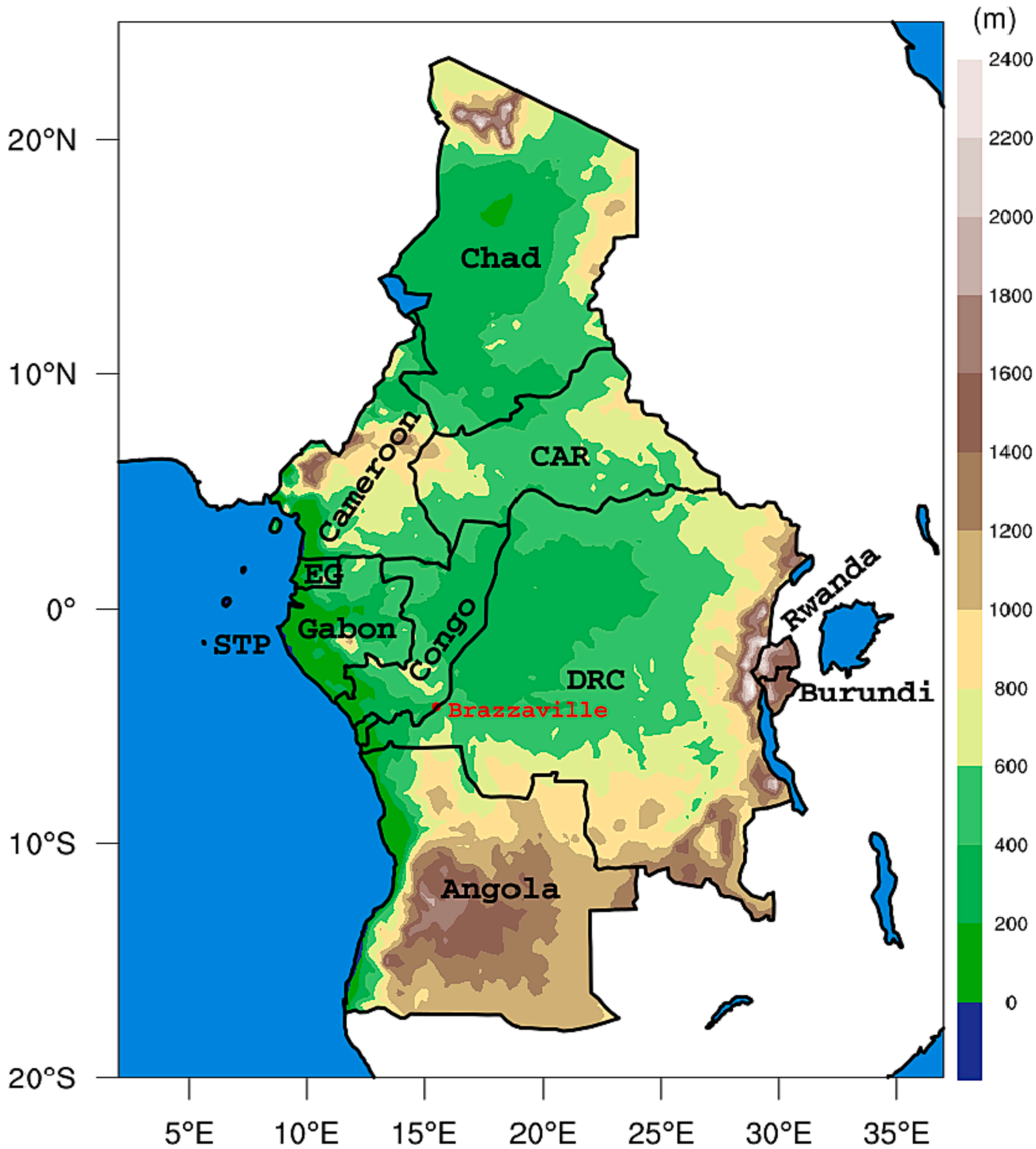

Fig. 1. Elevation (m) map with country labels highlighting ECCAS member states. Abbreviated country labels include: Central African Republic (CAR); Democratic Republic of Congo (DRC); Equatorial Guinea (EG); and Sao Tome and Principe (STP).

including the Angola desert, Congolian rainforests, Sahel in northern Cameroon and Chad, and highly populated cities such as Douala in Cameroon and Kinshasa in DRC. The variety of landscapes makes it non-trivial to understand hydrometeorological processes and challenging to produce reliable, user-relevant, localised forecasts. Rainfall in Central Africa is commonly associated with the seasonal cycle of the Intertropical Convergence Zone (Nicholson et al., 2018) and intense convective systems (Zipser et al., 2006; Cecil et al., 2015, Baidu et al., 2022). The annual cycle of rainfall contains two maxima, one in June and another in October, with a short dry season in July (Sultan and Janicot, 2004; Le Barbé and Lebel, 1997; Vondou et al., 2010, 2017a, 2017b; Igri et al., 2020). Whilst recent extreme hydrometeorological events highlight the importance of developing climate services to support disaster risk reduction (UNICEF, 2019a; WMO, 2020), the need to develop accurate and effective warnings is further exacerbated by the increased frequency and intensity of extreme weather events due to anthropogenic climate change (Diedhiou et al., 2018; Taylor et al., 2018; Iyakaremye et al., 2021; Dosio et al., 2021).

Recent studies illustrate the latest advances in developing early warning systems for hydrometeorological events across the African continent at a range of forecast lead-times (Hirons et al., 2021; Parker et al., 2021; White et al., 2022). Given the low skill in numerical weather predictions at forecasting deep convection on daily timescales (Vogel et al., 2021), operational nowcasting is crucial for short-range (sub-daily) early warning systems (Roberts et al., 2021). Operational nowcasting procedures in South Africa illustrate the benefits associated with the effective delivery of sub-daily forecasts (de Coning et al., 2015; Gijben and de Coning, 2017). Synoptic forecasting is also inadequate across the African continent (Parker et al., 2021) making it challenging to produce reliable sub-weekly forecasts. On sub-seasonal to seasonal (S2S) timescales, there are sources of predictability of African atmospheric conditions including: large-scale sea surface temperature anomalies, such as the El Niño Southern Oscillation (ENSO; Camberlin et al., 2001; Farnsworth et al., 2011) and Indian Ocean Dipole (IOD) (Jiang et al., 2021); atmospheric tropical waves, for instance the Madden-Julian Oscillation (MJO) (Raghavendra et al., 2020); and long-lived soil moisture and vegetation anomalies (Taylor, 2008; Talib et al., 2022; Talib et al., 2023). These sources of predictability improve S2S predictions across Africa (de Andrade et al., 2021). Developing S2S forecasts has the potential to inform decision-makers and reduce the vulnerability to severe hydrometeorological events (Hirons et al., 2021; White et al., 2021). In this study we will illustrate how the latest forecasting improvements have benefited decision-making by multiple sectors across Central Africa.

To highlight the current successes and opportunities of CAPC in supporting decision-making across Central Africa, we discuss operational forecasting procedures that took place in advance of intense precipitation, flash flooding and landslides across Congo in early January 2020. Current procedures to produce regional-level climate services have been co-developed between NMHSs and CAPC. Following the WMO Global Framework for Climate Services (GFCS), we define a climate service as “a decision aide derived from climate information that assists individuals and organizations in society to make improved ex-ante decision-making” (WMO, 2013; 2018). It is important to note that CAPC expands beyond this definition of climate services to decision-making during high-impact events, as an event does not necessarily need to be extreme to have a high impact on the livelihoods of people. Before the establishment of CAPC, NMHSs in the ECCAS region provided minimal national-level climate services due to limited resources and a priority to maintain observational networks. If a climate service was provided, it typically relied on freely available, post-processed climate products. Through focusing on the co-production of climate services between CAPC and NMHSs we will answer the following questions: (i) What forecast products do CAPC currently provide to NMHSs? (ii) What resources are currently used to generate and communicate these forecast products? (iii) How can CAPC improve its forecasting operations to reduce vulnerability to climate extremes further?

Through discussing the generation of forecast products and current communication techniques, this study motivates further collaboration and research across Central Africa, which will ultimately improve climate services across the region and reduce the losses associated with severe hydrometeorological events. In this study we discuss recent impact-based forecasts created at CAPC supported by the SAWIDRA framework. Section 2 provides an overview of the operational procedures used to generate forecast bulletins. Section 2.1 opens section 2 with an introduction to CAPC forecast users. Sections 2.2.1 and 2.2.2 then document the observational and forecast products utilised to develop forecast bulletins respectively, whilst section 2.3 discusses the analysis techniques used to produce bulletins. Section 3 documents the production of impact-based forecast bulletins at CAPC through focussing on operational practices before an extreme precipitation event in Congo. Section 3 also discusses sector-focused climate information provided by CAPC to multiple industries including agriculture and aviation (3.2.1), feedback received from users (3.2.2), and increased resources accessed through the SAWIDRA framework (3.3). Section 4 and 5 close the paper with discussion and conclusions respectively.

2. Operational procedure

2.1. Central Africa CAPC and forecast users

In May 2015 ECCAS members commissioned the Central Africa CAPC, which aims to provide the appropriate infrastructure and institutional expertise to deliver up-to-date, user-centred, and science-based climate services. CAPC, which is based in Douala, Cameroon, is an intergovernmental body responsible for the design, production, and dissemination of climate and weather services to eleven member states and the private sector. Alongside providing regular weather forecast bulletins, CAPC also supports policy development by generating relevant weather and climate information. In particular, CAPC provides monitoring and predictions for various socio-economic sectors, such as agriculture and food security, water resources management, disaster risk reduction, energy, and health. Considering that CAPC is a relatively new organisation, procedures are underway to sign cooperation partnerships with universities, the private sector and regional bodies. Currently, CAPC is a relatively small organisation with an operational team consisting of two meteorological technical officers and three forecasters.

To support the generation of forecast products which support multiple sectors, CAPC has been working through the SAWIDRA framework, which aims to improve the core capacities of NMHSs by meeting the needs of disaster risk management agencies and socio-economic sectors. CAPC strives to build the capacity of each NMHS in Central Africa through providing forecasts on a range of timescales and standardising the generation of services. Fig. 2 illustrates the main workflow between the generation of forecasts by research institutions (orange box), such as the European Centre for Mid-range Weather Forecasts (ECMWF), and actions taken by local organisations to reduce vulnerability to extreme weather (grey box). Black arrows indicate the communication pathways with which CAPC are directly involved. This study focuses on climate services provided to NHMSs and regional organisations rather than the use of climate services by end users. CAPC is responsible for providing regional-scale meteorological forecast bulletins which are sent to NMHSs and public authorities. Supported by these bulletins, and after considering current meteorological conditions, forecasters at NMHSs produce national-level bulletins. These national-level forecasts are also sent to governmental organisations to support disaster risk management. In addition to interactions with NMHSs and public-sector organisations, private-sector bodies, including cotton production companies such as Sodecoton and Cotontchad, have been using forecasts provided by CAPC. Table 1 summarises the majority of organisations which CAPC collaborates with.

2.2. Data

To provide NMHSs and relevant regional users with forecast products, meteorologists at CAPC combine information from multiple observational datasets and Numerical Weather Predictions (NWPs). Table 2 summarises the different data sources used to produce forecast bulletins. In this subsection, we discuss observational (section 2.1.1) and forecast (section 2.1.2) datasets.

2.2.1. observations

Forecasters at CAPC frequently use rainfall, temperature and cloud cover observations to produce climatologies, generate nowcasts, and to verify previous forecasts. Rainfall products which are used include the Climate Hazards group InfraRed Precipitation with Stations (CHIRPS; Funk et al., 2015) dataset, the Climate Prediction Centre (CPC) African Rainfall Climatology version 2 (ARC2; Novella and Thiaw, 2013), and the Global Precipitation Measurement (GPM) Integrated Multi-satellitE Retrievals for GPM (IMERG; Huffman et al., 2017). The use of multiple rainfall products removes an over-reliance on one rainfall observation, which is necessary given the uncertainties associated with remotely sensed precipitation products across Central Africa (Camberlin et al., 2019). CHIRPS, which is on a 0.05° latitude/longitude grid and provides data from 1981 to the present day, and ARC2, which provides observations from 1983 on a 0.1° latitude/longitude grid, both combine satellite-derived infrared measurements with gauge-based rainfall totals (Novella and Thiaw, 2013; Funk et al., 2015). GPM IMERG on the other hand, relies on a dual-frequency precipitation radar, a conical-scanning multichannel microwave imager, and rain gauge measurements (Huffman et al., 2017). GPM IMERG provides rainfall observations from 2001 on a 0.1° latitude/longitude grid. In this paper we only show precipitation data from the “final run” IMERG product which is recommended for research studies. Alongside precipitation products, observations of thermal infrared brightness temperatures (10.8 μm, channel 9) from Meteosat second generation satellites (Sobrino and Romaguera, 2004) are also used to observe cloud cover. These images are available every 15 min at a spatial resolution of approximately 3 km.

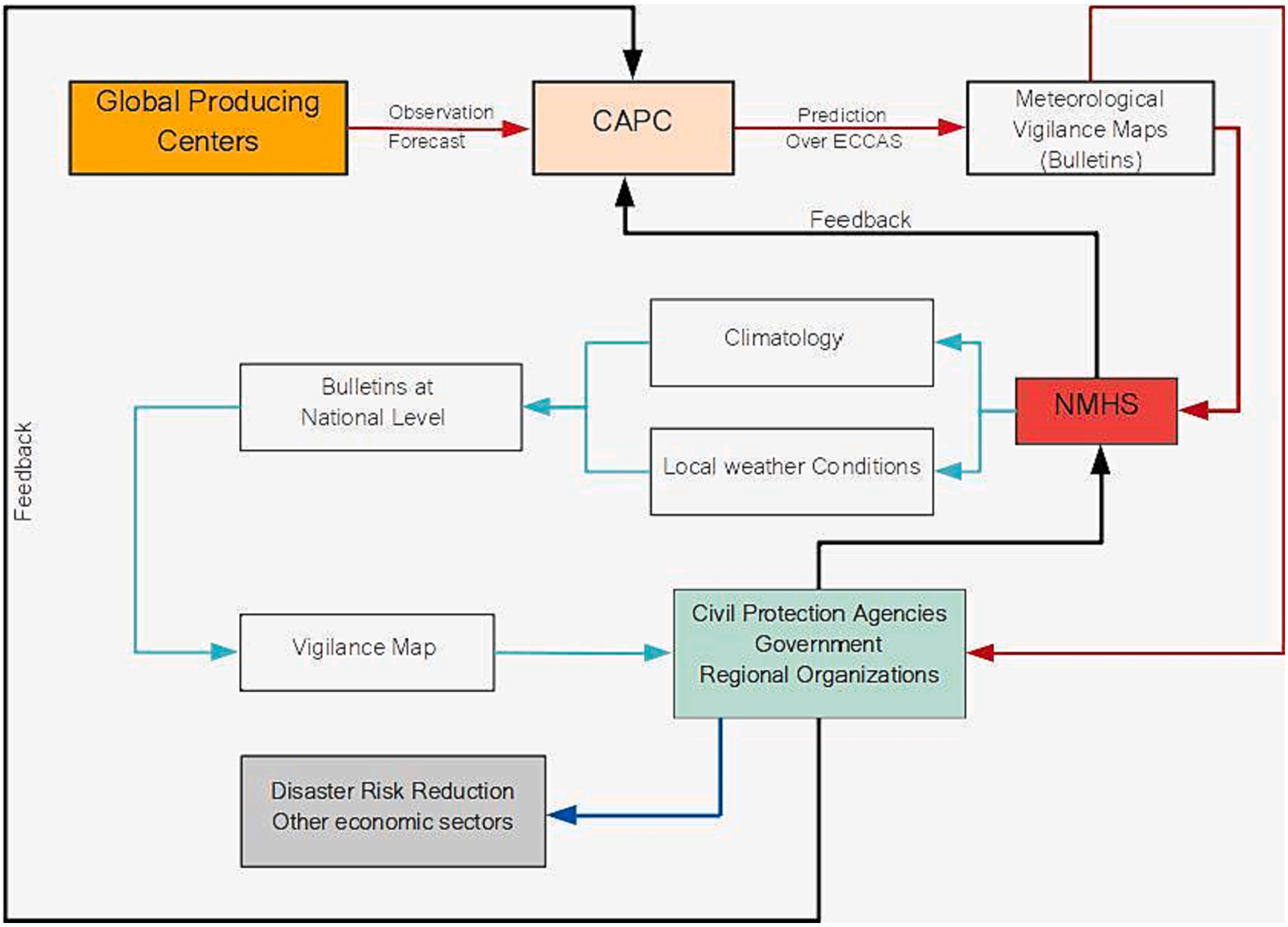

Fig. 2. Workflow at CAPC in relation to data acquisition, processing and forecast dissemination including pathways for feedback. This schematic also highlights interactions between stakeholders and CAPC forecasters within the dissemination chain of weather and climate services. Red arrows indicate the production and dissemination of forecasts by CAPC for NMHSs, whilst cyan arrows denote procedures by NMHSs. Black arrows denote communication pathways with which CAPC are directly involved. The large blue arrow highlights that products produced by CAPC and disseminated by national authorities support a variety of sectors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Different institutions that collaborate with CAPC.

Institutions	Type
National Meteorological and Hydrological Services (NMHSs)	National
Office for the Coordination of Humanitarian Affairs (OCHA)	Regional
International Federation of Red Cross (IFRC)	International
Gabonese Agency for Space Studies and Observation (AGEOS)	National, with regional coverage
Cotton Development Company (SODECOTON)	Private (National)
Chad Cotton Company (COTONTCHAD)	Private (National)
Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA)	Intergovernmental Public service
Lake Chad Basin Commission (CBLT)	Regional
International Commission of the Congo-Oubangui-Sangha Basin (CICOS)	Regional
Civil protection agencies	National

2.2.2. *Forecast products*

To produce good quality forecast products for NMHSs and regional organisations, multiple forecasts from different global producing centres are qualitatively combined with observations. CAPC forecasters make use of freely available NWPs, high-resolution U.K. Met Office (UKMO) pan-African simulations, and co-produced sub-seasonal forecast products in partnership with the African Centre of Meteorological Applications for Development (ACMAD).

Nowcasts and synoptic forecasts products. To create products with a forecast lead time of up to 10 days, freely available forecasts from the National Centers for Environmental Prediction (NCEP), such as the operational Global Forecast System (GFS) and the Global Ensemble Forecast System (GEFS), and high-resolution UKMO forecasts are analysed. GFS is a spectral model that is run four times a day with a horizontal resolution of approximately 13 km for the first 10 days and 27 km for days 10 to 16. Alongside GFS, model output from the GEFS, where 21 ensemble members are run for 16 days at a horizontal resolution of approximately 25 km are used. For both GFS and GEFS, model output on a 0.25° latitude/longitude grid is used. In addition convection-permitting simulations of the UKMO Unified Model (MetUM; Walters et al., 2019) in the latest regional atmosphere tropical science configuration (Bush et al., 2020) are utilised to refine forecasts. Simulations are performed at a 4.4 km resolution across tropical Africa (-11-22°N, −19-53°E) with data outputted every three hours during a 48-hour forecast. The boundary conditions for tropical Africa simulations are implemented every three hours and sourced from global MetUM simulations, which are performed at an approximately 10 km resolution in the mid-latitudes.

Sub-seasonal to seasonal forecast products. The creation of S2S forecast products, those with a lead time greater than 7 days, use model output from the second version of the NCEP Climate Forecast System (CFSv2; Saha et al., 2014). The spectral model is run at the equivalent of approximately a 100-km grid resolution with 45-day forecasts run every

Table 2
Different data sources used at CAPC.

Product type	Variable	Data	Resolution	Valid time	Source
Observations	Rainfall	Station observations	Single point		These data are collected by CAPC from NMHSs and Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA) on removable media.
		CHIRPS	0.05^0	Daily	ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/africa_daily/bils/p05/2020/
		ARC2	0.1°	Daily	https://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/arc2/bin
		IMERG	0.1°	Daily	https://pmm.nasa.gov/data-access/downloads/gpm
	Brightness temperatures	MeteoSat	3 to 8 km	Every 15 min	https://eumetview.eumetsat.int/static-images/MSG/PRODUCTS/ PUMA station
Numerical weather predictions	Multiple	GFS	27 km	0 – 8 days	https://nomads.ncep.noaa.gov/
		GEFS	111 km	0 – 35 days	https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs
		CFSv2	111 km	4 weeks	https://origin.cpc.ncep.noaa.gov/products/people/mchen/CFSv2FCST/weekly/
		UKMO	4.4 km	2 days	https://www.metoffice.gov.uk/premium/vcpafrica/#/map
ACMAD PRODUCTS					
Sub-seasonal products	Precipitation	Sub-seasonal dataset	Sub-seasonal products	1 day to 1 month	Received by email

six hours and nine-month forecasts run every five days. CFSv2 forecasts are accessed at CAPC through the North American Multi-Model Ensemble (NMME; Kirtman et al., 2014) at a 1.0° latitude/longitude resolution. Alongside using model output from the CFSv2, output from the National Oceanic and Atmospheric Administration (NOAA) Sub-seasonal Experiment (SubX) project (Pegion et al., 2019) is used as well. The free SubX project provides 17 years of hindcast data and 18 months of real-time forecasts from seven American and Canadian modelling groups. As the SubX project includes NCEP CFSv2, the project provides an additional six sets of sub-seasonal forecasts from different modelling centres.

Alongside using all of these different forecast products to produce bulletins, CAPC has been working alongside ACMAD researchers to co-produce regional forecasts that support decision-making by NMHSs. Co-produced sub-seasonal forecast products were developed as part of a two-year Global Challenges Research Fund (GCRF) African Science for Weather Information and Forecasting Techniques (SWIFT) S2S testbed (Parker et al., 2021; Hirons et al., 2021). The GCRF African SWIFT testbed is one of sixteen projects granted access to real-time forecast data as part of the S2S Real Time Pilot Initiative (Vitart et al., 2017). For the collaboration between CAPC and ACMAD, real-time forecast data from ECMWF are analysed and processed. ECMWF forecasts shown in this study used the CY46R1 model cycle and had a 16 km resolution to day 15 and 32 km thereafter. The collaborative effort utilised all 51 ECMWF S2S forecast ensemble members that were available every Monday. The project also used 20 years of reforecasts (hindcasts) to produce a climatology. Previous evaluations of ECMWF sub-seasonal precipitation forecasts show mean errors of up to 10 mm week^{-1} across inland regions of Central Africa at a three- and four-week lead time during wet-season months (de Andrade et al., 2021). However, forecast errors substantially increase up to 25 mm week^{-1} across coastal areas. Forecasters at CAPC regularly consider forecast evaluations performed by the research and operational communities.

Table 3
Forecast products generated at CAPC and their frequency of production.

Products	Description	Frequency of production	Validity	Shown in figure
Nowcasting	12 h accumulated rainfall	Twice a day	12 h	4a
Daily forecasts	Daily accumulated rainfall	Twice a week	5 days	4b
Weekly technical note	Analysis of weather conditions and trends	Twice a week	5 days	
Sub-seasonal	Weekly precipitations anomalies	Once a week	4 weeks	4c and 4d
Monthly technical note	Briefing	Once a week	3 weeks	
Humidity index	Degree of discomfort	Twice a week	10 days	
Weekly forecast for Douala, Yaounde, and Coton region	Daily accumulated rainfall	Twice a week	5 days	
Monthly weather watch	Dry and wet spells monitoring over past month	Once a month	1 month	
Dry and wet spells sub-seasonal forecast	Total accumulated rainfall, dry and wet spells forecasts over sub-season	Once a week	16 days	
Dry and wet spells seasonal forecast	Total accumulated rainfall anomalies, seasonal rainfall performance probability, dry and wet spells forecasts over season	Once a month	3 to 6 months	9a, 9b and 9c
Special forecast for Adamaoua, Gabon or Kribi	Daily accumulated rainfall	on demand	on demand	

2.3. Product generation

Regional advisories and outlooks on daily to seasonal timescales are regularly produced. Table 3 provides a summary of all forecasts produced at CAPC at the time of writing. The products generated at CAPC were those approved through the SAWIDRA framework to address the lack of climate monitoring and forecasting across Central Africa. CAPC focuses its products on nowcasting and sub-seasonal timescales due to successes in other regions of Africa (de Coning et al., 2015; Hirons et al., 2021; Roberts et al., 2021; Parker et al., 2021).

Generating each product requires an in-depth analysis of observations and model outputs. In this paper we focus on the production of vigilance maps, example shown in Fig. 3, which highlight the likelihood of an extreme weather event. Vigilance maps are sketched freehand over a map of Central Africa. Sketching freehand allows knowledge of forecaster expertise and model biases to be incorporated into the final forecast product. The drawing of vigilance maps takes place on Quantum Geographic Information System software with probability zones based on the risk matrix from the WMO (WMO, 1150, 2015). Two types of risk matrices are used for precipitation vigilance maps depending on the forecast lead time. The first is used for sub-weekly forecasts and

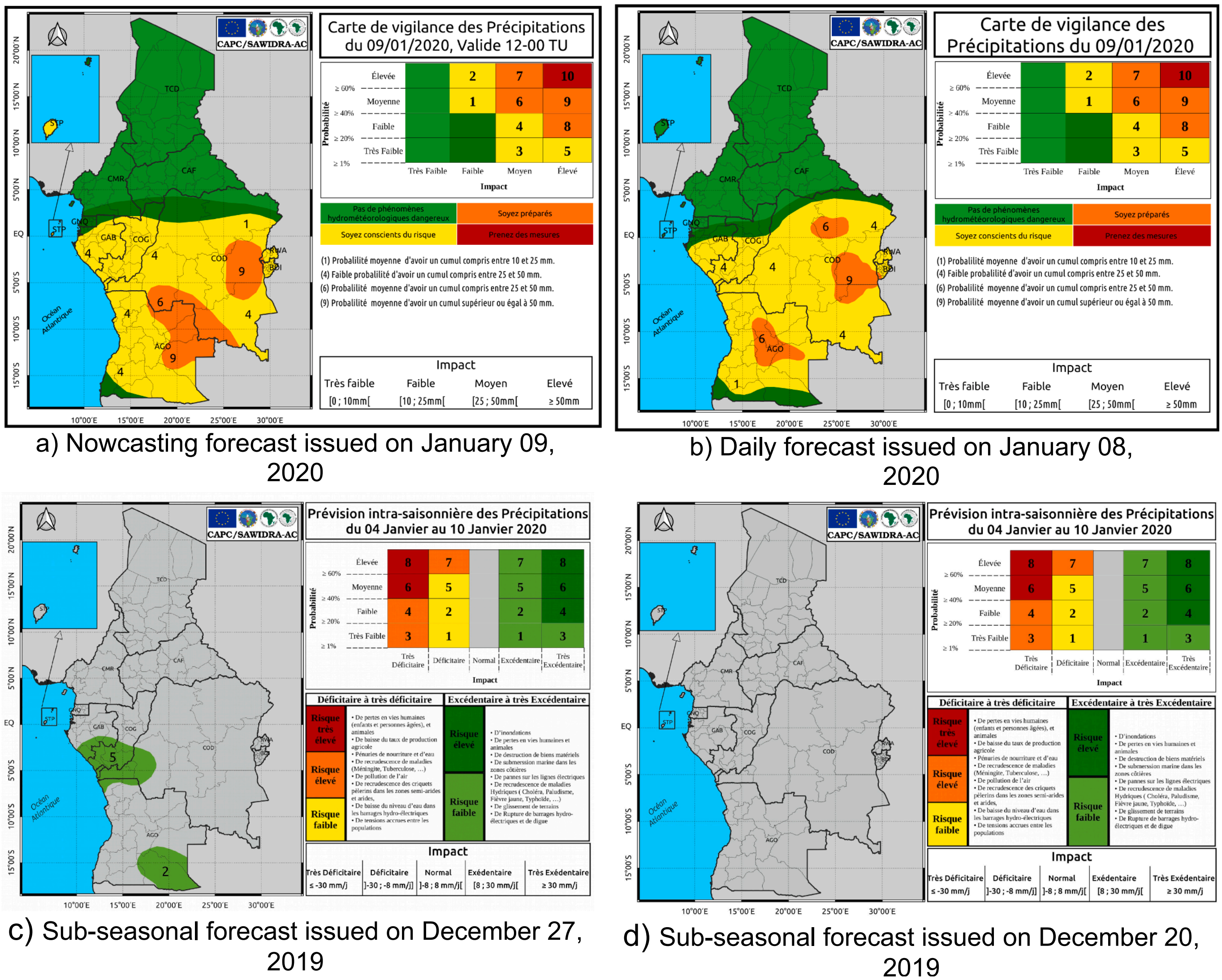

Fig. 3. Forecast bulletins valid for 09 January 2020 issued on (a) 09 January 2020, (b) 08 January 2020, (c) 27 December 2019 and (d) 20 December 2019.

highlights the probability of an extreme rainfall event to occur (Fig. 3a and 3b). The second is used for forecasts with a lead time greater than one week and illustrates regions with high probabilities of anomalous high and low rainfall (Fig. 3c and 3d). Advisories also provide users with predicted impacts of rainfall anomalies. In the following section we discuss the aggregation of observations and model outputs to produce forecast vigilance maps before an extreme rainfall event across Central Africa.

3. Case study

To highlight the observations and forecasts used to produce bulletins across Central Africa, we focus on one extreme weather event in Brazzaville, the capital of the Republic of Congo, between the 1st and 10th of January 2020 (Fig. 4). Rain gauge data at Brazzaville airport during this period highlights three days with accumulated daily precipitation exceeding 90 mm (Fig. 4a). Heavy rainfall recorded at Brazzaville airport was underestimated by ARC2, IMERG and CHIRPS (Fig. 4b). Accumulated daily precipitation greater than 50 mm were observed across most of the southern Republic of Congo (Fig. 4b) leading to localised landslides and the collapse of the Corniche in Brazzaville on the 9th January 2020, which is considered as a national monument. For this case study we focus on the forecast issued for the three days preceding and including the 9th January 2020.

To illustrate the generation of forecast products at CAPC, the following subsection describes the development of forecast bulletins before this event. To do this succinctly, we have chosen to partition forecast product development into different forecast lead times: nowcasting/daily (3.1a); sub-seasonal (3.1b); and seasonal (3.1c). Following on from the discussion of forecast product development for the chosen case study, the following subsections discuss climate information produced by CAPC (section 3.2), feedback received from NMHSs (section 3.3); and increased capability and resources to the regional climate centre (section 3.4).

3.1. Generation of impact-based forecast bulletins

3.1.1. Nowcasting and daily forecasts

CAPC provides very short-term precipitation advisories to NMHSs in Central Africa every twelve hours (Table 3). Fig. 3a shows the 12-hour precipitation forecast bulletin issued at 11 UTC on the 9th January 2020, whilst Fig. 5 illustrates a selection of forecast products used to generate this bulletin. Alongside using model outputs of precipitation and vertically-integrated precipitable water from GFS, GEFS, and UKMO (Fig. 5b), forecasters attempt to determine precipitation characteristics using observations and forecasts. This is done as convective precipitation is more likely to cause flash flooding, whilst persistent large-scale rainfall may lead to widespread floods. To predict the nature of

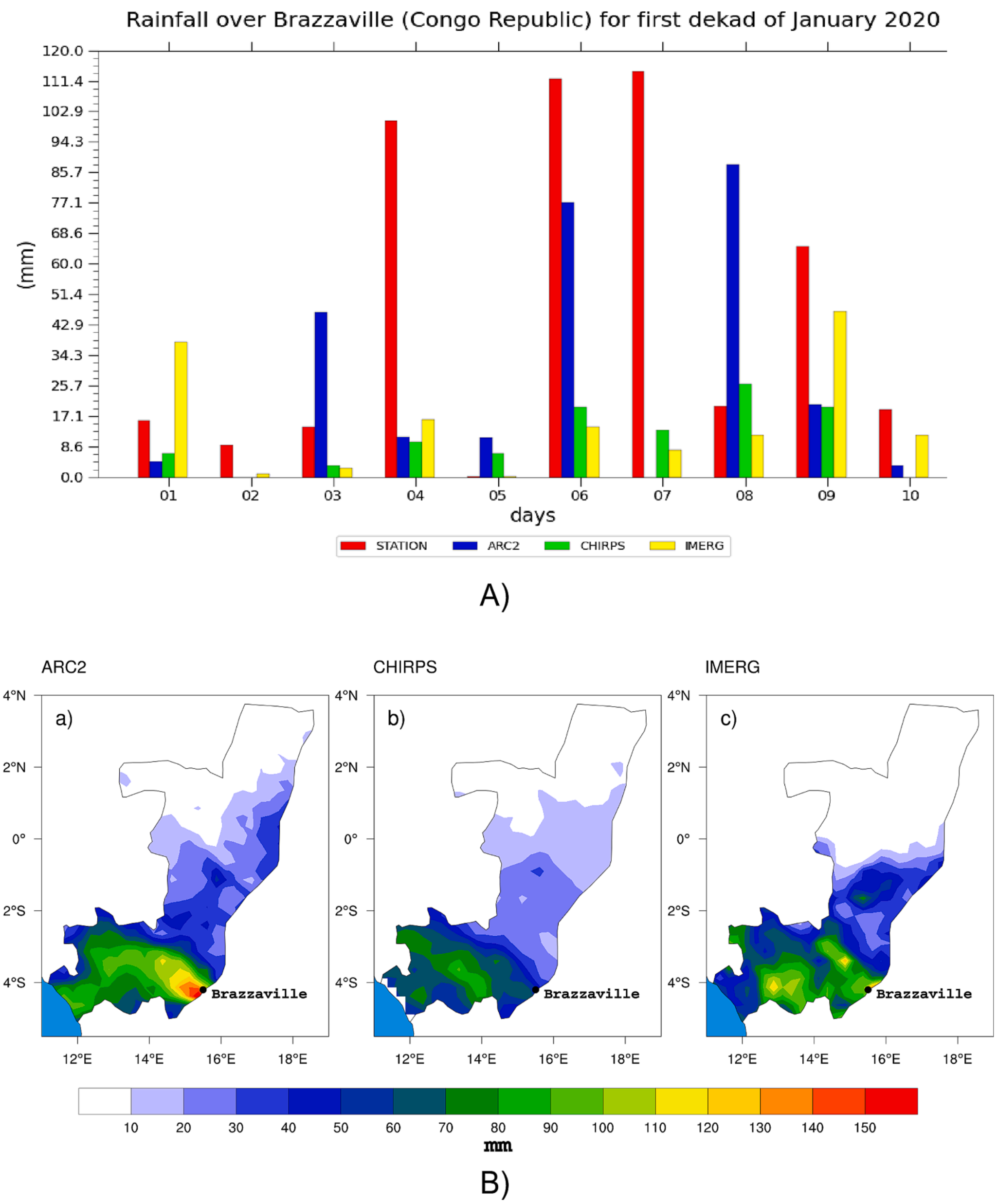

Fig. 4. Observations of January 2020 case study. A) Daily accumulated rainfall amounts (mm) at Brazzaville Airport rain gauge (red), and satellite products including ARC2 (blue), CHIRPS (green) and IMERG (yellow) from 01 to 10 January 2020. B) Total rainfall (mm) from 06 to 09 January 2020 observed by (a) ARC2, (b) CHIRPS and (c) IMERG. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

precipitation, forecasters initially use infrared Meteosat observations (Fig. 5a) where low cloud-top temperatures highlight possible regions of deep convection. Forecasters also use predicted atmospheric conditions to determine whether high atmospheric instability may lead to convective precipitation. Atmospheric instability is approximated using forecasts of vertical velocity (Fig. 5c), low-tropospheric temperature and relative humidity. As well as approximating instability from atmospheric fields, forecasters use NWP output of instability indices including the lifting condensation level and convective available potential energy.

As well as producing 12-hour accumulated precipitation forecasts (Fig. 3a), CAPC issues bulletins for daily-accumulated precipitation twice a week (Table 3). Fig. 3b shows the forecast bulletin issued on January 8th 2020 for precipitation on January 9th 2020. A similar collection of forecasts is used for the generation of daily accumulated rainfall bulletins as 12-hour rainfall advisories. Additional products used include predicted daily-accumulated precipitation from five NWPs processed by ACMAD (examples shown in Fig. 6a and 6b), precipitation probability forecasts generated by NOAA (Fig. 6c) and 3-day CFSv2 predictions of outgoing longwave radiation (OLR) anomalies and equatorial waves (Fig. 6d). For both nowcasts and daily precipitation forecasts, a 20 to 40% likelihood of 25 to 50 mm of rainfall across southern Cameroon (Fig. 3a and 3b) was predicted. For this forecast, strong atmospheric uplift (Fig. 5c) and high relative humidity were predicted over this region. However, a low level of confidence was attributed to this rainfall total because only a few models predicted rainfall over southern Cameroon (Fig. 6b). In reality on January 9th 2020, heavy rainfall was observed across the region (Fig. 4a). However, the forecast bulletin did not highlight the need to prepare for heavy rainfall because of inconsistencies between NWPs.

3.1.2. Sub-seasonal forecasts

Alongside generating synoptic advisories, the centre also produces sub-seasonal forecasts (Table 3). The issuing of sub-seasonal forecast

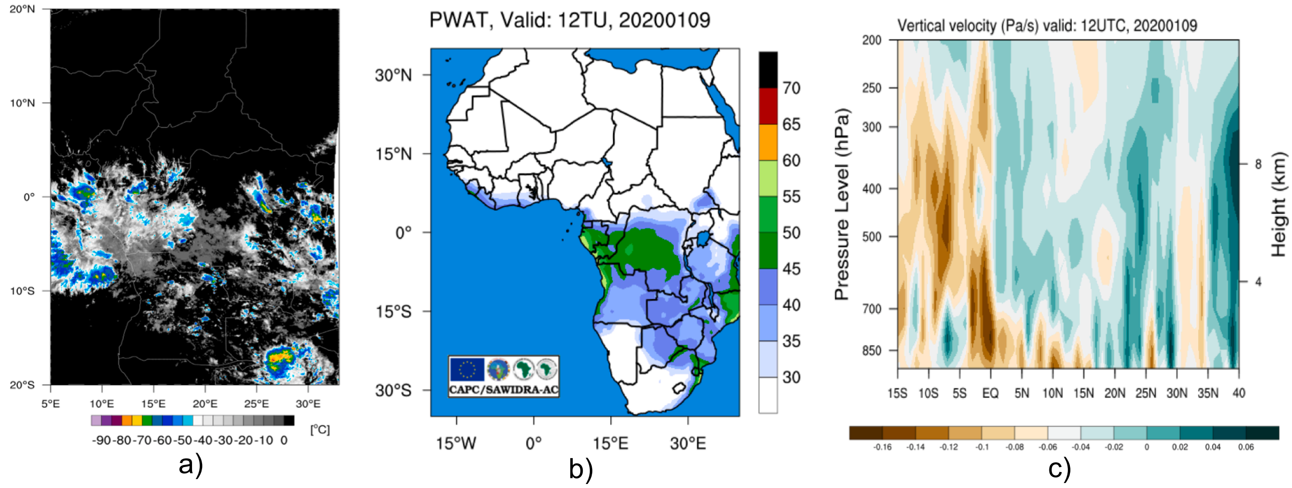

Fig. 5. Selected products used for nowcasting on 9th January 2020 including: a) EUMETSAT IR10.8 image (°C) at 11 UTC 9th January 2020; b) GEFS precipitable water forecast (mm); and c) GEFS vertical velocity (Pa s^{-1}).

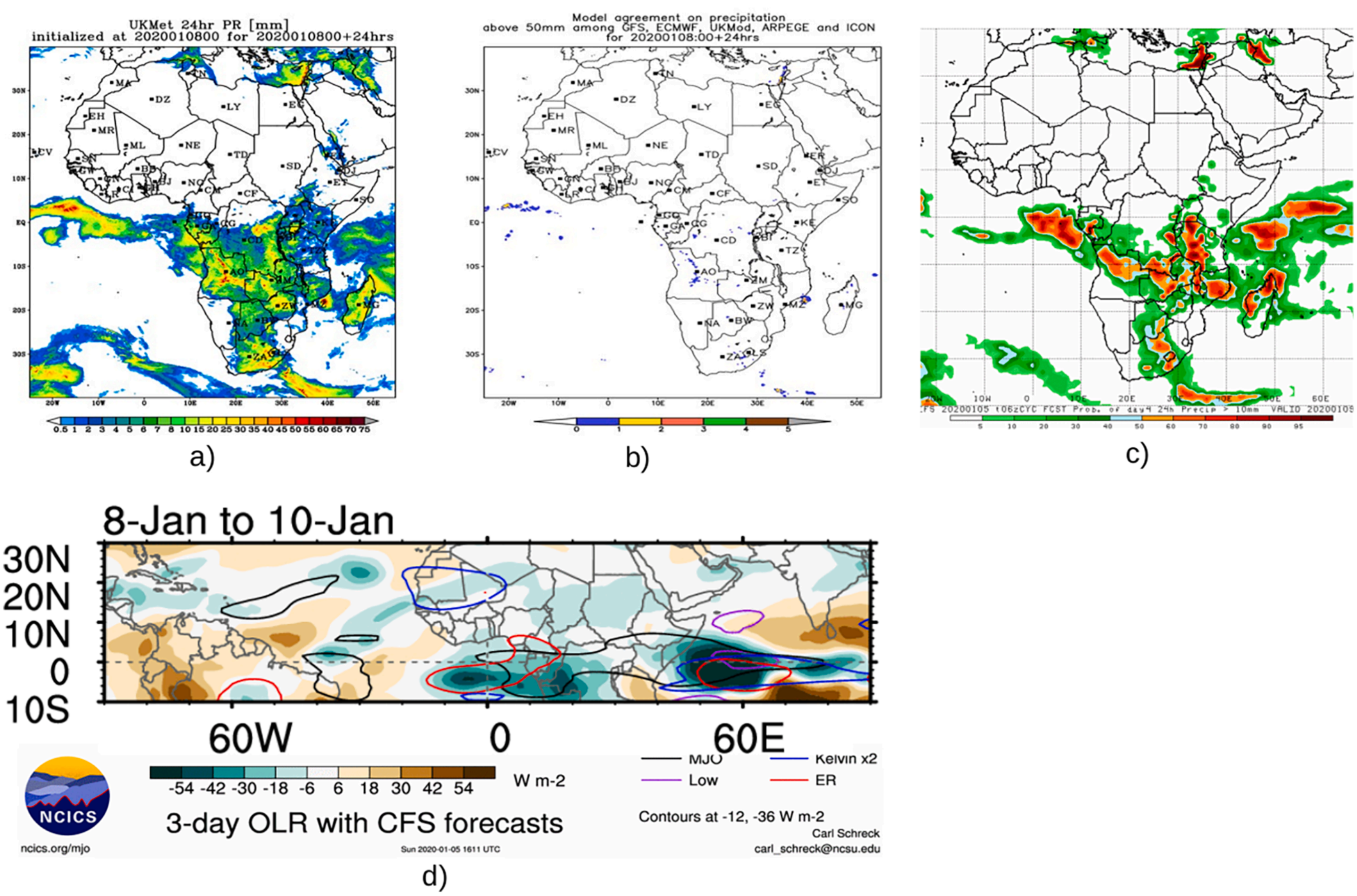

Fig. 6. Selected products used for daily forecasting on the 8th January 2020 and valid for 9th January 2020 including: a) UKMO precipitation (mm) forecast from ACMAD, b) model agreement between precipitation forecasts (GFS, ECMWF, ARPEGE, UKMet and ICON) of surpassing a threshold of 50 mm day^{-1}, c) NOAA (NCEP) probability of precipitation greater than 10 mm and d) CFSv2 forecasts and equatorial waves and 3-day OLR anomalies (W m^{-2}) ending 10 January 2020.

bulletins takes advantage of the predictability driven by intraseasonal variability of atmospheric, oceanic, and land surface processes (Vitart et al., 2015), and extends the period in which decision-making is supported. For the chosen flood event in Brazzaville, two sub-seasonal forecast bulletins were issued on the 27th and 20th December 2019 for the week of the 4th to 10th January 2020 (Fig. 3c and 3d respectively). Fig. 7 shows several sub-seasonal forecast products used to generate sub-seasonal bulletins and includes multi-model mean OLR predictions from the SubX database (Fig. 7a), ECMWF weekly-mean precipitation anomalies processed by ACMAD (Fig. 7b), forecasted precipitable water anomalies from CFSv2 (Fig. 7c), and predictions of the MJO phase using forecasted OLR anomalies from the GEFS model (not shown). At a two-week lead time, CAPC issued a bulletin highlighting a 60% probability for above normal rainfall across southern

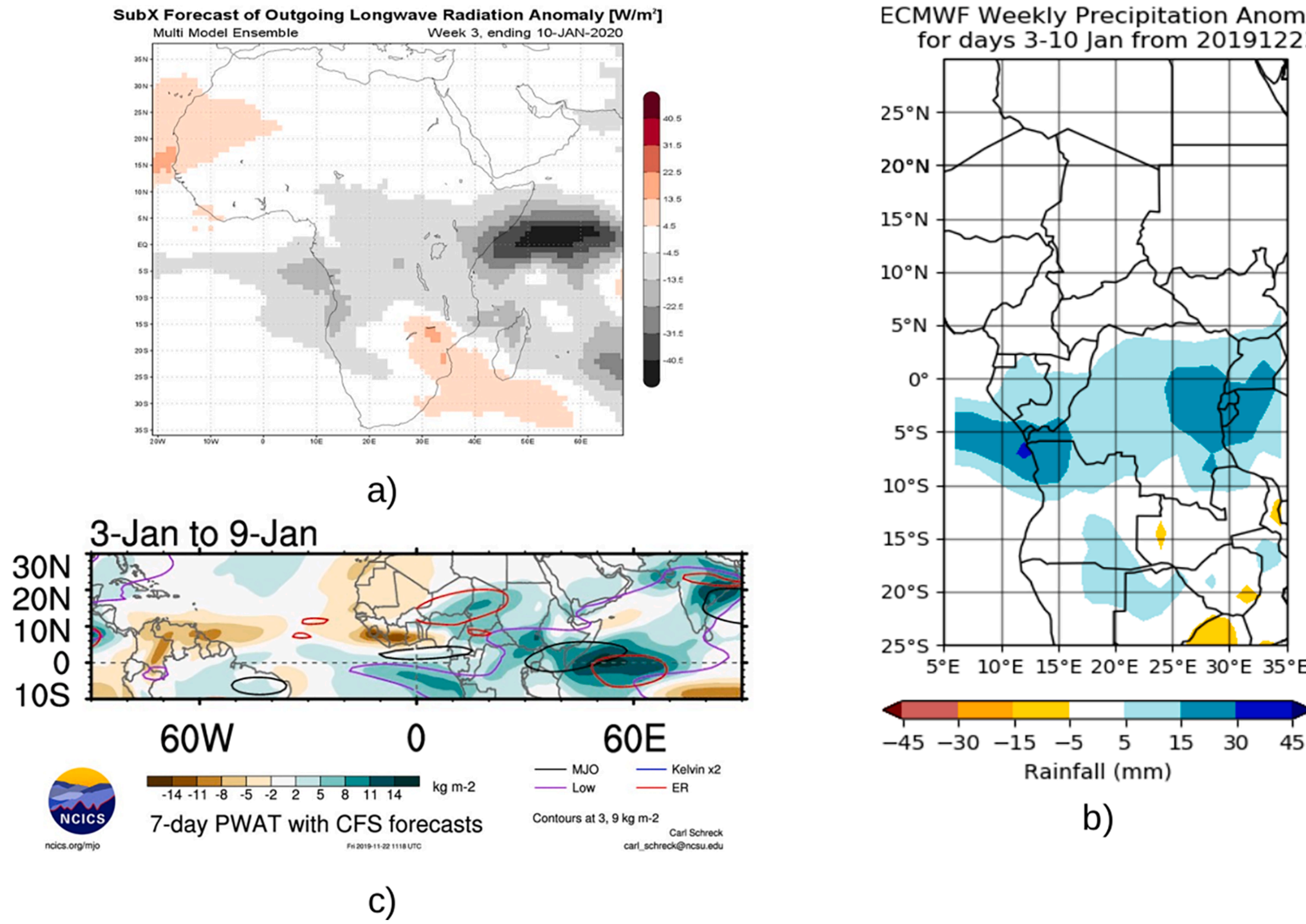

Fig. 7. Selected sub-seasonal products issued on December 27th 2019 used for forecasts valid between the 4th and 10th January 2020 including: a) Outgoing Longwave Radiation (OLR) (W m^{-2}) multi-model ensemble anomaly forecast; b) ECMWF weekly precipitation anomaly (mm) forecast (African SWIFT product); and c) filtered equatorial waves using 7-day precipitable water anomalies (kg m^{-2}) with CFSv2 forecast.

Gabon, southern Congo, south-western DRC and northern Angola (Fig. 3c). This outlook was given based on negative OLR anomalies predicted by SubX models (Fig. 7a), well above-normal precipitation anomalies from ECMWF forecasts (Fig. 7b), and positive precipitable water anomalies in CFSv2 (Fig. 7c). The current and predicted state of the MJO were also considered due to previous work showing an influence of the MJO on extreme events across Central Africa (Sandjon et al., 2012; Kamsu-Tamo et al., 2014). Enhanced precipitation typically occurs during MJO phases 8, 1 and 2, whilst rainfall is suppressed during MJO phases 4 to 6.

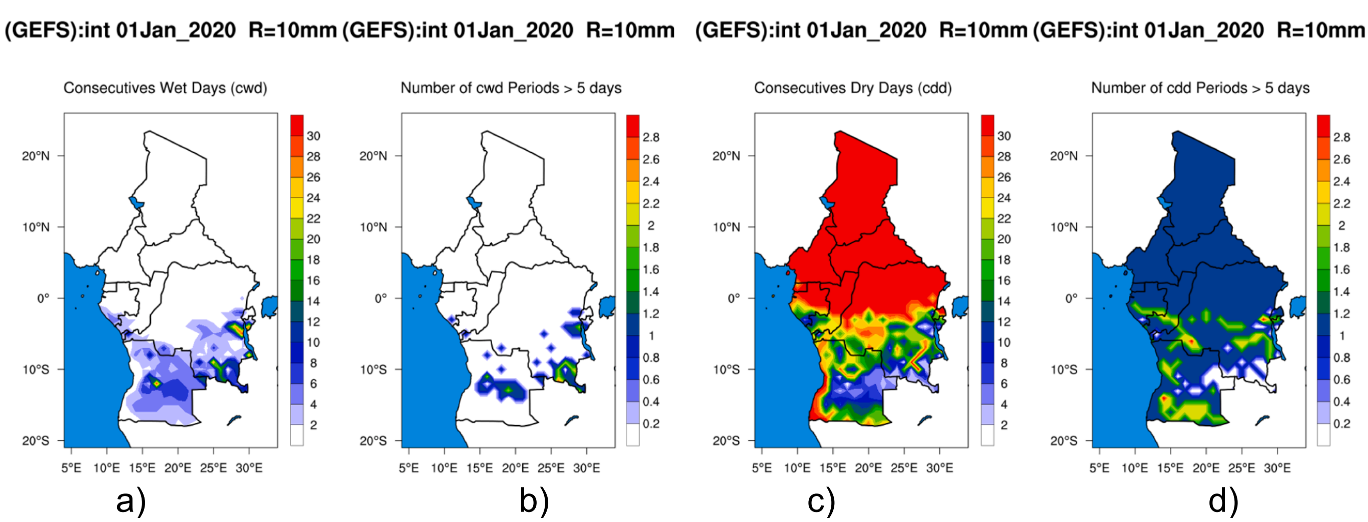

Fig. 8. CFSv2 forecasts patterns corresponding to a) maximum number of consecutive wet days (CWD), b) number of sequences of CWD greater than 5 days, c) maximum number of consecutive dry days (CDD) and d) number of sequences of CDD greater than 5 days. Plots are shown for a threshold of 10 mm for the month of January 2020 in order to assess wet and dry spells in the Central Africa region.

To further support drought and flood monitoring across Central Africa, predicted temperature and precipitation data from GEFS CFSv2 were analysed and several indices derived. Computed indices include the number of consecutive wet or dry days, the maximum amount of precipitation forecasted over a certain period, and the number of days with maximum temperatures above a certain threshold. Fig. 8a and 8c show the forecasted maximum number of consecutive (a) wet and (c) dry days during the month of January 2020, whilst Fig. 8b and 8d show the number of occurrences in which five consecutive (b) wet or (d) dry days are forecasted. A threshold of 10 mm is used to define a wet or dry day. Analysing forecast data to produce personalised indices enables better decision-making by users of CAPC products. For example, Fig. 8a and 8b show that CFSv2 forecasts predict a single sequence of 10 to 12 consecutive wet days across south-west Congo. The combination of this information with the predicted maximum daily rainfall total (not shown), highlights that a prolonged period of high intensity rainfall was likely to occur across southern Congo.

3.1.3. Seasonal forecasts

Seasonal precipitation forecasts are also provided by NHMSs using simulation data from CFSv2. Fig. 9 shows the predicted seasonal precipitation anomaly, the accumulated seasonal rainfall and the seasonal rainfall performance probability for January to March 2020. The seasonal forecasts were initialised on the 1st December 2020. Knowledge of the seasonal forecast enhanced planification and preparatory actions for prolonged extreme climate events such as drought. For example, seasonal predictions of abnormally high rainfall across Southern Congo (Fig. 9) encourages long-term planning for widespread flooding.

3.2. Improving the capability of ECCAS member states through providing weather and climate information

3.2.1. Climate information provided by CAPC

Alongside generating forecast products to support NMHSs, CAPC produces climate information to aid companies from a variety of sectors including agriculture (i.e. Sodecoton and Cotontchad), energy, forestry, transport (i.e. Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA) and water quality. Climate information is sent to NMHSs, who then disseminate and communicate this knowledge to the appropriate national organisations. CAPC also sends climate information to intergovernmental bodies such as the Office for the Coordination of Humanitarian Affairs (OCHA), the Gabonese Agency for Spatial Studies and Observation (AGEOS), the International Federation of Red Cross and Red Crescent Societies (IFRC), the Lake Chad Basin Commission (CBLT), the International Commission of the Congo-Oubangui-Sangha Basin (CICOS; Table 1) to enable better integration of climate information in decision-making at all levels of responsibility. The main products generated include observed and forecasted seasonal precipitation accumulations, the probability of exceeding severe precipitation accumulations, the Standardized Precipitation Index (SPI) for multiple timescales (1 to 24 months), the number of observed and forecasted dry and wet spells, likelihoods of heatwave conditions, and dust distributions across the Sahelian parts of Central Africa. Climate information provided by CAPC allows institutions and companies in ECCAS member states to monitor drought conditions, support forest management, adapt agricultural planning, control the management of hydropower dams, and aid the planning and preparation of disaster response teams. The channel used by CAPC to provide these real-time climate services to users is currently email. Nevertheless, state-of-the-art equipment provided through the SAWIDRA framework is being acquired and will improve communication pathways.

3.2.2. Development of feedback communication pathways

At the time of writing, CAPC relies on two sources of feedback from NMHSs: (1) annual surveys completed by NMHSs and; (2) a recent assessment of hazards and risks in ECCAS member states implemented by the World Bank Group and Global Facility for Disaster Reduction and Recovery (GFDRR) (CEEAC, 2020). In general, annual surveys highlight that most operational procedures by NMHSs benefit from climate services produced by CAPC. However, further training and capacity building is required in NMHSs to fully exploit published climate products. For example, national forecasters in the DRC emphasise that training is required to fully understand sub-seasonal forecast products. Weather forecasters from the Rwandan NMHS use regional-level advisories and outlooks to support national forecasts. Previous feedback reports have also congratulated CAPC for forecast quality and overcoming logistical challenges. Information collated in the CEEAC 2020 report illustrates that forecasts issued by CAPC are regularly used by NMHSs. Interestingly, the CEEAC 2020 report not only highlights that NMHSs use regional-level climate services to support national-level predictions, but they also use forecasts to validate observations. Through informal qualitative feedback, positive interactions and annual surveys, we infer that the improved coordination between CAPC, NMHSs and research institutions is enhancing the resilience to

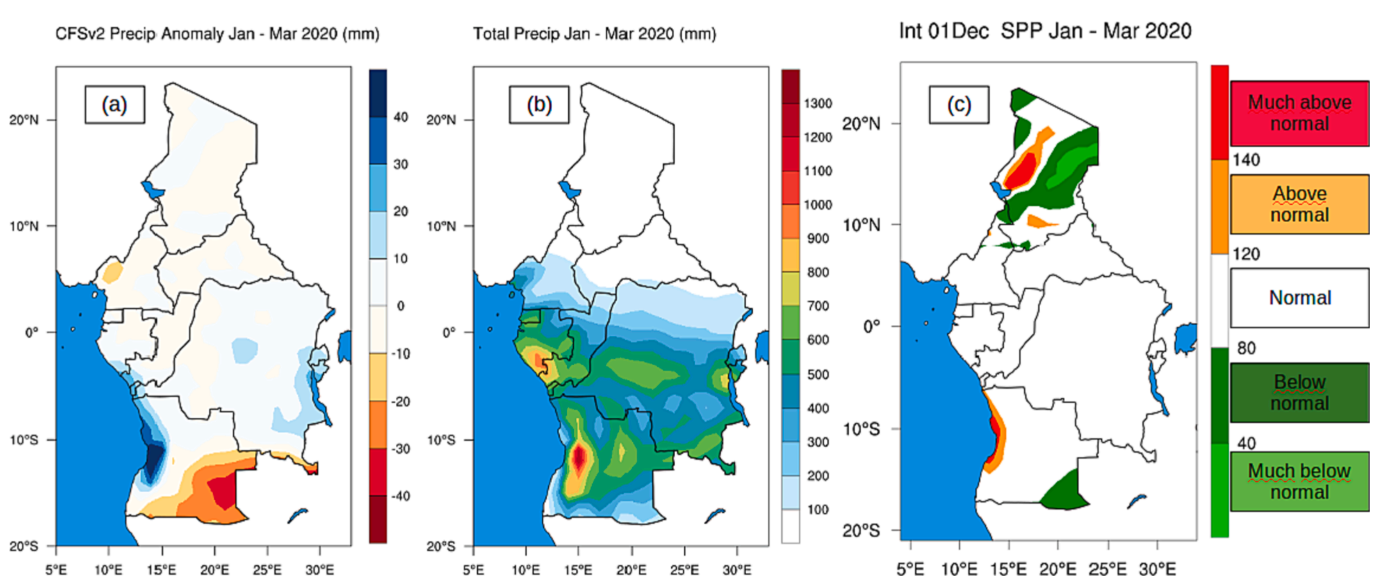

Fig. 9. Seasonal (JFM) precipitation forecast from CFSv2 NMME. Variables shown include: (a) Precipitation anomaly (mm); (b) total precipitation (mm); and (c) seasonal rainfall performance probability.

hydrometeorological disasters.

Whilst from current feedback pathways we infer that the enhanced communication between CAPC, NMHSs and research organizations improves resilience to extreme hydrometeorological events, it is acknowledged that not only are feedback mechanisms between NHMSs and CAPC currently inadequate, but the collaborative dialogue with local decision-makers and forecast 'end-users' needs to be increased to establish if and how evidence-based information developed at CAPC actually informs decision-making. Currently, there is a lack of resources to quantify the reduced vulnerability along the whole forecast value chain, with initial feedback focussed on improved operational practices. In order to improve its forecasts and better respond to the needs of NMHSs and regional institutions, CAPC is currently developing improved communication pathways to better support receiving feedback. Such feedback mechanisms are being established under the Climate Services and Applications (ClimSA) initiative funded under the 11th European Development Fund. The process encompasses the ECCAS Commission as policy designer and decision authority, NMHSs as primary stakeholders, and regional working groups in agriculture, forestry, disaster risk reduction and health as regional decision actors. Regional and national User Interface Platforms (UIPs), the ECCAS Climate Outlook Forums (RCOFs), and interactive web-services provide structured mechanisms for co-production, capacity building and outreach. The development of structured UIPs encourages continuous interactions between users, researchers, and climate service providers, and enhances dialogue which supports the co-development of more user-driven and user-relevant services. For instance, CAPC will focus on the availability and functionality of Regional Climate Service UIPs. To this end, CAPC will ensure that a system for receiving and broadcasting climate services is available and functional to all end-users. CAPC will equip the platform with appropriate reception and distribution capability, and strengthen the capacity of platform users on installation, configuration and maintenance of climate services retrieval. CAPC plans to identify and train users who support the communication of climate services. Crucially, feedback mechanisms such as this need to be continually monitored and evaluated to ensure new learning can be iteratively implemented.

3.3. Increased capability and resources at CAPC through the SAWIDRA framework

The SAWIDRA framework has initiated the procurement of key meteorological goods and services to CAPC including a high-performance computing server, a server room, and a Monitoring for Environment and Security in Africa (MESA)-PUMA electronic station. Through utilising this equipment, CAPC has created a functional training centre where forecasters from NMHSs are trained. For example, training has been provided to sixteen forecasters and twenty graduate students from Cameroon to improve their capability of using PUMA electronic stations.

4. Discussion

Through discussing advisories issued before a severe rainfall event across Congo, this study documents current operational practices and forecasting capabilities at the Central African regional climate centre, ECCAS CAPC. Forecast products and services delivered by CAPC aim to reduce the socio-economic impacts associated with extreme hydrometeorological events and support the management and monitoring by multiple stakeholders. At present, CAPC has two communication pathways to enable forecast bulletins to reduce the risk associated with climate variability. The first, and most important, pathway involves CAPC providing forecast bulletins to NMHSs in Central Africa. Through doing so, national forecasting capabilities are enhanced and greater forecaster confidence is gained at NMHSs. The second pathway provides governmental and private organisations with user-focused forecast products which support local and regional-scale decision-making. Given that CAPC has direct communication with both NHMSs and governmental/private organisations, the regional climate centre is an important knowledge broker of weather and climate services across a wide range of technical and non-technical stakeholders with a variety of needs and applications. Even though CAPC has limited capacity and is one of the smallest regional climate centres across Africa (United Nations, Economic Commission for Africa, 2018), it has taken full advantage of the resources provided through the SAWDRIA framework and enhanced the use of weather and climate information across the region.

During the first 10-day period of 2020, heavy rainfall across Congo led to localised landslides and significant infrastructure damage. This study highlights forecasting procedures issued by CAPC before this heavy precipitation event and motivates future developments in operational practices at the regional climate centre. Due to the poor skill of NWPs at predicting deep convection on synoptic timescales (Vogel et al., 2021), regional advisories and outlooks from CAPC mainly focus on nowcasting, daily, sub-seasonal and seasonal forecasting. The seamless approach of forecasting across a range of timescales supports the development of more effective climate services and increases the uptake of weather information (Vaughan and Dessai, 2014; Gudoshava et al., 2022; White et al., 2022; Visman et al., 2022; Hirons et al., 2023). Forecasts developed at CAPC require in-house expertise of atmospheric dynamics, with forecasters assuming that most rainfall across Central Africa is associated with mesoscale convective systems. For nowcasting and daily advisories, forecasters use knowledge of atmospheric dynamics and the latest satellite retrievals of brightness temperatures to predict the development and track of large-scale deep convective systems. Whilst recent nowcasting developments across Central Africa have been minimal compared to other African regions (Roberts et al., 2021), initial procedures implemented by CAPC show the potential for nowcasting techniques to support decision-making across the region. Developments in operational nowcasting at CAPC should include the latest developments in nowcasting techniques performed in other parts of the African continent (de Coning et al., 2015; Roberts et al., 2021).

Alongside providing nowcasts and daily advisories to users, CAPC also produces sub-seasonal forecast bulletins and provides meteorological expertise during the Central African Regional Outlook Forum (RCOF). At the time of writing, forecasters at CAPC take advantage of multiple sub-seasonal forecast models to predict abnormally high or low precipitation across the region. Partnerships have also been enhanced between CAPC and ACMAD through the African SWIFT sub-seasonal testbed (Hirons et al., 2021), which gave CAPC access to state-of-the-art ECMWF sub-seasonal forecasts. Through disseminating sub-seasonal forecasts from multiple centres, forecasters at CAPC have developed sub-seasonal forecast bulletins which are communicated to NMHSs and governmental organisations. To ensure the successful provision of sub-seasonal forecasts into the future, sub-seasonal forecast data needs to be easily accessible and forecaster training is required to ensure there is expertise to interpret and communicate sub-seasonal forecasts. In this piece of work we have focused on forecasts during a particular flooding case study. Forecasting procedures and the mechanisms to receive feedback are similar during other times of the year and for different extreme weather events. For instance, the same forecast bulletin templates are used before intense drought events. Due to current deficiencies in feedback mechanisms between NMHSs and CAPC, it is unknown whether the usefulness of climate services developed by CAPC is dependent on the type of extreme weather event. Alongside a more comprehensive assessment of the use of climate services across the whole value chain, efforts should also prioritise a quantitative evaluation of forecast quality and uncertainty of products provided by CAPC.

Many studies have shown that anthropogenic climate change will increase the severity and frequency of extreme weather events (Diedhiou et al., 2018; Dosio et al., 2021; IPCC, 2021; Iyakaremye et al., 2021). Recent Intergovernmental Panel on Climate Change reports (IPCC, 2018) highlight that even if global warming is limited to levels compatible with the Paris Agreement, a cascade of effects on natural and human systems, with substantial risks for impacts on ecosystems, health and agriculture, will be unavoidable. The increased frequency and intensity of hydrometeorological extreme events across central Africa due to anthropogenic climate change (IPCC, 2018; Nkiaka et al., 2017, Hua et al., 2018), has highlighted insufficient capacity across the region to minimise impacts associated with extreme weather. The successful communication of weather and climate advisories and an improved early warning system increases the capability of ECCAS member states to prepare and respond to extreme weather events. To continue improving the communication of weather forecast products from CAPC to NMHSs and regional organisations, communication network and co-production frameworks need to be established with dedicated regional and national strategies and rules for dialogue, harmonisation and co-ordination. From experiences of effective co-production activities in other parts of Africa, it is recognised that co-production is resource-intensive (Hirons et al., 2021; Visman et al., 2022) and substantial efforts need to be taken to ensure decision-making is balanced between climate service providers and users. Co-production is an increasingly popular approach to knowledge generation encouraged by donors and research funders. However, power dynamics between institutions in the Global North and South can, if not adequately managed, impede the effectiveness of co-production and pose risks for long-term sustainability (Vincent et al., 2020). The recently developed ClimSA initiative aims to improve co-production practices, with CAPC as the climate service provider, through developing interactive web portals that host regional climate services.

Finally, efforts by CAPC have developed capacity-building activities for ECCAS member states on NWP at different timescales, including seamless sub-seasonal predictions. These achievements are the first step in making CAPC a designated WMO regional climate centre and a regional specialised meteorological centre for high resolution NWP. In the future we hope that CAPC will become the Central African Regional Training Centre for NWP and related applications. CAPC is already recognized as an ECCAS specialised institution in Central Africa and supports regional cooperation and integration at the political, institutional, diplomatic, ecological, socio-economic and environmental level. At the political level, CAPC enables the implementation of the Paris Agreement (UNFCCC; 2015), the International Conventions on Climate Change (UNFCCC; 1992), the Sendai Framework for Disaster Reduction in Central Africa (UNISDR; 2015) and medium term (approximately 10 years) action plans for individual ECCAS member states. Central Africa is an under-studied and under-resourced region with a population highly vulnerable to high-impact weather events. Through providing seamless forecast predictions across a range of timescales, CAPC will play a pivotal role in developing weather and climate services across the region in the future.

5. Conclusions

This study illustrates how observations and weather forecasts are brought together at CAPC to create regional impact-based warnings across different timescales (nowcasting, daily forecast, sub-seasonal and seasonal). The main aim of CAPC is to strengthen the capacities of ECCAS member states by producing and exploiting numerical weather and climate forecasts for multiple weather forecast application sectors. Through focusing on a rainfall event in the Republic of Congo, we illustrate how user-focussed operational forecast products support seamless anticipatory action across a region vulnerable to extreme weather events. Bulletins are based on scientific tools and techniques that have been developed in global producing centres, with a specific added value through using the WMO risk matrix. The creation of forecast bulletins is supported by close coordination between NMHSs, ACMAD, regional and international research institutions. These partnerships enable the sharing of knowledge and expertise, which ultimately improves the communication of early-warnings. Specifically, the process of developing an impact-based framework leads to an improvement in planning, communication of forecast confidence, social development, and post-event evaluation. Impact-based forecasts communicate a message of greater relevance to enable those at risk to take appropriate mitigating actions to reduce the effects of hydrometeorological hazards. This study also highlights that future investment should focus on developing feedback mechanisms between the CAPC, NMHSs and regional-level users. Once a sufficient feedback mechanism is in place, efforts can focus on understanding the value of regional-scale advisories and outlook by users at the end of the value chain. Not only should future work aim to improve our understanding of the mechanisms responsible for extreme weather across Central Africa, but it should also develop the communication of weather forecasts across the region.

CRediT authorship contribution statement

Igri Moudi Pascal: Conceptualization, Project administration, Supervision, Writing – review & editing. **Taguemfo Kammalac Jores:** Methodology, Data curation, Visualization, Methodology, Formal analysis, Software, Writing – original draft. **Joshua Talib:** Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition. **Vondou D. Appolinaire:** Writing – review & editing. **Linda Hirons:** Writing – review & editing. **Dassi Tene Romeo-Ledoux:** Writing – review & editing. **Talla Fogang Michael:** Writing – review & editing. **Mabi Marceline:** Writing – review & editing. **S. Tanessong Roméo:** Writing – review & editing. **Cheikh Dione:** Writing – review & editing. **Elisabeth Thompson:** Writing – review & editing. **Abubakr A. M. Salih:** Writing – review & editing. **Semingar Ngaryamgaye:** Writing – review & editing.

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.

Data availability

The authors do not have permission to share data.

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